NUCLEAR DIVISION

Report No. RN-Q-0046

QUARTERLY PROGRESS REPORT NO. 46

To

AEC-NASA Space Nuclear Propulsion Office

For Third Quarter, CY 1968

Covering the Period of
April, May, and June 1968

MASTER

NERVA Program

Contract SNP-1

July 1968

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FOREWORD

The work reported herein by Aerojet-General Corporation was conducted under, and in partial fulfillment of, Contract SNP-1 of the Space Nuclear Propulsion Office, a joint office of the National Aeronautics and Space Administration and the Atomic Energy Commission.

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CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	11
A. Module 0 - Technology	11
B. Module 1 - Reactor	117
C. Module 2 - Engine	123
D. Module 5 - NERVA Component Development	161
E. Module 7 - NRDS	227
F. Module 9 - Support	249

TABLES

<u>No.</u>		<u>Page</u>
1	TPA Readiness Review Action Items: Item 1	40
2	TPA Readiness Review Action Items: Items 2 and 4	41
3	TPA Readiness Review Action Items: Item 3	42
4	TPA Readiness Review Action Items: Item 5	43
5	TPA Readiness Review Action Items: Item 6	44
6	TPA Readiness Review Action Items: Item 7	45
7	TPA Readiness Review Action Items: Item 8	46
8	TPA Readiness Review Action Items: Item 9	47
9	1200°F Stress-Rupture Test Summary	99
10	Preliminary Cryogenic Tensile Structural Data for Irradiated Aluminum Alloy 1034 and Hastelloy X	101
11	Radiation Effects on Average Cryogenic (-320°F) Notched and Unnotched Tensile Strength of Aluminum Alloy 7039-T61 and T64 Plate	102
12	R-Test Reactor System State Summary	119
13	Missions	124
14	Stages	125
15	NERVA Engine Steady-State Values	149
16	Specific Impulse Performance	154

TABLES (cont.)

<u>No.</u>		<u>Page</u>
17	Malfunction Analysis	157
18	Time Hydrogen Molecule Spends in 75K Engine at Design Power	159
19	Basis for Performance Predictions: Centrifugal Pump	166
20	Basis for Performance Predictions: Axial Pumps	167
21	Basis for Performance Predictions: Turbine	168
22	Basis for Performance Predictions: Coolant/Balancer Circuit	169
23	Performance Summary: Basic Configurations	170
24	Operational Flexibility Comparison	174
25	Alternate Configuration Performance Summary	175
26	Alternate Configurations of Base Case	176
27	Percent Change from Control Valve Chart Elongations, GTR-21 High-Temperature Test	261
28	Effect of Strain Rate on Elongation	263
29	Preliminary 1200°F Stress-Rupture Test Summary	264
30	Change in Electrical Resistivity at -320°F vs Neutron Fluence (Preliminary)	265

FIGURES

<u>No.</u>		<u>Page</u>
1	NERVA Major Program Milestones (2 sheets)	7
2	Emergency Cooldown System Open-Valve System Configuration	13
3	Five-in. Butterfly Valve Seal, PN 1117405	24
4	Five-in. Check Valve Damper	27
5	Marotta Valve, 3-Way 2-Position N.C. Solenoid Shown Energized	29
6	Four-in. Butterfly Valve Bearing Torque-Load Test Setup	31
7	TPCV-TBV Shaft Bearing Torque vs Load	33
8	Shaft Side Bearing After Testing	34
9	Spherical Bearing After 25-Cycle Test	35
10	Eight-in. PSV Shaft Seal Redesign	37
11	Comparison of CFDTS and XECF Parameters for Wet-Pump Start	67
12	Comparison of CFDTS and XECF Parameters for Dry-Pump Start	69

FIGURES (cont.)

<u>No.</u>		<u>Page</u>
13	XECF EP-2 Warm Pump, Time from TPCV Opening	72
14	XECF EP-2 Warm Pump, Time from First Motion of TPCV	73
15	Predicted XE-1 Reflector Inlet Temperature	78
16	Illustration of Coherence Function for T-8 Sine Input-Output Data	81
17	Flow Discrepancy	86
18	Schematic - Topping Cycle Nuclear Rocket Engine and Test Reactor	122
19	NERVA Map 75K Engine, Preliminary	127
20	High I_{sp} Startup	128
21	High I_{sp} Shutdown	129
22	Cooldown Requirements	130
23	Cooldown Parameters, First Burn	131
24	Cooldown Parameters, Second Burn	132
25	Cooldown Parameters, Third Burn	133
26	Cooldown Parameters, Fourth Burn	134
27	Sum of Propellant Usage Requirements for All Cooldown Phases	135
28	Synchronous Orbit, One-Way Trip, Mission-Cooldown Characteristics	136
29	Specific Impulse Change Due to Cooldown	137
30	Effects of Pump Discharge Pressure on Turbine Inlet Pressure and Flow Rate	150
31	Fission Product Decay Heat vs Time After Shutdown	152
32	106K NERVA Hot-Bleed Port, Entrance Wall Temperatures Section Between Spacers	178
33	Plug Nozzle Concept	181
34	Nozzle Length Comparison, Multi vs Rao Contours	182
35	Nozzle Length Comparison, Rao vs Forced Deflection	183
36	Comparison of Sample End Caps	186
37	Test Fixture with Instrumentation and Fluid Line Attached	187
38	Typical Flow Pattern Around a Flat End Cap	188

FIGURES (cont.)

<u>No.</u>		<u>Page</u>
39	Upper Thrust Structure Concept: 75K Engine	192
40	75K Engine, Optimum Nozzle Area Ratio	206
41	Operating Characteristics of Skirt Under Partial Power Conditions	208
42	Operating Characteristics of Skirt, Nuclear Subsystem	209
43	NERVA Skirt Extension, Design Point Limit Conditions	211
44	NERVA Skirt Extension, Operating Characteristics	212
45	75K Skirt Extension, Coolant Tube Exhaust Nozzle Performance	213
46	NERVA Skirt Forward Flange Detail	216
47	Full-Scale Vortex Valve	223
48	Vortex Valve Performance Curves	224
49	Typical Results (Preliminary) Stress-Rupture Test - 1200°F, Inconel 718, 37 ppm Boron	266
50	ETS-1 (E-2) NASS Exhaust Duct Configuration	275
51	Ejector Performance, Centerbody Ejector	276
52	Estimated 75K Engine, Startup Ramps	277
53	NASS Multi-Ejector Concept	279
54	Ejector Performance, Parallel Ejector	280
55	E-2 NASS Performance	281
56	Subscale Duct Hardware for E-2 and Subsequent NERVA Ground-Test Engines	282

SUB-SUBTASKS

All sub-subtasks covered in this report are listed below in numerical order. The pertinent module is indicated in parentheses after each title, and the page number for the sub-subtask is given.

<u>No.</u>	<u>Sub-Subtask</u> <u>Title</u>	<u>Page</u>
1.1.0	Engine-System Design and Integration (0)	11
1.1.2	Engine-System Test Engineering (0)	19
1.2.0	PFS Components (0)	23
1.2.1	Pneumatic Systems (5)	161
1.2.3	Valves (5)	161
1.2.5	Turbopump (5)	163
1.3.0	Reactor Test and Interface Control (0)	48
1.3.4	Reactor Development (0)	49
1.3.5	Reactor Development (9)	24
1.3.6	Fuel Development and Fabrication (0)	50
1.4.0	Nozzle Development (0)	51
1.4.1	Nozzle Development (5)	173
1.4.2	Thrust Structure and Lines (0)	51
1.4.3	Thrust Structure and Thrust-Vector System (5)	190
1.4.4	Pressure Vessel (0)	52
1.4.5	Pressure Vessel (5)	191
1.4.6	Lines (5)	194
1.4.7	Skirts and Poison-Wire Withdrawal Assembly (5)	200
1.5.0	Control-System Design and Analysis (0)	54
1.5.1	Control-System Design and Analysis (5)	217
1.5.2	Control Actuators (0)	59
1.5.4	Electronic Development (5)	219
1.5.5	Control Actuators (5)	220
1.5.6	Facility Engine-Control-System Design (0)	61

Sub-Subtask (cont.)

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.5.7	Engine Flight-Programmer Development (5)	221
1.5.8	Facility Engine-Control-System Design (9)	250
1.5.9	Control System Fluidic Chamber Pressure Control NERVA Component Development - Phase I (5)	222
1.7.2	Instrumentation Components and Systems (0)	63
1.7.6	Instrumentation and EPIC Development (9)	250
1.8.0	Engine System Analysis (0)	66
1.8.2	Reactor System Analysis (0)	82
1.9.2	Radiation-Effects Integration, Analysis, and Documentation (9)	257
1.9.3	Radiation-Effects Support for Reactor Development (9)	260
1.9.4	Instrumentation, Components, and Subsystem Radiation Effects (9)	260
1.9.8	Materials Radiation Effects (9)	260
2.1.0	Mechanical GSE (0)	87
2.1.1	Mechanical Ground Support Equipment (9)	267
2.2.0	Electrical GSE (0)	92
2.2.1	Electrical GSE (9)	268
2.5.0	Ground-Operations Safety (0)	92
2.5.1	Ground-Operations Safety (7)	227
2.6.0	Product Assurance - Contractors' Plants (0)	94
2.6.3	Quality Assurance - NASA (7)	229
2.7.0	Malfunction Studies (0)	96
2.8.2	Nonfuel Materials Planning, Design Review, and Data Reporting (0)	96
2.9.2	Assistance to LASL (0)	103
3.1.0	Engine-System Design and Integration and Engine- Configuration Documentation (2)	123
3.1.2	Engine-System Test Engineering (2)	148
3.4.3	Thrust Structure, Nozzle, Skirt, and Lines (2)	148
3.8.0	Systems Analysis (2)	148
4.1.2	Program Planning and Control (0)	103
4.2.0	Fiscal Control (0)	104
4.2.1	Material Inventory (9)	268

Sub-Subtask (cont.)

<u>No.</u>	<u>Title</u>	<u>Page</u>
4.3.1	Technical Reports (NASA) (0)	104
4.3.2	Technical Reports (AEC) (0)	104
4.4.0	Central Data System (0)	105
4.5.0	Program Management (9)	268
4.5.1	Program Management Projects (0)	107
4.6.0	New-Technology Reporting (0)	107
5.3.0	Reactor Test and Interface Control (1)	117
5.4.3	Thrust Structure, Nozzle, Skirt, and Lines (1)	118
5.4.5	Pressure Vessel (1)	118
5.8.0	Systems Analysis (1)	118
6.2.0	Other Test Zones and Laboratories, Sacramento (9)	269
6.3.0	Test Zone H, Sacramento (9)	270
6.4.0	NRO Laboratories, Sacramento (9)	273
7.0.0	General Support (7)	232
7.1.0	Test-Cell-C Operations (7)	235
7.3.1	MAD-Building Reactor Operation (7)	239
7.3.2	MAD-Building Engine Operation (7)	240
7.4.0	Engine Test Operations (7)	242
7.7.1	Engineering Support for Existing NRDS Facilities (NASA) (0)	109
7.7.3	NRDS Instrumentation (0)	115
7.7.5	Engineering Support for ETS-1 Nuclear Exhaust System (9)	274
7.7.6	Engineering Support for Existing NRDS Facilities (NASA) (9)	283
7.7.8	Engineering Support for NRDS Instrumentation System (9)	285

I. INTRODUCTION

This document, which covers the progress of the NERVA Engine Development Program and its associated tasks, is submitted in partial fulfillment of Sub-Subtask 4.3.1 of Contract SNP-1. This report covers the third quarter of Contract Year 1968 (1 April through 30 June 1968). The work performed under Subcontract NP-1 to Westinghouse Astronuclear Laboratory (WANL) is covered in a separate quarterly progress report issued by WANL.

II. SUMMARY

A. PROGRAM HIGHLIGHTS

XECF was subjected to a successful cold-flow test on ETS-1 on 11 April 1968, after which it was transferred by the EIV to the E-MAD cold bay for external UTSM modification. Subsequently, the XECF has been transferred to E-MAD hot bay, where a remote-cycle demonstration of removal and replacement of the UTSM will be accomplished in the next report period. The XECF UMA will be returned to Sacramento next quarter for upgrading to the XE-1 configuration.

Assembly of the XE-1 is continuing at NRDS, and the XE-2 UMA is being held at Sacramento until all readiness review items have been completed.

SNPO-C provided a program requirements document (PRD) for the NERVA engine to Aerojet-General on 3 May 1968 for a 750,000-lb-thrust engine. This document was reviewed, discussed with SNPO and SNPO-C on 5 June 1968, and is being used as the program requirements baseline for the NERVA Program.

As a result of the NERVA Task Force activities and the PRD definitive programs were started to resolve the following major problem areas that are required for definition of the NERVA engine: crew shielding, turbopump selection, and thrust spoiling.

Support was provided to LASL at NRDS to prepare for and to conduct EP-IV on the Phoebus-2A reactor.

1. Engine Systems

- a. Technology

Design and fabrication of modification kits for the XE-1 engine control system in support of the XE cold-flow and XE-1 power tests continued. Fourteen modification kits were completed and delivered to NRDS, and two modification kits are presently in work at Sacramento. The design and fabrication of modifications for the XE-1 test stand control system and test simulation system were continued. Nineteen modification kits were completed and delivered to NRDS, and five modification kits are currently in work at Sacramento. The first Bendix TPCV actuator, Model NT-D2, S/N 19, was successfully acceptance tested by the Bendix Corporation, Southfield, Michigan, and NRO Controls Laboratory. The actuator was then assigned to XE-2.

An evaluation of XECF data shows that similar wet- and dry-pump starts can be achieved and that performance can be predicted. This minimizes the differences in engine performance for different initial conditions. Also, engine-start characteristics can be predicted without using a separate venting system in the pump discharge line to prechill the turbopump.

Studies to define the open-valve system have been completed. Requirements for the various check valves and the V-5002 pressures have been analyzed. Predictions in support of FEP-V have been completed.

XECF EP-1 and EP-2 test data were reduced by the use of the narrow-band data-analysis program at Sacramento. A total of 24 data tapes were read and approximately 50 million pieces of data were processed through the computer, resulting in the production of more than 9000 individual data plots on approximately 3300 multiplots.

Using NRX data, an analytical method has been established based on the choked-flow equation to obtain best estimates of chamber pressure, temperature, flow rate, and throat area. The basis of the procedure is to weight the variables according to the magnitude of their variance.

b. NERVA

The primary effort during this report period was devoted to analyzing the four reference missions described in the NERVA Program Requirements Document and to conducting subsystem design studies that will enable the establishment of firm design requirements. Specific areas of study have been:

- (1) Crew-shielding optimization
- (2) Turbopump optimization
- (3) Thrust-nulling devices
- (4) Nuclear engine mission evaluation
- (5) Engine startup, shutdown, and cooldown
- (6) Nozzle optimization
- (7) Control-system definition

In addition to the preceding effort, first-, second-, and third-level functional flow diagrams have been prepared for the four reference missions and preparation of requirement allocation sheets has been started. This effort will result in the completion of the Nuclear Propulsion System Specification during the next quarter.

For NERVA, analysis was made of the overall specific impulse performance including startup, full-power operation, shutdown, and cooldown for the NERVA engine. Analyses were for a 300-sec run and a 1-hour full-power run. Also, an investigation was made of the measurement of specific impulse using spacecraft performance. Methods available have been applied to Thor, Atlas, and Titan flights with an accuracy of 0.1 to 0.5% at the 95% confidence level.

The results of the technology program have been reviewed relative to their applicability to NERVA flight safety. The first step in analyzing flight safety, that of establishing engine and reactor system computer models, is in process.

2. Support Systems

A review draft of the XE-2 Operational Support Plan, Volumes I and II, was issued. The XE-1 and XE-2 Engine Test Specification and five NTO procedures were reviewed. Two items of GSE were completed and delivered to NRDS, and coordination effort was provided relative to remote-equipment operation testing at the E-MAD. Status of GSE in support of the XE-1 readiness review was described in a presentation.

Collection of GSE data pertinent to the NERVA engine transportability study was completed.

3. Facility Systems

Engineering support and assistance were provided as required for the analysis, design, and procurement activities related to facility modifications in support of ETS-1 activation. Some of the activities involving significant effort included the following:

- a. Control drum actuator cryogenic-trap installation
- b. ETC latch-cylinder modifications
- c. Duct-vault and pipe-chase inerting
- d. Heat-shield reinforcement
- e. Permanent cooldown piping

Major design, procurement, and fabrication efforts were devoted to providing a new 100-mesh propellant feed-line screen; fabricating and reworking SGS components as part of the SGS spare parts and refurbishment activity; and to the design of a new steam line and related procurement actions.

Engineering assistance and analysis were provided in support of the NRDS instrumentation system required for the XE Engine program and development of the TSCS.

ETS-1 Data Acquisition System Final Accuracy, Report RN-S-0459, was published on 1 May 1968.

ETS-1 Failure Mode Analysis, Report RN-S-0454, was reviewed and efforts were expended toward resolving problems indicated in the report.

Engineering support for the ETS-1 nuclear exhaust system (E-1) was provided in the design and fabrication of hardware for the scale-model testing conducted at VKC. Gas separation in the nozzle skirt during testing required a new gas-side contour geometry to be developed, and this new configuration is being fabricated.

Analysis and engineering efforts have been provided for support of the NASS (E-2 and subsequent engines), with effort being expended in the areas of a full-scale-ejector predicted performance for a high-Isp engine ramp; the design and fabrication of a scaled nozzle and diffuser and all other

scale-model hardware associated with the full-scale duct configuration; and the conduct of high-temperature and water-penetration tests.

Additionally, copies of the preliminary NASS specification SS-90204 were transmitted to SNPO-C on 31 May 1968, to meet the schedule established during the meetings at Sacramento, which were attended by SNPO-C and NRO personnel. The specification is currently being revised in accordance with SNPO review comments and a final version is expected to be ready for issuance about 17 July 1968.

Engineering assistance was provided for the definition of ETS-1 modifications required for E-engine testing and design and for the modifications required to facilitate duct removal.

4. NERVA Tier-One Milestones

The overall program milestones reflecting the program status as of the end of the third quarter of CY '68 are presented in Figure 1. Continuing studies of the NERVA Program will refine the schedules shown.

B. END-ITEM HIGHLIGHTS

1. NRX-6

The NRX-A6 program highlight was the completion of post-operational examination of major components. Effort is being devoted to the remaining postoperational examinations and to issuance of posttest reports.

Figure 1 - NERVA Major Program Milestones (Sheet 1 of 2)

Figure 1 - NERVA Major Program Milestones (Sheet 2 of 2)

2. XECF

The XECF assembly was successfully tested at ETS-1 and returned to E-MAD. A series of posttests were completed, together with two series of vibration tests, which were made to further evaluate the effects of pump-induced vibrations on the TPCV.

3. XE-1

XE-1 assembly is continuing at NRDS. The lower module assembly is completed except for minor modifications. After reinstallation of the TPCV, TBV, and 3/8-in. Marotta pilot valves, the UMA will be ready for mating and engine checkout can proceed.

4. XE-2

The XE-2 PVARA has been received at NTO. The XE-2 UTSM is completed and is being held at Sacramento pending completion of all readiness review action items.

5. NERVA

Detailed definitions of the missions described by the NERVA program requirements document (PRD) have been started. The stages required for each of these missions have been defined. Preliminary investigations of the 75K NERVA engine for startup, shutdown, and cooldown have been completed and a preliminary operating map has been defined. Various trade studies, identified in the PRD and engine task force meetings, have been initiated. These include thrust nulling, flight shielding, engine to ETS-1 remote interface definition, and maintainability.

The NERVA propulsion system specification and associated systems engineering documentation have been started. The functional flow diagrams received as Appendix B of the PRD are being reviewed and modified as required. The completed and modified diagrams will be forwarded to SNPO for approval.

6. Test Zone H Facility

Full-flow and temperature-demonstration testing of the GH_2 heater has been deferred to enable additional TBV and TPCV testing of the NERVA technology engine. TBV testing was started on 28 May.

7. ETS-1 Facility

Facility modifications were continued in support of scheduled experimental plans leading up to and including the XE-1 power test. The XECF test programs were successfully completed on ETS-1 in April 1968.

8. E-MAD Facility

— — — — — The E-MAD complex was operationally utilized in the NRX-A6 postoperative examination, posttest operations on XECF, assembly operations of XE-1, and the receipt and storage of the XE-2 PVARA prior to assembly, which will be initiated during the next report period.

III. TECHNICAL DISCUSSION

A. MODULE 0 - TECHNOLOGY

1. Engine-System Design and Integration (1.1.0)

a. XE-Engine Assembly Drawings and Assembly Parts Lists

The current assembly drawing configurations in effect for XE-1 and XE-2 are 1116931-A (Engine Assembly); 1117122-C (Lower Module Assembly); and 1117061-U (Upper Module Assembly). Design changes were incorporated by DCN's and FCO's that included the following:

- (1) The addition of lockwiring to mechanical fasteners requiring this feature.
- (2) Welded washers were added in lieu of snap rings to the remote Marman couplings at Station 185.14.
- (3) Stiffener strips were added to the electrical connector modules at Station 119.64 and UTS/TSA interfaces.
- (4) Reinforcement plates were added to the On-Mark bracketry at the Station 119.64 interface.

Two additional design changes are being initiated for the Upper Module Assembly. The first is to increase the size of the bypass line around CKV by addition of a 1-in. line; this change is required to support the engine/facility cooldown limits (see A.1.c). The second is to reroute the 5-in. valve supply system. The purpose of this change is to isolate the valve purge system from hot TIL gas or cold PIL/TPA gas that could result from a 3/8-in. check valve malfunction.

In the TSA, a design change has been made to incorporate a flow screen in the PIL directly above the PSV. A second change incorporated a spring restraint on the cooldown supply line.

Module 0 (1.1.0)

b. XE-Engine Interface Control

ICOR 10209 was approved, making the following changes to Interface Control Drawing Number 1010058.

- (1) Thrust ring was changed to new design; installation control, mounting configuration, installation hardware, etc., were modified to the upgraded drawing.
- (2) Diffuser plumbing was added with orientation and dimensional controls being established.
- (3) The gas detector line within the TSA was relocated.
- (4) General updating to interface drawing was accomplished to verify completeness and correctness.
- (5) Re-evaluation of all dimensional controls was completed and the drawing was updated to reflect final assembly configuration.

c. XE-Engine Cooldown System

Final selection of the open-valve liquid hydrogen emergency cooldown system was made (Figure 2). The system effectively floats on line with PCV-472 open and V5002 at a low pressure (~300 psia at design point operation). The check valve (CHV-2302) in the 4LH-6 line checks the pump discharge pressure against the lower Dewar pressure. The liquid/gas accumulator is charged to pump discharge pressure by backflow from the engine. The accumulator provides LH₂ flow to the engine during the initial 0.8 sec of blow-down, after which CHV-2302 opens and Dewar flow takes over.

Special studies were completed that established the need for each check valve in the system. Malfunction studies demonstrated that the bypasses around CKV and through CHV-3364 could be sized to support a cooldown on the worst malfunction (TPCV opens) without exposing the engine to potentially catastrophic malfunctions upstream of the CKV. This requires an additional 1-in. bypass line around CKV.

Figure 2 - Emergency Cooldown System Open-Valve System Configuration

Module 0 (1.1.0)

Malfunction studies showed that failure-to-open malfunctions of CKV, CHV-3364, CHV-3365, and CHV-2302 are unacceptable. Closing malfunctions of PDKV and CHV-2302 (on-switch to GHe) are also unacceptable.

Additional studies showed that manual control of the V5002 Dewar and the accumulator vent, PCV-543, would probably be sufficient. However, the final demonstration must be obtained during FEP-V (see FEP-V Development Status). The cooldown controls (FR-145) requirements were documented and the cooldown controls chassis was delivered to NTO for installation ahead of schedule.

The emergency shutdown and Scram chains were combined into the emergency/scram shutdown. The action taken is similar to the old emergency shutdown, which means that the Scram was effectively eliminated. This was done because of the lack of apparent reasons for the Scram, together with the need to keep PCV-472 open for safety reasons. With PCV-472 open, the Dewar would interfere with the Scram pump tailoff. However, the normal shutdown pump tailoff mode was retained.

d. FEP-V Development Program

The FEP-V test is scheduled for the next quarter. The test description was prepared by NTO and coordinated with NRO. Comments were resolved and the final issue, NTO-I-0434, was distributed. The recording and display requirements document was also coordinated between NTO and NRO to finalize the data log. A preliminary issue of the test operating procedure was made.

The ETS-1 piping modification for the cooldown system was initiated this quarter and should be completed by the end of the quarter.

Module 0 (1.1.0)

Temporary piping for the engine simulator was installed. Temporary controls for FEP-V (FR-403,404) and the permanent controls (FR-145A) for the cooldown system were installed and checkout started.

The controller designs and FEP-V analog predictions were completed in preparation for the test.

e. XE-Engine Vibration-Analysis Program

Analyses and tests were performed to determine the vibration environments of the TPCV and the TBV during XE testing.

A vibration program was conducted on the XECF assembly in E-MAD to determine the transmissibility factor from the TPA and nozzle to the line sections, which include the TPCV and TBV. The final results of these tests will be reported during the next report period.

Analysis was performed to predict the vibration environment of the TPCV and TBV using forcing function information obtained from the NRX-EST test series and transmissibility factors obtained from the aforementioned vibration tests on XECF.

The program will continue during the next report period.

f. WEMU and RADA Development and Evaluation

No operations were performed with RADA this quarter due to unavailability of the E-MAD hot bay and the impending remote UTSM replacement demonstration to be conducted on XECF. Any problems encountered during the XECF demonstration cycle will be resolved using RADA.

Module 0 (1.1.0)

The WEMU was used this quarter to check out wrenches and closures in a semi-remote mode. Fully remote operations will be used during similar tests next quarter. Access problems encountered during remote removal of XECF from ETS-1 will be resolved using WEMU. Use of the MCC/EIV in programs other than the technology engine has caused delays in development of engine remote installation and removal capability.

g. XECF Assembly

Testing of the XECF at ETS-1 was completed. The engine was returned to E-MAD and posttest checks were completed. Two series of vibration tests were subsequently conducted to evaluate the effects on the TPCV of pump-induced vibration.

Remote-control features of the UTSM will be upgraded to incorporate those of the XE-1 configuration. A semi-remote UTSM removal and replacement cycle and a fully remote UTSM replacement demonstration cycle will then be performed.

The XECF UTSM is scheduled for return to Sacramento next quarter for upgrading to XE-1 configuration.

h. XE-1 Assembly

Assembly of the XE-1 lower module was completed except for completion of control drum actuator checkout and several minor modifications to be made. Completion of the engine assembly is scheduled for next quarter.

The pump discharge and cooldown lines were removed from the upper module and were cleaned this quarter. Reinstallation is in progress.

Module 0 (1.1.0)

The TPCV and TBV were removed from the upper module and delivered to Sacramento for rework of the bearings. Rework and acceptance tests have been completed and the valves are being prepared for return to NTO for reinstallation.

The 3/8-in. Marotta pilot valves were removed from the upper module and returned to the supplier for modification because of malfunction of one of the valves during XECF tests.

Completion of the upper module assembly and installation on the lower module is expected to be complete next quarter.

i. XE-2 Fabrication and Assembly

The XE-2 upper module was prepared for shipment to NTO; however, directions were received from SNPO to hold the unit at Sacramento until the TPCV and TBV are installed and all XE-1 readiness review actions are completed.

The XE-2 PVARA was received at NTO and will be stored until the engine shield is available from XECF to proceed with assembly of the lower module.

j. XE-Engine Field Design Changes

The "A" change to RN-PD-S-1101, Field Change Order Procedure for XECF, XE-1 and XE-2, was released on 13 May 1968. The change clarifies some of the aspects of processing FCO's.

Module 0 (1.1.0)

Significant FCO's processed in this quarter included:

(1) Change to the TSA PIL adapter to incorporate a machined groove for installing a flow screen upstream of PSV.

(2) Addition of a spring restraint to the TSA cooldown supply line.

(3) Several FCO's were issued to upgrade the XECF shield for XE-2 use. Included were changes in the liquid-level switch heights, additional level requirements for the Station 119.64 interface On-Marks, reinforcing the On-Mark brackets, and the addition of stiffeners to the electrical modules.

(4) The remote Marman couplings at the Station 185.14 interface were modified by replacing the snap rings on the drive screws with welded washers and increasing the lead in chamfer.

k. XE Readiness Review

Considerable effort was directed toward preparation of material to respond to action items assigned during the SNPO XE-1 design readiness review. Action item responses were made relative to the engine system, test stand adapter, external shield, TSA fluid lines, and the remote interfaces.

2. Engine System Test Engineering (1.1.2)

a. XECF

XECF tests EP-I and EP-II were completed during this report period. The Phase II Test Review Board was presided over by Aerojet-General.

Revision D to the XECF test specification, RN-S-0314, will be the final revision and will incorporate the remaining approved modifications in the next report period.

The following modifications to the XECF test specification were in various phases of processing as indicated:

<u>AGC Mod.</u>	<u>Description</u>	<u>Status</u>
12	Demonstration of remote removal procedure	Approved by the board as Changes No. 15 and 20; to be incorporated into Revision D
13	Additional test requirements	Approved by the board as Change No. 19; to be incorporated into Revision D
14	Change to remote cycle requirements	Approved by the board as Change No. 22; to be incorporated into Revision D
15	Additional vibration tests	Approved by the board as Change No. 21; to be incorporated into Revision D
16	Additional vibration tests	Pending board action
<u>NTO Mod.</u>	<u>Description</u>	<u>Status</u>
3	Test termination requirements	Approved by the board as Change No. 12; to be incorporated into Revision D
4	Revised chilldown requirements	Approved by the board as Change No. 14; to be incorporated into Revision D

Module 0 (1.1.2)

<u>NTO Mod.</u>	<u>Description</u>	<u>Status</u>
5	Revisions to operations section	Approved by the board as Change No. 18; to be incorporated into Revision D

The XECF TS&PRB, Phase III, was convened during this report period.

Measurement change requests (MCR's) were initiated and processed since the previous issuance of the revised XECF MRL.

Aerojet participated in the XECF EP-I SPEAR team activities.

The preliminary preparation for the XECF final report was initiated. A report outline was prepared and requests were made for input to the report from cognizant groups.

b. XE-1

Revision C to the XE-1 test specification, RN-S-0352, was initiated during this report period.

The following modifications to the XE-1 test specification were in various phases of processing as indicated:

<u>AGC Mod.</u>	<u>Description</u>	<u>Status</u>
2	Revisions to the operations section	Being reviewed
8	Updating of engine control system requirements	Superseded by AGC Mod. 18

Module 0 (1.1.2)

<u>AGC Mod.</u>	<u>Description</u>	<u>Status</u>
10	Trial run of engine transportation equipment between E-MAD and ETS-1	Approved by the board as Change No. 27; to be incorporated into Revision C of the Test Spec. RN-S-0352
11	Allowable opening and closing times for PSV	Revision 2 issued for review
13	Checkout of TSA and flush of external shield	Approved by the board as Change No. 25; to be incorporated into Revision C of Test Spec. RN-S-0352
14	Pressurization of structural bolt actuators and cycling of steam generator	Approved by the board as Change No. 29; to be incorporated into Revision C of Test Spec. RN-S-0352
15	Change in locations of dosimetry packets	Pending board approval
16	Deletion of log power override	Being reviewed
17	Requirements for microfilm of 1 S/S digital listing	Being reviewed
18	Revisions to operations section--general requirements and the test parameter limits justification	In preparation
<u>NTO Mod.</u>	<u>Description</u>	<u>Status</u>
5	Trickle purge requirements	Approved by the board as Change No. 26; to be incorporated into Revision C of the Test Spec. RN-S-0352
6	Changes in dosimetry packet locations	Pending board approval
<u>WANL Mod.</u>	<u>Description</u>	<u>Status</u>
9	Changes to the operations section	Approved by the board as Change No. 28; to be incorporated into Revision C of the Test Spec. RN-S-0352

Module 0 (1.1.2)

<u>WANL Mod.</u>	<u>Description</u>	<u>Status</u>
13	Change in Station 26 temperature limit (Classified CRD)	Pending board approval
14	Provides some of the information marked "To be supplied" in the initial issue of the test specification	AGC comments transmitted to WANL
16	Change in instrumentation field repair approval procedure	Disapproved by AGC
18	Revisions to fuel-element post-operational examination	AGC comments transmitted to WANL
20	Revisions to the control drum receiving inspection requirements	Being reviewed

Participation in the XE-1 TS&PRB, Phase I, was continued during this report period.

A revised XE-1 measurement requirements list (MRL) incorporating all approved instrumentation changes since the previous issue was transmitted. Additional MCR's were initiated and are being processed.

Extensive preparations were made for the XE-1 documentation readiness review. The presentations made to SNPO at Sacramento, were directed by test engineering personnel.

c. XE-2

The XE-2 test specification, RN-S-0400, Phase I (Pretest Section), was approved by SNPO-C and issued in the latter part of this report period. Phase II (Test Operations Section) has been initiated and is scheduled for release in August 1968.

The XE-2 TS&PRB, Phase I, was convened during this report period.

Module 0 (1.2.0)

The XE-2 measurement requirements list (MRL) was issued and additional MCR's were initiated and processed.

Aerojet personnel coordinated the assembly of the PVARA at WANL.

d. NTO Documents

NTO documents pertaining to test descriptions and operating procedures for the XECF, XE-1 and XE-2 were reviewed and comments were transmitted to NTO.

3. PFS Components (1.2.0)

a. 5-in. Butterfly Valve

During the XECF/XE-1 readiness review meetings, several action items were requested to clarify the 5-in. butterfly valve readiness review presentation. A summary of the work accomplished in response to these questions follows:

Two new lipseals, PN 1117405, SN's 162 and 172, were evaluated using an X-ray diffraction technique to determine sense and magnitude of residual stresses. Tangential readings were taken on the downstream flat face outboard of the gold-plated lip as shown in Figure 3. Results of the residual stress determinations and X-ray determinations of the α iron (martensite) content are shown below. The tensile residual stresses at several areas of one of the seals, SN 172, may be associated with the straightening or other rework operations, following forming.

Figure 3 - Five-in. Butterfly Valve Seal, PN 1117405

Module 0 (1.2.0)

X-RAY RESIDUAL STRESS RESULTS OF
5-in. BUTTERFLY VALVE LIPSEAL

<u>SN</u>	<u>Material</u>	<u>Downstream</u> <u>Tangential Stress, ksi</u>
162	SS302A	-10, -9, -33
172	SS302A	-40, +42, +15

X-RAY DETERMINATIONS OF AUSTENITE CONTENT OF
5-in. BUTTERFLY VALVE LIPSEALS

<u>SN</u>	<u>Austenite (Fe) Content, %</u>
162	54
172	56.5, 61

Further effort is needed in this area, and more seals will be tested to evaluate residual stress levels.

During this report period Convair, San Diego, was contacted to establish the fatigue strength of 1/4-in. hard 302 stainless-steel sheet at LH₂ temperatures. Data are expected during the next report period.

Contact with the National Bureau of Standards, Boulder, Colorado, revealed that a maximum of 10% (volume) of 302 stainless steel may possibly transform from gamma iron to alpha iron upon exposure of the material to cryogenic temperatures. Transformation of one volume percent gamma to alpha would cause an expansion of 140×10^{-6} in./in. (i.e., $140 \times 10^{-4}\%$) in accordance with studies of Auerback and Cohen. No detrimental effects of the volume change could be established.

b. 5-in. Swing Check Valve

A requirement was instituted during this report period to triple the bypass flow area around the 5-in. swing check valve located in

Module 0 (1.2.0)

the cooldown line. Design studies were initiated with layout and detailed drawings released as required to fabricate a new adapter spool (located between the 5-in. check and the cooldown supply valves) with provisions for a 1-in. bypass line. Fabrication has been started.

As a result of the XE-1 readiness reviews, it was required to assess the opening and closing reliability of the 5-in. check valve. Moisture accumulation and subsequent freezing was established as the most probable cause of flapper sticking. A maximum pressure differential across the flapper of 20 psid was established based on the acceptable time delay in opening of the cooldown check valve during an emergency shutdown from full power. This pressure differential is equivalent to a 380-lb force acting on a closed flapper and is more than an adequate gradient for satisfactory performance at normal operating conditions.

A test was devised to evaluate the force required to crack and slide a damper assembly after the unit was exposed to 100% humidity for approximately 100 minutes and then soaked in LN_2 (Figure 4). It would have been desirable to subject the entire valve assembly to the humidity test so that the effects of a frozen flapper-housing interface could have been established, but no housings were available. The environment of 100% humidity was selected because it represented the most extreme condition the valve would be subjected to as part of the propellant feed system.

A pressure of 20 psid across the closed flapper is equivalent to a 365-lb force directed through the damper assembly. Although none of the readings were as high as this critical value, such values are possible. The random manner in which the condensate settles in the damper significantly affects the test results.

NOTE: AS THE TENSION BOLT IS TORQUED, THE METAL SLEEVE IS FORCED TO EXPAND. THIS EXPANSION INCREASES THE FRICTIONAL LOAD EXPERIENCED BY THE CHECK VALVE ROD..... AND, OF COURSE, THE FLAPPER TO WHICH IT IS CONNECTED

Figure 4 - Five-in. Check Valve Damper

Module 0 (1.2.0)

Although the crack force of each specimen in this test was influenced by the 100% humidity, an earlier exposure to 90% humidity for 30 minutes prior to LN_2 soaking failed to increase the specimen's crack force from its ambient setting. Another specimen exposed to room environment (approximately 10 to 50% humidity and then soaked in LN_2 without a purge) also cracked at its ambient setting. It was concluded that if the valve is exposed to 100% humidity just prior to chilldown the force required to open the valve would exceed the 20 psi pressure differential; however, if the engine is properly dried and purged prior to chilldown, such a malfunction will not occur.

c. 3/8-in. Pilot Valve

During testing of the XECF engine system the 3/8-in. Marotta pilot valve, SN 880124, would not pull in at 28 vdc. However, when voltage was increased, the valve pulled in and allowed engine testing to continue. The valve was removed after XECF testing and returned to Aerojet-Sacramento. Several ambient checkout tests were performed and the erratic behavior was verified. After valve disassembly, it was learned that the dynamic Kel-F poppet shaft seal (a hat design) has axial and circumferential fractures. The seal dimensions were checked against those of the original design, and it was found that excessive deformation had occurred. Except for two nicked corners on the ID of the adjacent stainless-steel spacer, no other irregularities were observed. The electrical checkouts confirmed that the solenoid had not been damaged. Figure 5 shows a cross section of the valve and the location of the Kel-F seal.

Shortly after receiving SN 124, three other 3/8-in. Marotta pilot valves malfunctioned at Aerojet-Sacramento. Two of them (SN 117 and SN 134) were disassembled. The dynamic Kel-F seals showed fractures and excessive deformation, and with the exception of the nicked ID of the adjacent

Figure 5 - Marotta Valve, 3-Way 2-Position N.C. Solenoid Shown Energized

Module 0 (1.2.0)

stainless steel spacer, no other irregularities were observed. A new Kel-F dynamic seal was put in the SN 134 and it functioned satisfactorily; the valve responded consistently at a pull-in voltage of about 18 volts. After the new seal was withdrawn and the old seal replaced, performance gradually became erratic, and pull-in voltage slowly increased from 18 to 32 volts.

Disassembly of a fourth valve, SN 138, revealed a fractured Kel-F seal, an elliptically worn stainless steel spacer, and a retainer containing fine graphite powder. The retainer had been so deformed that it could not be repositioned on the electrolyzed stainless-steel poppet. The defective components were the same as those in the three valves previously examined.

As a consequence, valve SN 880134 was reassembled with a Mylar seal substituted for the Kel-F seal. The valve was then subjected to 74,000 ambient cycles and 40,000 LN_2 cycles with no degradation of the Mylar dynamic seals. The static Mylar poppet seat seals were replaced after ambient cycling. In both cases (ambient and LN_2), the pull-in and pull-out voltages were within specification, and upon completion of LN_2 testing the valve passed the leakage requirements.

d. Turbine Block/Turbine-Power Control-Valve Butterfly

Efforts to redesign the bearings in the valve butterfly were continued. Modifications of the existing TiC bearing rollers and race are complete. Backup bearings have been purchased, received, and modified and tested as necessary. Other components such as the valve axle, shaft, and thrust plate have been electrolyzed to reduce friction between mating surfaces.

Preliminary testing of various bearing configurations consisted of laboratory bearing-load tests at both ambient and elevated temperatures. The test setup is shown in Figure 6. Actuation torque was measured as a function of applied load. The shaft bearings were heated externally with Calrods.

Figure 6 - Four-in. Butterfly Valve Bearing Torque-Load Test Setup

Several variations of the spherical stainless-steel bearings were tested. The lowest torque values were obtained with a bearing that had an enlarged and gold-plated ID and operated as a shaft journal bearing. Misalignment between shaft and bearing was accommodated by rotation of the ball within its race. The ball and ID were also lubricated with MoS₂. The bearings were tested at both ambient temperature and at 775°F.

<u>Delta-P Load, psi</u>	<u>Torque, in.-lb (max.)</u>
100	100
200	190
300	270
400	360
500	430
600	500
650	560

The bearings were cycled 25 times at temperature; maximum torque after 25 cycles was 560 in.-lb at 650 psid load. The bearings withstood the test without significant damage.

Similar tests with the modified titanium carbide bearings resulted in slightly lower torque values, and the bearings withstood these tests without failing. The torque load data are presented in Figure 7 and are compared with TPCV actuator stall torque and TBV actuator torque. Figure 8 shows the shaft side bearing after the test.

Prior to selection of either bearing candidate, three ambient-temperature hydrogen flow tests were conducted. The bearing loads were simulated by closing the valve against a pressure of 650 psi. Figure 9 shows the spherical bearing after a 25-cycle test. No bearing failures were

- 1 MODIFIED STAINLESS STEEL SPHERICAL BEARING - 775°F
- 2 MODIFIED TiC ROLLER - 1000°F
- 3 MODIFIED TiC ROLLER - AMBIENT

Figure 7 - TPCV-TBV Shaft Bearing Torque vs Load

Figure 8 - Shaft Side Bearing After Testing

AXLE SIDE

SHAFT SIDE

Figure 9 - Spherical Bearing After 25-Cycle Test

encountered; however, galling of the snap ring, which retains the actuator side shaft, occurred. This problem has been attributed to the valves opening with 650 psi pressure in the inlet for a condition that will not exist for the valves in the X-Engine system. Future testing will be modified to eliminate the necessity of opening the valve against pressure.

Following this testing, the modified titanium carbide bearings were selected as the prime candidate bearing for both the TPCV and TBV. Two each 4-in. valves (SN 880030 and SN 880031) for the XE-1 engine unit were assembled; two units (SN 880023 and SN 880026) for demonstration testing have also been assembled.

e. 8-in. Propellant Shutoff Valve

Redesign of the 8-in. PSV was initiated during XE-1 readiness reviews. The redesign effort is directed toward reducing shaft seal leakage and shaft galling, which occurred on the previous demonstration unit. The major design change was to incorporate a leaded-bronze piston shaft guide, using either metal or Kel-F shaft seals with positive retention. Figure 10 is a cross section showing both configurations.

Two valves were modified during this report period (SN 880102 and SN 880103). Modifications of the A-Area test facility for testing the above valves in an LH_2 environment were completed during this report period.

Both valves were assembled with metal shaft seals and successfully passed the ambient portion of the acceptance tests. However, valve SN 880103 failed to pass the LN_2 poppet-seal leak requirement. Posttest disassembly revealed the following problems:

Figure 10 - Eight-in. PSV Shaft Seal Redesign

Module 0 (1.2.0)

- (1) Galling between the inner spring and inner spring guide.
- (2) The inner diameters of the shaft seals were apparently expanded during initial modification, were not to drawing dimensions, and did not contact the shaft.
- (3) The shaft guide ID was not to the drawing requirement of 0.7530 ± 0.0005 in. diameter; the actual value was $0.7521/0.7519$ in. diameter.
- (4) The piston apparently bottomed in the actuator causing the poppet leakage at LN_2 temperatures.

Based on the problems detected with valve SN 880103, valve SN 880102 was disassembled after completing the ambient and LN_2 portions of the acceptance test plan. Disassembly revealed that the metal shaft seal had a fractured lip, the presence of galling between the inner spring guide and inner spring, and that the ID of the shaft seals was oversize.

Because of previous lipseal failures and unsatisfactory leakage performance on the metal shaft seal, valves SN 880102 and 880103 were reassembled with Kel-F seals as shown in Figure 6. Valve SN 880102 successfully completed the ambient and LN_2 portions of the acceptance test and was installed in the cryogenics laboratory for LH_2 testing. During LH_2 acceptance testing, the valve cycling was erratic. As a result, it was decided to remove the valve from the test rig and disassemble it to determine hardware condition. In addition, efforts were made to re-evaluate the test stand purge, relief, and sequence procedures to determine if the test system and procedures were affecting the test hardware. Disassembly and inspection of valve SN 880102 revealed that all hardware was in satisfactory condition, with no signs of shaft galling or seal failure. Further testing of the valve configuration will be conducted with improved purge and dehydrating procedures.

Module 0 (1.2.0)

f. Turbopump

A review was made in March to assess the readiness of the turbopump for use in the experimental engine test program. The review covered the mechanical and aero/hydrodynamic adequacy of the turbopump.

During the review, the following nine action items were defined:

- (1) Provide a description of all TPA operating limits and/or constraints.
- (2) Review and analyze the impeller blade failure of SN 19 TPA and the nozzle cracking (and trailing edge parting) evidenced on all the demonstration units.
- (3) Review and explain the heavy impeller rubbing of SN 20 TPA.
- (4) Analyze Scram-shutdown impact on TPA turbine nozzles.
- (5) Review malfunction analyses in terms of impact on TPA.
- (6) Compare the basis of accepting for use the speed probes to the acceptance or qualification testing per AGC 42213 that was not done.
- (7) Explain the cause of the turbine inlet-manifold discoloration that was evidenced after demonstration testing of SN 18 TPA.
- (8) What are the consequences of the graphite seal failures?
- (9) Explain the turbine manifold cracking that was discovered after demonstration testing.

Tables 1 through 8 show the current status of the action items. Response to the action items is complete, with the exception of Item 5, which will be completed early in the next quarter.

Module 0 (1.2.0)

TABLE 1

TPA READINESS REVIEW

ACTION ITEMS: ITEM 1

ITEM 1

Provide a description of all TPA operating limits and/or constraints.

STATUS

Complete

SUMMARY

1. Stall limit - left boundary of operating map.
2. NPSP limits - shown on operating map.
3. Turbine temperature limit - speed and time related (1500°R max).
4. Turbine inlet pressure limit - 600 psia max.
5. Turbine exhaust pressure limit - not to exceed inlet pressure.
6. Shaft speed limit - 26,650 rpm max.
7. Vibration displacement limit - 0.030 in. max.
8. Turbine rotor vibration limit - no steady-state operation within
+ 450 rpm of 16,000 rpm.

TABLE 2

TPA READINESS REVIEW

ACTION ITEMS: ITEMS 2 AND 4

ITEMS 2 AND 4

Review and analyze the impeller blade failure of S/N 19 TPA and the nozzle cracking (and trailing edge parting) evidenced on all of the demonstration units.

Analyze scram shutdown impact on TPA turbine.

STATUS

Complete, but requires additional analysis to define acceptable shutdown transient.

SUMMARY

1. Impeller failure - failure caused by very heavy cyclic rubbing on a single vane due to operation at overspeed at or near shaft critical speed.
2. Nozzle cracking - cracks resulted from repeated shutdown thermal stress cycles on demonstration TPA's.

Emergency shutdown thermal stress will probably crack nozzle vanes.

Module 0 (1.2.0)

TABLE 3

TPA READINESS REVIEW

ACTION ITEMS: ITEM 3

ITEM 3

Review and explain the heavy impeller rubbing of S/N 20 TPA.

STATUS

Complete

SUMMARY

Rub was caused by a combination of normal component deflections under normal loads and high radial loads exerted by the deformed seal ring.

Module 0 (1.2.0)

TABLE 4

TPA READINESS REVIEW

ACTION ITEMS: ITEM 5

ITEM 5

Review malfunction analysis in terms of impact on TPA.

STATUS

Approximately 50% complete pending resolution of engine malfunction analysis.

SUMMARY OF COMPLETED ANALYSIS

Sudden PSV Closure - overspeed/stall will occur. Low risk because of low input power at time of occurrence.

Scram Shutdowns - nozzle cracks probable
(Item 4)

Module 0 (1.2.0)

TABLE 5

TPA READINESS REVIEW

ACTION ITEMS: ITEM 6

ITEM 6

Compare the basis of accepting for use the speed probes to the acceptance or qualification testing per AGC 42213 that was not done.

STATUS

Complete

SUMMARY

Probes demonstrated adequate during qualification and acceptance testing.

Module 0 (1.2.0)

TABLE 6

TPA READINESS REVIEW

ACTION ITEMS: ITEM 7

ITEM 7

Explain the cause of the turbine inlet manifold discoloration that was evidenced after demonstration testing of S/N 18 TPA.

STATUS

Complete

SUMMARY

Straw color is normal oxide formed when stainless steel is heated to about 700°F in air.

Mottled appearance of the inlet duct transition section resulted when porosity was weld repaired using cres 349 weld rod per Drawing 1010163-1.

TABLE 7

TPA READINESS REVIEW

ACTION ITEMS: ITEM 8

ITEM 8

What are the consequences of the graphite seal failure?

STATUS

Complete

SUMMARY

0.016 x 0.5 x 0.1 particles present no hazard to other turbomachinery component.

Sufficient coolant flow will be maintained even in event of complete carbon failure.

Module 0 (1.2.0)

TABLE 8

TPA READINESS REVIEW

ACTION ITEMS: ITEM 9

ITEM 9

Explain the turbine manifold cracking that was discovered after demonstration testing.

STATUS

Complete

SUMMARY

Crack apparently resulted from an undetected casting defect.

A similar flaw might exist in XE-1 manifold and a crack could occur.

No adverse consequences would be expected since the compartment is adequately purged and crack did not propagate through wall on S/N 18.

Module 0 (1.3.0)

In general, the turbopump has been shown to be adequate for the planned XE test program. Continued action will define acceptable shut-down transients and will confirm or re-establish turbopump vibration limits.

4. Reactor Test and Interface Control (1.3.0)

With the conclusion of the NRX-A6 nozzle and propellant feed line leak check, the principal highlight of Sub-Subtask 1.3.0 during this report period was the completion of the NRX-A6 program, except for issuance of technical reports.

Postoperative examination of NRX-A6 non-nuclear components was completed.

The NRX-A6 nozzle leak check was conducted by filling the tubes with dye penetrant and spraying the developer on the hot side at the thermocouple pass-through locations. No leakage was observed. Photographs were taken and the nozzle was returned to the radioactive material storage facility (RMSF) pending further analysis.

The NRX-A6 propellant feed line was visually examined, pressurized to 50 psig with helium, and the bellows was leak checked. No leakage was observed. The line was returned to the RMSF.

The NRX-A6 Systems Data Analysis Report No. RNS-0464 was reviewed and will be issued shortly.

NRX-A6 Systems Engineering continued the microfilming of the NRX-A test documents for historical records.

Module 0 (1.3.4)

In support of the XE-2 program, Sub-Subtask 1.3.0, Aerojet personnel packaged and shipped hardware and were at WANL during the assembly of the reactor into the pressure vessel and preparation for shipment to NRDS.

In summary, postoperative examination leak checks of the NRX-A6 nozzle and propellant feed line bellows confirmed that no leakage of these components occurred during the test series. The NRX-A6 program was completed except for issuance of technical reports.

5. Reactor Development (1.3.4)

Activities performed in this task were to review NRX and XE reactor development work for consistency with engine requirements and to facilitate WANL-NRO interchange of information necessary for the integration of reactor-engine hardware, test planning, testing, and data interpretation. Specific activities performed in support of these purposes were:

- a. Reviewed the NRX-A6 postoperative examination of the fuel elements. Made comments and suggested areas for additional investigations.
- b. Participated in XECF performance review through SPEAR Team membership for reactor subsystem performance.
- c. Participated in WANL XE-1 and XE-2 Readiness Review.
- d. Provided technical review and coordination on WANL actuator procurement for ganged-drum drive system.
- e. Exchanged information related to anticriticality poison wire system requirements and WANL-AGC interface.

Module 0 (1.3.6)

f. Provided technical support for test planning and post-operative examination on XE-1 and XE-2.

g. Participated in monthly Thermo Flow Lab and Engineering Mechanics Lab Progress Meetings.

6. Fuel Development and Fabrication (1.3.6)

Fuel-element meetings were attended and information was supplied to Program Controls personnel concerning status, problem areas, and projected schedules.

The graphite-flour problem was reviewed with WNCO.

Information concerning hypereutectic carbide composites and thermo capsule was forwarded to WANL and LASL.

The existing WNCO computer system and requirements were investigated in planning for a computer system improvement relative to process control, quality control, and product certification.

7. Technology Nozzles--XE-1 and -2 and NRX-A6 (1.4.0)

The XE-2 Nozzle Readiness Report has been prepared. This report was written as documentary proof that the PN 1114263-99, SN 880028, is suitable for inclusion in the XE-2 engine assembly. The document is in the process of being approved.

This report describes the nozzle and lists the primary documents applicable to the design, fabrication, and testing of a nozzle. These primary documents provide the design requirements, and the Readiness Report shows the compliance with the design requirements. The report discusses the differences between the NRX/EST and the XE nozzles, which are minimal. It covers the chemical simulation testing to which nozzles of the XE design have been subjected and the thermal and mechanical margin of safety. A modes of failure analysis is included. Inspection reports that were made during the fabrication of the nozzle are included in the report, together with the basis for the acceptance of a condition not complying with the drawing.

Further analyses have been made using the results of the NRX-A6. These analyses confirm that radial temperature gradients existed in the nozzle and were particularly severe near the wall. The data also confirm the braze alloy indications of low tube-wall temperatures, which occurred in the core end of the nozzle. The analyses also show that the temperature indicated by the chamber temperature thermocouples was the temperature that existed at the thermocouple junction.

8. Thrust Structure and Lines (1.4.2)

During the initial vibration testing at NTO of the XECF system, a potential vibration problem associated with the upper TIL was identified. An immediate design study was initiated in an effort to determine the feasibility

of damping the TIL by proper supports or by replacing the current stiff gimbaled bellows with a braid-restrained bellows. Line layout drawings for the line support and damping are being made, as well as envelope drawings for a braid-restrained bellows and a pressure-compensating bellows (a backup for the braid-restrained bellows).

In addition, a test program is being planned to conduct a resonant frequency search of a 4-in. internally gimbaled bellows of the type currently used on the XE system at pressure levels that realistically simulate engine operational conditions.

9. Pressure Vessel (1.4.4)

a. NRX-A6 Pressure Vessel

Evaluation of the NRX-A6 test data was completed, and Report RN-S-0457, Evaluation of NRX-A6 Pressure Vessel Assembly, was published. The structural and functional integrity of the pressure vessel assembly was again substantiated by NRDS test data.

b. XE-1 Pressure Vessel

Engineering coverage was provided at NRDS for the flame-spray tie-down of instrumentation cables to the XE-1 pressure vessel.

c. XE-2 Pressure Vessel

Aerojet was represented by design and material engineering personnel at WANL on 8 May 1968 to determine a suitable course of action relative to reported discrepancies in the XE-2 pressure vessel. The reported discrepancies consisted of surface stains and indentations noted during WANL receiving inspection.

Module 0 (1.4.4)

The WANL inspection report was written to call for hand rubbing of the stain area with No. 240 grit aluminum oxide paper to collect samples for analysis and to remove the stains. The two indentations (0.200 x 0.068 and 0.080 x 0.040, both 0.010 deep) at 135° clockwise from $\theta = 0^\circ$ were hand-blended with aluminum oxide paper, penetrant inspected, and found to be acceptable. All remaining superficial surface scratches were found to be acceptable.

Aerojet analyzed the abrasively removed samples. The small amount of stain residue obtained prevented an accurate wet chemical analysis, but a X-ray diffraction test indicated metallic aluminum and aluminum oxide with no evidence of foreign material. Since the test failed to uncover foreign material, a positive identification of the staining medium was not possible. The probable cause of the stains appears to be condensation that occurred during shipment.

Since the stains were completely removed in an attempt to secure enough material for analysis, the pressure vessel is considered to be acceptable as is.

Engineering coverage was also provided at WANL for the XE-2 reactor/pressure vessel assembly.

Module 0 (1.5.0)

10. Control-System Design and Analysis (1.5.0)

a. XE-1 Engine Control System (ECS)

(1) XE-1 ECS Development Status

The design and fabrication of modification kits for the XE-1 engine control system (ECS) in support of the XE cold-flow and XE-1 power tests continued throughout this report period. The status of the modification kits is as follows:

Modification Kits Completed and
Delivered to NTO

Reject relay circuit for temperature and pressure average and reject circuit
Reset of manually rejected temperature or pressure signals
Change averagers to medium selector gate type circuit
Dry temperature autostart chassis
Improved scram shutdown schedule
Removal of temporary XECF valve logic
Change roll-off capacitor on each zero suppression amplifier
Add variable clamp for TPCV open position
Modify programmer for high I_{sp} start
Modify programmer for high thrust start
Change operation of programmed light on CTE console
TPCV and pressure control perturbation
Linearize chamber temperature averager
Remove hysteresis from chamber temperature loop closure

Modification Kits Presently
in Work

Improvement of compensation
Expand reflector inlet temperature averager from 3-signal to 5-signal capacity

Module 0 (1.5.0)

Technical coordination meetings were conducted at Aerojet-Sacramento and NTO with Engine Controls personnel, NTO Operational personnel, WANL Controls personnel, and Program Management Office personnel to review all proposed modifications of the ECS. The meetings resulted in the cancellation of a modification to the relay status indication.

b. XE-1 Emergency Cooldown System

The analog model of the XE-1 emergency cooldown system was modified to analyze the open valve LH₂ emergency cooldown system with a GH₂ accumulator.

In the first study, a GH₂ accumulator was added to the LH₂ cooldown system by providing bypasses around CHV-1721 and CHV-681 or CHV-685, or both. The study showed that this type of system would allow for the Dewar (V-5002) to be operated in the 250 to 400 psia range, eliminating sequencing and closed-loop control of PCV-472.

The analog model was again modified to incorporate the final facility configuration, which includes a 4 cubic foot GH₂ accumulator and a 10 cubic foot LH₂ buffer separated from the 4LH6 line by CHV-3364.

The analysis showed that it is necessary to add a 1-in. bypass line around CKV in addition to the existing two 3/8-in. bypass lines to maintain 1 lb/sec chill flow and achieve an acceptable emergency shutdown for a TPCV fails-open malfunction.

c. XE Analysis

Determination of engine-transfer-function sensitivity to variation of sixteen model parameters continued. An evaluation was made of the effects of a model equation change on previously computed sensitivities. The equation change shifted the basic frequency response but had a negligible effect on parameter sensitivities.

A procedure has been developed to compare the dynamics of sections of the engine model against test data. A digital program has been written to compare frequency response calculated using subsection transfer functions against frequency response measured during testing, and to relate discrepancies to small sections of the model.

Transfer function gain differences on the order of 1.0 db have been traced to the use of straight-line approximations to represent engine model function curves. A procedure is being developed to minimize the effects of straight-line approximation by maximizing the number of break points located within the operating region of each curve and by optimizing the location of these break points.

A report is being prepared that provides the derivations of the XE CAM engine equations. The source of all constants is also given, together with explanation of the evaluation of the equations in the present form.

A current set of open-loop XE equations were programmed for the IBM 360 version of TAF. The program is being checked out.

Module 0 (1.5.0)

A series of runs were made on the analog computer to determine the desirability of adding filter circuits in the flow-shutdown activation devices. Study of the addition of a flow-shutdown trip to PDSV indicated that this would not significantly change the characteristics of the inadvertent PDSV closure malfunction.

A series of runs were made on the Aerojet analog computer for WANL controls and safety analysis. These runs were included under the following categories:

- (1) Development of T-26 setup and checkout procedures for XE-1.
- (2) Studies of the effects of the addition of filters in drum and override and drum roll-in circuits.
- (3) Studies to perfect the analog simulation of drum scram-profile characteristics.
- (4) Studies of core cluster exit temperature as a control parameter for temperature override.

d. FEP-V Predictions

A dynamic study was made of the FEP-V test facility configuration to provide predictions for FEP-V. A mathematical model of the system was formulated and simulated on an analog computer. The following major systems were simulated:

- (1) V-5002 Dewar
- (2) Engine cooldown system
- (3) Facility engine simulation line
- (4) PCV-250 control system
- (5) PCV-701 control system
- (6) PCV-543 control system

Module 0 (1.5.0)

A series of studies were made to predict the fluid dynamic phenomena associated with FEP-V testing. These studies included the following:

(1) The first series of runs were made to determine the most appropriate position for PCV-750 and initial P_3 pressure to obtain the best pressure and flow decay associated with a 30-millisecond exponential loss of flow. Shutdowns from three different engine flow and pressure operating points were investigated, and the following conditions appear to give the best simulation of a 30-millisecond exponential loss of flow.

Engine Conditions			Simulator Conditions	
P_3 , psia	W, lbm/sec	T(c), °R	P_{888} , psia	W, lbm/sec
960	77	4090	960	60
527	42	3600	500	30
289	29	2200	300	13

(2) The V-5002 pressurization system was observed to determine the capability to deliver the LH_2 flow at the required pressure. The ability of the pressurization system to follow a 50°/sec and 100°/sec pressure profile was checked and was found capable of following only the 50°/sec ramp. This is due to the limitation of gas-flow capability of the pressurization system.

(3) Emergency cooldown line blowdown simulating the operation during an emergency cooldown with the Dewar at 300 psia was run for various locked-up pressures, line temperature distribution, and PCV-543 modes of operation.

(4) Failures of PCV-543 and RSV-109 were run to determine the effect on the system.

A total of 156 computer runs was made. All data have been transmitted to NTO for inclusion in an FEP-V prediction report.

Module 0 (1.5.2)

The FEP-V equations were programmed on the IBM 360 version of TAF to cross-check the analog model.

e. Transfer Function Summary

An effort to document the system and component transfer function measurement made during all NRX tests has been initiated. A file of all available frequency response plots generated from those tests has been compiled. The work is an attempt to correlate the predicted and measured frequency responses made by Aerojet and WANL. Evidently, many of the computed response functions are not useful since they were not repeated during all tests. As a result, the experimental data could not be compared with the predicted data. It is expected that the XE response measurements will be more complete. This collection of NRX response functions also contains the XE-CAM transfer-function predictions.

11. Control Actuators (1.5.2)

a. Actuators, Model NT-D2

The acceptance tests of the Bendix TPCV actuator, Model NT-D2, SN 19, were successfully completed on 24 April 1968 at the Bendix Corp., Southfield, Mich. The actuator was received by Aerojet-Sacramento, 1 May 1968, and engineering acceptance verification tests were conducted in the NRO Controls Laboratory. The actuator was then assigned to XE-2.

The acceptance tests of the Bendix TPCV actuator, Model NT-D2, SN 19, were accomplished with a seal provided by Aerojet because of a problem relative to Bendix Subcontract NP-000141. To date, the suppliers selected by Bendix to provide output shaft dynamic seals have been unable to

Module 0 (1.5.2)

deliver seals that perform satisfactorily under the pressures and temperatures indicated in Aerojet Specification 90080E. The seals provided by both suppliers have been returned to correct the weld failures that occurred during testing at Bendix. Aerojet has initiated an output shaft dynamic seal backup program with Donaldson Corp. The first backup seal is expected to be ready for acceptance testing between 17 and 24 July 1968. The other nine seals are expected to be completed by 31 July 1968.

The scheduled dates for the remaining component and actuator acceptance tests at Bendix are as follows: servo motors 2, 3, 4, and 5 and transmission 2 on 8 and 9 July; transmissions 3, 4, and 5 and actuator serial number 20 on 25 and 26 July; and actuators serial numbers 21, 22, and 23 on 19 to 28 August.

b. Actuators, Model NT-D1

An action item that resulted from the XE readiness review, 28 February 1968, stated that the TPCV actuator is considered acceptable for XE-1 providing the predicted vibration environment does not exceed the levels for which the actuator was qualified.

Evaluation of XECF vibration data and vibration data obtained from test of Model NT-D1 TPCV actuators in the NRO Controls Laboratory indicated the possibility of a TPCV actuator performance problem under the vibration conditions of the current turbine inlet line configuration. A test plan has been devised that will determine the ultimate performance capability of the actuator under severe vibration and comparisons will be made with the expected engine environment.

Module 0 (1.5.6)

12. Facility Engine-Control-System Design (1.5.6)

a. Design Modifications

The design and fabrication of modifications to the XE-1 test stand control system (TSCS) and test simulation system (TSS) in support of the XE cold-flow and XE-1 power tests were continued. The status of the modification kits is as follows:

Modification Kits Completed and
Delivered to NTO

Lamp verify circuit
Purge panel
TPCV override
Pump discharge dp/dt detection
XE-1 cold-flow requirements
LH₂ cooldown
Additional cooldown requirements
Temperature loop closure
ECS reset during simulation
Simulation for wet and dry autostart
Simulated source pressures
Cooldown simulation rescaling
Add redundant reset contacts
Cooldown simulation changes
Single drum control
Add inert-cooldown switch
Zero suppression voltage adjust
Deletion of +10 vdc and +15 vdc
Scram bypass
Active signal conditioners

Modification Kits Presently
in Work

Removal of change TSCS-59
Torque motor current meter
panel
Elimination of Scram shut-
down
Zero suppression noise and
drift
CTE panel changes

Module 0 (1.7.2)

b. Technical Coordination Meetings

Technical coordination meetings were conducted at Aerojet-Sacramento and NTO with Engine Controls personnel, NTO Operational personnel, WANL Controls personnel, and Program Management Office personnel to review all proposed modifications to the TSCS/TSS. As a result of the meetings, the following modifications were cancelled: power demand generator, shutdown mode, GHe and GH_2 coefficients, Tc averager, LH_2 storage Dewar and CVV power control, temperature demand power loss, He inerting control, LH_2 cooldown simulation, PCV simulation, CTE indicators, PCV-248/179 controller, and the PSV and RSV-132 emergency shutdown input.

c. Engineering, Drafting, and NTO Support Documentation

Preparation of line diagrams continued. The second package of drawings was submitted to NTO during this period.

d. NTO Engineering Support

TSCS personnel accompanied the modification kits that provide controls for the integrated cooldown system and are participating in the installation and checkout in preparation for FEP-V.

13. Instrumentation Components and Systems (1.7.2)

a. Application

(1) XE-1

The development of an automatic computer routine was initiated to detect and identify ETS-1 measurement system anomalies by analyzing pretest and posttest channel calibrations. This routine is being developed to assist the XE-1 SPEAR team activities.

Module 0 (1.7.2)

(2) XECF

Support was provided for the XECF EP-II SPEAR team activities to detect and identify anomalies in the ETS-1 data-acquisition system.

An investigation is being made of the noise problem encountered on XECF vibration and sound measurement channels. Charge amplifiers are currently being checked out at Sacramento and at the vendor's facilities to determine the cause of oscillations that occur at particular gain settings.

b. Installation

(1) XECF

A procedure was written and submitted to upgrade the XECF UTSA to the XE-1 configuration. A second procedure was also submitted that recommended replacing the instruments at TT109, PT882, and TE844. Performance of this instrumentation appeared to be questionable when the XECF data were reviewed.

All parts required to upgrade the XECF UTSA to the XE-1 configuration were shipped to NTO, as well as the instruments to replace TT109, PT882, and TE844. However, because of the decision to rework the UTSA at Sacramento, the hardware is being prepared for return to Sacramento.

Data from the XECF runs were reviewed and anomalies were reported through the NTO reporting system. All anomalies suspected of being transducer-induced will be reported in the XECF instrumentation posttest report. Data from the final end-to-end checks have not been received.

The pins at the top of XECF UTSA and the sockets in the TSA were inspected and tested. The tests and results are summarized as follows.

Module 0 (1.7.2)

The TSA sockets were submitted to a contact separation force in accordance with MIL-L-26636A. Of 3662 sockets tested, 15 failed the minimum weight test and 30 failed the maximum weight test. Only two instrumentation circuits could have been affected by the sockets that failed the minimum weight test. However, no anomalies could be detected in the two channels from the XECF data.

Visual inspection of the UTSA pins indicated that five were bent, only two of which were used. These two were used in the plug-mated circuits and presented no problems.

(2) XE-1

Liaison was provided at NTO during the assembly of XE-1 LMA instrumentation. The assembly, including electrical end-to-end checks, was completed during this report period except for moisture proofing the Station 119 standoffs. This operation is scheduled for mid-August 1968.

In addition to the XE-1 LMA instrumentation kit, four RTT's were added to the pressure vessel and two flush-mounted evaluation pressure transducers were installed on the nozzle.

During flame-spray electrical postchecks, it was determined that the tungsten-rhenium thermocouple for measurement TE141 was open. This unit, AGC 1010306-9G, SN 890659, was removed and replaced by a spare (SN 890652). Further investigations at NTO and Sacramento revealed a break in the 5% tungsten conductor where the cable had been bent in the area of the nozzle flange. The break is about 2 in. outside of the flame-sprayed area and is in a bend of approximately 1.12R, which exceeds the 2.00R minimum called out on the arrangement drawing. Apparently, the tight radius contributed

PAGES 65-66

Figure 11 - Comparison of CFDTS and XECF Parameters for Wet-Pump Start

pump discharge line (Figure 12); in CFDTs, a speed and flow oscillation occurs prior to the establishment of a bootstrap condition in the engine with speed peaking up at 46 sec after the opening of the turbine-power control valve. On XECF, with the preconditioning cycle, by establishing a 50°R reflector inlet temperature the speed peaked 15 sec after the opening of the turbine-power control valve. The performance of XECF on the wet and dry pumps with the preconditioning cycle shows speed peaks within 2 sec of each other, with the differences accounted for by instrumentation differences, leading the TPCV valve to open faster on the dry-pump than the wet-pump start.

The tests were not conducted in accordance with the test specification used for the test predictions of Revision A, Modification 1, of Report No. RN-S-0354. Prior to the tests, the operating specification was changed to require a nozzle-tube-outlet temperature of 50°R as a signal to initiate opening of TPCV, whereas the previous predictions were based on a nozzle-tube-outlet temperature of 100°R. Consequently, computer runs were made after the tests to establish a basis for comparison of computer and test results. The measured initial metal temperatures, tank pressure and temperature, and the measured TPCV opening rate were used as input for these runs. In general, the computer results showed the correct trends but the analysis predicted too rapid an engine chill. The most applicable computer results relative to the bootstrap phase were obtained by selecting the time during computer chillover at which the dome and chamber temperatures were approximately equal to the measured data at completion of chillover, to start opening of TPCV. Under these conditions, the computer results for both tests showed a bootstrap to about the right peak speed; but this occurred too soon after initial opening of TPCV.

Based on opening the TPCV at corresponding dome and chamber temperatures, computer runs were made for both the warm and chilled pump tests, using the computer option in which the measured pump speed versus

Figure 12 - Comparison of CFDTS and XECF Parameters for Dry-Pump Start

Module 0 (1.8.0)

time is input and the corresponding turbine efficiency required to attain the input pump speed match is calculated. In this option of computer operation, the system temperatures, pressures, and flow rates are calculated in the same way as they are in a normal run. This option, therefore, provides a means of matching the computed pump speed versus time with the test data, so that the other parameters can be readily compared. Comparison of the results of these runs with test data showed that chamber temperature and turbine inlet temperature decreased more rapidly during the bootstrap phase than indicated by the test data.

Based on the preceding results, it appeared that the computer model did not provide enough heat capacity for the reactor core. An investigation of the input data for this parameter revealed that the C_p input for the graphite core as a function of temperature was in error in the temperature region of 300°R. The tabular input had a value of 0.0191 Btu/lb-°R at 300°R. The correct value is 0.091 Btu/lb-°R. The adjacent values input at 0°R and 520°R were correct. Therefore, at core material temperatures below 520°R the heat capacity of the core was too small in the model, resulting in insufficient heating of the core flow under cold-flow test conditions. Correcting the value of core heat capacity at 300°R resulted in better agreement of computed and measured chamber temperature data.

After the core heat capacity correction had been made, the warm-pump test was rerun on the computer, again using the option in which the measured pump speed versus time was input and the required turbine efficiency was calculated. The results showed good correlation among computed and measured engine parameters throughout the bootstrap, except that the computed turbine inlet temperature was about 100 to 150°R lower than measured throughout the bootstrap. The test data for Run 1 show that the turbine inlet temperature is about 50°R higher than chamber temperature. This means that appreciable

Module 0 (1.8.0)

warming of the turbine flow occurs in the unjacketed portion of the turbine inlet line. In the past, heat transfer in this line was not required in the program. Instead, an approximate method is used in which the mass of the unjacketed turbine inlet line is included in the diluent line, and the program performs an enthalpy balance of diluent and hot-bleed flow and uses the results of this balance as the turbine inlet temperature. This approach was satisfactory for all engine startup conditions previously used in which the TPCV was opened at the start of propellant flow. However, for the start sequence used for XECF (and planned for XE-1) the diluent line and core are partially chilled during the engine chilldown phase, but the unjacketed portion of the turbine inlet line is not chilled since the TPCV is closed. Therefore, when the TPCV is opened, the GH_2 entering the line is well below the temperature of the line and significant heat transfer occurs. Addition of heat-transfer calculations for the unjacketed turbine inlet line would require a program change.

The turbine efficiency curve was also refined for low values of U/C_o (less than 0.08). Computer runs were then made for the bootstrap phase of the XECF warm- and chilled-pump tests. Results of computer predictions are compared with test data in Figures 13 and 14. The results of the previous computer prediction is also shown so that the improvement of correlation to test data resulting from the input changes made is discernible. In general, for both tests, the computer data now correlate well with test data (except turbine inlet temperature) prior to peak pump speed, but decays are more rapid during the period following peak speed. This was to be expected since during this time interval the calculated turbine efficiency required deviates from the input curve generated; also during this time, the effect of lower computer turbine-inlet temperature would be most pronounced.

Figure 13 - XECF EP-2 Warm Pump, Time from TPCV Opening

Figure 14 - XECF EP-2 Warm Pump, Time from First Motion of TPCV

Module 0 (1.8.0)

b. XECF Malfunction Analysis: Steam Line Rupture

An analysis was made to estimate the amount of air backflow into the engine test compartment (ETC) if the steam line should rupture during the XECF tests. Assuming that the system is completely purged of air and that complete mixing of all gases in the ETC and the duct occurs, the calculated air concentration for the various cases considered varied from 11% to 20%. If the initial concentration of oxygen in the ETC is assumed to be 1%, then the air concentration would vary from 14% to 22%. Assuming that the characteristics of helium are the same as those of nitrogen in defining the flammability limits of hydrogen, the operating points for all cases of interest lie within the safe region.

c. XECF Narrow-Band Data-Reduction-Program Performance

XECF EP-1 and EP-2 test data were reduced via the narrow-band data-analysis program at Aerojet-Sacramento. A total of 24 NTO data tapes were read (6 from EP-1 and 18 from EP-2) and approximately 50 million pieces of data (15 million from EP-1 and 35 million from EP-2) were processed through the computer. The net result of this effort was the production of over 9000 individual data channel plots that were formed into approximately 3300 multiplots. In addition to the plot input, the program produced events data, steady-state data (averages over specific time periods), and turbopump performance plots. The total effort required about 15 hours of computer time.

Test data recovery during the EP-1 test was more than 90 percent, although approximately 30 sec of critical data were lost during engine startup because of the acquisition system failure. During EP-2, 80 percent data recovery was achieved. Although a greater percentage of data was lost during the latter test, it occurred during noncritical periods. The data losses have been investigated and can be attributed to one or more of the following conditions:

Module 0 (1.8.0)

(1) Data were not available on the DN-3 tapes.

(2) Spurious time errors on DN-3 tapes resulted in skipping data records with the program merged system logic.

(3) Tape format errors that did not forewarn the program of a mode change or sampling rate change. Steps have been taken to circumvent these errors by the use of proven tapes for the data-acquisition system, changes in program logic, and a general cleanup of the tape format.

d. XE-1 Emergency-Cooldown System and FEP-V Predictions

The analog model of the XE-1 emergency cooldown system was modified to analyze the open-valve LH₂ emergency cooldown system with a GH₂ accumulator.

In the first study, a GH₂ accumulator was added to the LH₂ cooldown system by providing bypasses around CHV-1721 and CHV-681 or CHV-685 or both. This study showed that this type of system would allow for the Dewar (V5002) to be operated in the 250- to 400-psia range, eliminating sequencing and closed-loop control of PCV-472.

The analog model was again modified to incorporate the final facility configuration, which includes a 4 cubic ft GH₂ accumulator and a 10 cubic ft LH₂ buffer separated from the 4LH6 line by CHV-3364. The analysis showed that it is necessary to add a 1-in. bypass line around CKV in addition to the existing two 3/8-in. bypass lines to maintain 1 lb/sec chill flow while achieving an acceptable emergency shutdown for a TPCV fails-open malfunction. Also, an evaluation was made of the requirements for each of the check valves in the emergency cooldown system.

Module 0 (1.8.0)

A dynamic study was made of the FEP-V test facility configuration to provide predictions for FEP-V. A mathematical model of the system was formulated and simulated on an analog computer. The following major systems were simulated: V5002 Dewar; engine cooldown system; facility engine simulation line; and PCV-250, PCV-701, and PCV-543 control systems.

A series of studies were made to predict the fluid dynamic phenomena associated with FEP-V testing. These studies included the following:

(1) The first series of runs were made to determine the most appropriate position for PCV-750 and initial P_3 pressure to obtain the best pressure and flow decay associated with a 30-millisecond exponential loss of flow. Shutdowns from three different engine-flow and pressure-operating points were investigated and the following conditions appear to give the best simulation of a 30-millisecond exponential loss of flow.

Engine Conditions			Simulator Conditions	
P_3 , psia	$\dot{w}$, lbm/sec	T_c , °R	P_{888} , psia	$\dot{w}$, lbm/sec
960	77	4090	960	60
527	42	3600	500	30
289	29	2200	300	13

(2) The V5002 pressurization system was observed to determine the capability to deliver the LH_2 flow at the required pressure. The ability of the pressurization system to follow a 50°/sec and 100°/sec pressure profile was checked and found capable of following only the 50°/sec ramp. This is due to the limitation of gas-flow capability of the pressurization system.

Module 0 (1.8.0)

(3) Emergency cooldown line blowdown simulating the operation during an emergency cooldown with a Dewar at 300 psia was run for various locked-up pressures, line temperature distribution, and PCV-543 modes of operation.

(4) Failures of PCV-543 and RSV-109 were run to determine the effect on the system.

A total of 156 computer runs were made. All data have been transmitted to NTO for inclusion in a FEP-V prediction report.

e. XE-1 Reflector Inlet Temperature Accuracy Study

To ensure bootstrap operation in a minimum time interval and with no oscillations, individual signals from the reflector inlet are input to a temperature averager, which is input into a temperature comparator. When chilldown is completed at 50°R, a set point is presumably reached and the comparator actuates the pressure-control loop by initiating TPCV opening. A review of XECF data showed that several factors could influence the detection of completion of chilldown and that an assessment of these factors was necessary to optimize the bootstrap operation for XE-1 tests. The factors considered were: (1) evaluation of the effect of adding a larger number of transducers; (2) investigation of two mode cards; and (3) investigation of asymmetry as it relates to chilldown detection. Figure 15 shows the predicted XE-1 reflector inlet temperature.

The following conclusions and recommendations were made:

(1) The asymmetry observed in XECF tests was also observed in NRX/EST and CFDTS with a similar pattern of temperature peaks and valleys relative to angular position.

Figure 15 - Predicted XE-1 Reflector Inlet Temperature

Module 0 (1.8.0)

(2) The analysis shows that five RTT transducers would be best for averaging reflector-inlet temperatures. The reasons for these conclusions are as follows:

(a) Uncertainty is reduced 42% by using three transducers instead of one; with five transducers instead of one, the uncertainty is reduced 55%. Use of additional transducers would further reduce uncertainty, but the magnitude would be less than 2% per transducer.

(b) The effect of an extreme value that uses a three-transducer average would be substantial; two extreme values would result in a constant output from the averager in a manner that would not indicate the completion of chilldown. By the use of a five-transducer averager, even with the loss of two transducers, the averager would have an acceptable error.

(c) The five-transducer average provides for a more reliable estimate of the mixed mean temperature as compared with the predicted XE-1 reflector-inlet temperature asymmetry.

(3) Eight RTT transducers are recommended to define the XE-1 asymmetry and to document temperature peaks and valleys more accurately. A 50% improvement in the sensitivity of detecting a given size asymmetry will result compared with the currently available four transducers.

(4) A comparison of the accuracy of the CC03 and ST03 mode card at the 50 and 300°R needed for chilldown and wet autostart indicates that a new mode card is necessary to meet the requirements at both positions.

Module 0 (1.8.0)

f. XE-1 Test Prediction

Comments have been received from WANL on the review draft of the test prediction report, RN-S-0418. The final issue of the report will be made 5 weeks before the test, following approval of the revisions of the operational section of the test specification.

g. Wide-Band-Data Analysis

Work is proceeding on developing the ability to utilize the 50 and 100 sample/sec data tapes from NTO for transfer function analysis. If this program provides good quality transfer functions, the number of data channels available will be greatly expanded. The program would accept the CDC 3200 N3 tapes and use them in conjunction with the deterministic and random input transfer function programs 2907 and 2909.

A coherence function has been incorporated into the computation using sinusoidal inputs. This will measure the validity of the transfer function to the data user and provide a clear quantitative expression of the validity of the transfer function. Examples of the coherence function in the presence of large signal-to-noise is shown in Figure 16.

Plans are underway in FEP-V to demonstrate the wide-band capability. This will be done by preparing oscillograph playbacks, analyzing transfer functions, preparing power spectral density and/or spectral analyses, and by preparing a wide-band calibration diagnostic summary. The channels to be analyzed have been selected, and a transfer function test has been incorporated into the FEP-V experimental plan.

Figure 16 - Illustration of Coherence Function for T-8 Sine Input-Output Data

Module 0 (1.8.2)

15. Reactor Systems Analysis (1.8.2)

The report, NRX-A6 and NRX Program Data Analysis Report, RN-S-0464, was completed and is now in final review.

Studies were made of mixing in an NRX-type nozzle chamber to determine if an analytical explanation could be developed for the low chamber temperatures recorded by the NRX-A6 thermocouples. The preliminary results do not substantiate sufficient temperature asymmetry in the nozzle chamber to explain the NRX-A6 results. The results, using WANL pretest flow distributions and existing thermocouple profiles, indicate that the chamber thermocouples should be measuring a temperature that is warmer, not cooler, than the mixed-mean temperatures. In the parametric studies where cool peripheral flow was increased, low temperatures were indicated at the chamber thermocouples, but the mixed-mean temperatures were also low, as there was no compensation in the hot-flow temperature. With 20 lb/sec of peripheral flow at 3200°R, the temperature at the probe was computed to be 3650°R, but the corresponding mixed-mean temperature was 3850°R. At full power, the A-6 thermocouples were indicating 3660°R when the best-estimate mixed-mean temperature was 4000°R.

The results are not believed to be conclusive because of program limitations and the input flow and temperature distributions. The program used has basically sound two-dimensional mixing equations, but rotational effects, the means of inputting wall heat transfer, and the means of simulating core entrance conditions limit its application to NRX-A6 conditions.

The program is limited to 72 constant-flow-rate stream tubes, and physical properties must be held constant within each tube. This causes particular problems in representing the wall boundary conditions where large gradients exist close to the wall. At the core entrance, actual flow enters through a series of small holes, with spaces between them, but the program used

Module 0 (1.8.2)

could not account for the gaps. Heat transfer was simulated by inputting wall temperatures as an estimate of the fluid temperature transferring heat to the wall. A check of program output with this assumption indicates erratic bulk heat transfer from the fluid to the wall in the distance from the core exit to the thermocouple.

The flow profiles used in the parametric studies may not represent a worst case, as the mixed-mean temperature was allowed to drop as the cooler peripheral flow was increased. With a compensation in the center flow temperature to obtain a best-estimate mixed-mean temperature, greater asymmetries could be obtained.

Studies will be made to obtain more realistic core exit profiles. These will include estimates of the maximum peripheral flow that could conceivably exist at the best-estimate mixed-mean temperatures. A literature survey will be conducted to determine if there are better programs or techniques available to study mixing as applicable to the NRX-A6 problem.

The nozzle choked-flow equation was used to evaluate the nozzle chamber parameters from the NRX test series where

$$\dot{w} = \frac{A_E Z P_c}{\sqrt{T_c}} \quad (1)$$

A_E is the effective nozzle-throat area, Z is a function of the specific heat ratio, P_c is the nozzle-chamber pressure, $\dot{w}$ is the nozzle-chamber flow rate, and T_c is the nozzle-chamber temperature.

To determine bias and random errors in the measured P_c , T_c , and $\dot{w}$, the nozzle choked-flow equation was used in the following form:

Module 0 (1.8.2)

$$E = \frac{A_E Z P_c}{\dot{w} \sqrt{T_c}} \quad (2)$$

where E is the overall choked-flow value.

If there are no errors in the parameters on the right-hand side of Equation (2), the error term E on the left-hand side is equal to 1.0. Since each of these parameters has some measurement error (uncertainty), E will vary and not necessarily be equal to 1.0.

Overall-error E values were determined from the steady-state data of all test series by using Equation (2), and then the standard deviation ($\sigma(E)$) of the E values was obtained. Measurement errors (standard deviations) of the parameters on the right-hand side of Equation (2) were statistically determined, and variances (σ^2) of these parameters were then inserted into

$$\frac{\sigma^2(E)}{E^2} = \frac{\sigma^2(A_E)}{A_E^2} + \frac{\sigma^2(Z)}{Z^2} + \frac{\sigma^2(P_c)}{P_c^2} + \frac{\sigma^2(\dot{w})}{\dot{w}^2} + \frac{\sigma^2(T_c)}{4 T_c^2} \quad (3)$$

to check against variance of the overall error E. Thus, Equation (3) was used to allocate the overall error E to each parameter.

The procedure was repeated using the measured average T_c , core station 26 extrapolated T_c , and cluster-exit gas extrapolated T_c .

When the data were considered for the entire NRX program, the following effects were observed: a large uncertainty of the measured flow rate at low flow rate level and the effect of the radial temperature gradient in the core on the measured T_c . Lower-than-predicted flow rates were observed at the lower flow rates. Investigation led to the test results published by LASL, in which the venturi discharge coefficient varied with flow rate showing a lower

Module 0 (1.8.2)

value at lower Reynolds number.* Since it is assumed that the venturi discharge coefficient is constant for all Reynolds numbers and therefore for all flow rates, the lower venturi discharge coefficient will result in lower-than-predicted flow rates at the lower flow levels.

The flow discrepancy is shown in Figure 17. A smoothed curve through the venturi discharge coefficient data, taken from LASL report,* is plotted as a function of Reynolds number. To correct for this influence at low flow rates, a correction curve was devised as shown in Figure 17. Flow corrections were then made to arrive at the improved E estimates.

Although the influence due to venturi discharge coefficient differing from a constant is obvious, the exact amount of the deviation is still uncertain. The only test data that have been published have been limited to the LASL tests, so that the corrections are only as good as the estimated discharge coefficient.

When a temperature gradient was observed from the center to the periphery of the core, the overall error E value was different, depending on whether it was colder or warmer in the periphery. To evaluate the effect of the radial temperature gradient in the core on the measured nozzle-chamber temperatures, E values were plotted as a function of nozzle-chamber temperature. It was observed in NRX tests A3 and A6 that large E deviations existed. However, it was also observed that the temperature gradient in the core from the center to the periphery, as measured at the core station 26, also showed large deviations. With this added information, an attempt was made to relate core temperature gradient and measured nozzle-chamber temperature.

*Reference: D. H. Liebenberg, R. W. Stokes, and F. J. Edeskuty, The Calibration of Flowmeters with Liquid Hydrogen in the Region Between 1000 and 7000 gpm, Los Alamos Scientific Laboratory, Los Alamos, New Mexico. (Proceedings of ASME Flow Measurement Symposium, Pittsburgh, Pennsylvania, September 1966.)

Figure 17 - Flow Discrepancy

Module 0 (2.1.0)

Analysis of NRX data demonstrated that the choked-flow equation is a valid equation to use for describing nozzle chamber conditions. Correlations and subsequent correction procedures were established so that a best estimate for P_c , T_c , $\dot{w}$, and A_t was established. However, if these four values are represented on a choked-flow performance chart, a triangular area represents the best estimate. To obtain a combined best estimate as a single point, a further procedure is introduced that provides for a correction of each of the four variables. The basis of the procedure is to weight the variable according to the magnitude of its variance. By this technique, a completely analytical approach is used to arrive at a unique best estimate of chamber pressure, temperature, flow rate, and throat area.

16. Mechanical GSE (2.1.0)

a. General

Coordination was maintained with appropriate NRO organizations, SNPO-C, NTO, WANL, and various subcontractors to ensure proper integration of support equipment activities with the NRX and XE program activities. This effort included the following activities:

(1) Issued the review draft of the XE-2 Operational Support Plan, Volumes I and II, RN-S-0471.

(2) Presented to SNPO the XE-1 Readiness GSE Status, including a summary of pertinent activities, with problems encountered and their solutions.

Module 0 (2.1.0)

(3) Made a presentation to SNPO-C and SNPO-W, as a separate part of the XE-1 readiness review, on the GSE documentation methods used in support of the XE-1 program.

(4) Prepared and coordinated a movie film sequence to document the XECF remote operations in the E-MAD and ETS-1.

(5) Completed review and issued comments on the following NTO documents:

- (a) Final issue and the attending Addendum I of XECF-P11, XECF Remote UTSM Replacement, covering recommended changes that had been submitted with the first review but had not been incorporated.
- (b) NTO-SOP-0107, Procedure for Pneumatic Actuator Checker, PL 6051.
- (c) XE-2-P2, NTO Procedure for Receiving Inspection of Mechanical Hardware.
- (d) XE-1-P8, NTO Procedure for Transport and Installation of the XE-1 Test Assembly to ETS-1.
- (e) XE-1-P7, NTO Procedure for Central Poison Wire Removal at E-MAD.

(6) Submitted comments on Revision B of the XE-1 test specification, RN-S-0352, relative to remote UTSM disassembly and the associated requirements for GSE not currently included in the XE-GSE program.

Module 0 (2.1.0)

(7) Reviewed and submitted comments on the XE-2 test specification, RN-S-0400.

b. Equipment Engineering and Fabrication

(1) The UTSM closure kit for XE-2 UTSM, part of PL 4404, engine closure kit, was completed and installed on the XE-2 UTSM at Aerojet-Sacramento. It was used during the checkout and the shipment to NRDS of the XE-2 UTSM.

(2) PL 4144, fluid line coupling tool kit, was completed, acceptance tested, and delivered to NRDS.

(3) Prepared and submitted a reissue of the operation and maintenance manual for the turbine exhaust nozzle closure, PL 4108, to reflect the changes in the hardware.

(4) Initiated three design criteria for thermocouple remote checkout, removal, and handling.

(5) Initiated investigation into operational problems developed in the OPS, which include adjustment of the floating head control system, nonoperation of the lower and middle mast sections under proof load (50,000 lb), erratic operation of the load readout range change unit, and drift of Jack No. 3 under load.

(6) Initiated a review and evaluation, in coordination with NTO, of the requirements for remote checkout and calibration equipment for XE instrumentation. The equipment will be installed in the postoperative cells in the E-MAD.

c. Remote Operations Testing

(1) XECF semiremote operations were initiated early in June 1968 in the hot bay of the E-MAD to test and check out GSE and engine modifications that have been made since the last remote assembly design aid (RADA) tests were performed. These tests will be followed during the next report period by a fully remote operation using the XECF to demonstrate remote capability to replace the XE-1 UTSM.

(2) The PL 4011, positioning head assembly, was tested during the XECF semiremote UTSM replacement program. The test included engagement of the positioning head with the XECF UTSM at engine station 42.89. A minor change of the positioning head was initiated.

(3) The remote electrical coupling assemblies of PL 4043, remote checkout adapter kit, were tested, demonstrating that recent modifications to improve remote alignment were successful.

(4) The turbine exhaust line support arms of PL 4122, engine reassembly stand, as relocated last quarter, were adjusted and subsequently successfully operated semiremotely on the XECF.

(5) The PL 4123, UTSM/shield nut actuation device, was calibrated and subsequently successfully semiremotely demonstrated on the XECF by providing the required torque to remove and install the nuts.

Module 0 (2.1.0)

d. MCC/EIV and E-MAD Equipment

(1) MCC/EIV

(a) The equipment was used in performing a remote removal of XECF from ETS-1.

(b) The engine nozzle closure, Item 4088, modification kit was shipped and installed. Difficulty was encountered in demating the pneumatic disconnects. The disconnects locking devices were removed and an over-center toggle clamp was provided. The pneumatic disconnects are now satisfactorily installed or removed remotely as demonstrated on the WEMU at SETS-1.

(c) The quick disconnect adapters for the turbine exhaust line closure lines were shipped and installed. New handles to facilitate remote operation of the turbine exhaust closure locking device have been designed and a prototype was tested. A pair of deliverable handles are being fabricated.

(d) Problems have been encountered with Item 4112, UTS/TSA bolt removal tool. The output torque of the tool is less than the design requirement and the torque required to loosen the UTS/TSA nut was greater than predicted. An offset angle drive on the tool caused a 70% loss of torque output of the tool. A design has been made that eliminates the need of an offset drive and tests will be made of ability of the tool to remove the nuts.

(e) The MCC/EIV umbilical had developed some operational problems in alignment and disconnection release. The alignment has been readjusted and larger air cylinders are being ordered for the

Module 0 (2.2.0, 2.5.0)

locking devices. Testing will be made when the equipment is available to assure that the problem has been resolved.

(f) An EIV manipulator clutch, which slipped in operation, was disassembled, cleaned, lapped in, reassembled, and readied for use.

(2) E-MAD Equipment

Limited testing of the FMHS dolly and carriage was completed at NRDS in accordance with a coordinated test plan to evaluate and improve the system power capability. The data revealed poor power regulation. Accordingly, a regulated, remote-sensing power supply has been selected, and NTO has been requested to procure and install it in the FMHS equipment. After installation, the FMHS system will be tested to confirm adequate operational capability of the equipment and to identify any remaining problems.

17. Electrical GSE (2.2.0)

The modification of PL 4043, remote checkout adapter kit, consisting of installation of an orifice in the control box vent line to limit the engine remote leak test gas-depressurization rate, was completed at NRDS.

18. Ground Operations Safety (2.5.0)

The final review copy of the XE-1 Operating Limits Document, Phase IB, NJD-12, and the XE-1 Safety Evaluation Report, Phase IB, NJD-10, was prepared jointly with WANL safety personnel and distributed for review and comment. These documents cover the safety aspects for transport of the XE-1 from E-MAD to ETS-1 and subsequent operations up to but not including initial criticality.

The final review copy of the XE-1 Safety Evaluation Report, Phase II, NJD-11, was prepared jointly with WANL safety personnel and externally distributed for review and comment. This document covers XE-1 operations from initial criticality through power testing to E-MAD disassembly.

The final review copy of the XE-2 Safety Evaluation Report, Phase IA, NJD-15, and the XE-2 Operating Limits Document, Phase IA, NJD-16, were prepared jointly with WANL safety personnel and externally distributed for review and comment. The comments have been resolved and the documents are being published. These documents cover XE-2 assembly operations up to but not including central-poison-wire removal.

The safety aspects of the shipment of the XE-2 PVARA from WANL, Large, Pa., to NRDS, Jackass Flats, Nevada, were reviewed by NRO Safety. Approval for the shipment was requested from SNPO-C. Approval was granted on 7 June 1968.

A draft of Supplement 1 to the ETS-1 Facility Safety Report (RN-S-0378) was completed and submitted to NRO/NTO for comment. This document discusses some of the major facility changes or additions that have been incorporated since issue of RN-S-0378 and which have a significant effect on the safety of operations. Comments relative to the draft copy of the report were satisfactorily resolved and a final copy was prepared, approved, and published.

A scheduled safety audit of WANL facilities at the Large, Waltz Mills, and Cheswick sites was conducted on 27, 28, and 29 May 1968 by NRO Safety. The audit involved a detailed review of emergency plans and procedures. The AEC's Emergency Planning Questionnaire for Accidents Involving Release of Radioactivity served as one of the bases for the review.

Module 0 (2.6.0)

Safety requirements were prepared for inclusion in the NASS Specification SS-90204, dated 31 May 1968.

19. Product Assurance--Contractors' Plants (2.6.0)

a. Reliability Engineering

(1) Engine Reliability Study

The initial reliability analysis of the NERVA flight engine was completed on 28 June 1968 with the resultant report scheduled for publication on 15 July.

The analysis was based on a 75,000-lb thrust engine performing a 10-cycle, 50-minute burn duration mission, with coast times of up to 1 year.

The report will include engine system failure modes and attendant predicted failure probabilities, a presentation of the crew safety and population-hazard aspects of the engine, a definition of related mathematical models, and an apportionment of the system reliability goal.

(2) Core-Flooding Probability

A reliability analysis to determine the launch pad probability of inadvertent liquid hydrogen flooding of the reactor was conducted in conjunction with the poison wire evaluation. The events required to cause flooding were identified and assigned failure probabilities of 0.01 to assure conservatism. Even with the high failure rates assumed, the flooding probability was in excess of 1×10^{-6} . This analysis was presented at a NERVA task force meeting at SNPO-C on 13 and 14 June.

(3) TPA Configuration Evaluation

The results of the TPA configuration reliability and performance evaluation were presented at SNPO-C on 6 June 1968. Details were presented on the candidate configurations and variations, tradeoff factors, reliability evaluation (including the method of assessment), performance evaluation, and a comparison of the TPA configurations.

b. Quality Assurance

The NRO reliability and quality assurance program plan, AGC Report No. 2469, Rev. D, has been approved by SNPO-C. The policies of the plan are currently being implemented. This plan provides the guidelines for all activities participating in the NERVA reliability/quality program.

The NERVA nuclear subsystem product assurance program plan, WANL-TNR-088, Rev. F, approved by NRO and SNPO-C, is currently being implemented. The related implemented quality methods and procedures (QMP) and reliability methods and procedures (RMP's) are scheduled for submittal to NRO for review.

The NTO product assurance program plan, Report No. NTO-A-0013, Rev. 1, and the related implementing procedures are being put in final form by NTO.

The WNCO quality control manual is being developed and will be submitted to WANL, NRO, and SNPO-C for review.

20. Malfunction Studies (2.7.0)

During the report period meetings were held with representatives of the government and WANL to formulate a plan of study to assess the effectiveness of poison wires in preventing criticality accidents from assembly through normal nuclear startup of the NERVA flight engine. A report outline was established and specific assignments were made. The scheduled completion date is early July.

Questions concerning operations at KSC and how the procedures may affect the use of poison wires were prepared and submitted to SNPO-headquarters for transmittal to KSC. Since these questions remain unanswered and due to the report schedule date, it has been necessary to make assumptions relative to operations at KSC.

The results of the poison-wire study were presented at the NERVA engine task force meeting on 14 June 1968. This presentation emphasized the assumptions necessary for KSC operations, and it was generally agreed that a draft of the report should be submitted to KSC for review as soon as possible.

Work on the overall NERVA safety plan continued. Copies of applicable safety documents have been reviewed. An outline for the safety plan was prepared and assignments have been made. The plan is approximately 50 percent complete.

21. Nonfuel Materials Planning, Design Review, and Data Reporting (2.8.2)

a. Drawing Review

Approval of 129 engineering drawings was accomplished. Prior to approval, 59 drawings required changes chiefly relating to weld design; also included were materials selection, specification, heat treatment and finishing.

Module 0 (2.8.2)

b. Materials Properties Data Book

The second CY '68 supplement, consisting of data on graphites and beryllium, was completed and prepublication check copies were sent to SNPO-C and WANL for approval.

At SNPO-C request, preliminary plans were prepared for a proposed upgrading of the data book to provide statistically developed information on key materials for both engine and reactor. The desired statistical approach is that designated A-basis by MIL-HDBK-5 and is defined as the mechanical-property value above which at least 99% of the population of values is expected to fall, with a confidence level of 95%. A detailed work plan for data acquisition, including testing where necessary, will be presented as a part of the CY '69 program plan.

c. Documentation

The following reports were issued: Report 2275, First CY '68 Supplement to the Materials Properties Data Book (2275); RN-S-0458, Second Progress Report, Bearing Retainer Materials Development; RN-S-0461, Plane Strain Fracture Toughness and Fatigue Tests of a Large Ti-5Al-2.5Sn (ELI Grade) Forging in Liquid Hydrogen; and RN-S-0463, NERVA Materials Developments, Second Quarter Contract Year 1968.

Two technical papers were issued: Dixon, C. E., Stadig, J. E., Funk, C. W., Cryogenic Radiation Effects on NERVA Structural Alloys, ANS Annual Meeting, 9 June 1968; and Lombardo, J. J., Funk, C. W., Nuclear Rocket Materials Program, AIAA 4th Propulsion Joint Specialist Conference, 10 June 1968.

d. Development of Materials and Processes

(1) Bearing Retainer Materials

Eight additional bearing retainers were received. Six PBI/glass parts, per PN 1134747-56, were obtained from the Narmco R&D Division of the Whittaker Corp. The parts were accepted on the basis of visual, dimensional, and radiographic inspections. Four hoop-tension specimens were also received and accepted. One of the hoops is to be tested as a control for the remaining three, which are scheduled for irradiation in GTR-20. The six retainers are to be used for control bearing tests and for irradiation in GTR-20.

Two PI/glass retainers and two hoops were received from the Brunswick Corp. per PN 1134747-6. One additional part was returned for remachining of undersize ball-pocket diameters. The two retainers and one of the test hoops are scheduled for GTR-20 irradiation. The other hoop will be used for control testing.

(2) Radiation Damage

Stress rupture and creep resistance of forged Inconel 718 (37 and 0.6 ppm boron) and Waspaloy (50 ppm boron) were evaluated at 1200°F after exposure in GTR-21 at three thermal neutron fluences. Test data summarized in Table 9 show that Inconel 718 has approximately the same reduction in rupture life and ductility regardless of boron content. At 5×10^{18} nvt Inconel 718 rupture life and elongation are degraded respectively to 16% and 4% of their original values. Waspaloy, in contrast, does not show the same degree of damage, since its rupture life and elongation at 5×10^{18} nvt are reduced respectively to approximately 56% and 36% of their original values. Preliminary analysis of strain/time data indicates that secondary creep rates are not affected by irradiation.

TABLE 9

1200°F STRESS-RUPTURE TEST SUMMARY⁽¹⁾

Fluence nvt (E < 0.48 ev)		0		1 x 10 ¹⁶		5 x 10 ¹⁷		5 x 10 ¹⁸	
Property		Time to Rupture, hr	Chart Elong- ation, %	Time to Rupture, %	Chart Elong- ation, %	Time to Rupture, hr	Chart Elong- ation, %	Time to Rupture, hr	Chart Elong- ation, %
Material	Inconel 718, (37 ppm Boron)								
	Ave value	69. (3)	6.9 (3)	56	3.9	36.	1.3	11.0	0.3
	Range	-	-	1.7	0.5	12.	0.6	5.1	0.3
	Inconel 718, (0.6 ppm Boron)								
	Ave value			51.8 (3)	3.3 (3)	30. (4)	1.9 (4)		
	Range			-	-	13	0.3		
	Waspaloy (50 ppm Boron)								
	Ave value	~100 hr (5)	14.3	70.	6.5	65.	7.4	56.	5.0
	Range	-	3.1	13.	0.3	25.	1.0	25.	1.7

Notes:

- (1) Stress levels were 110 ksi for Inconel 718 and 105 ksi for Waspaloy, except as noted in (5).
- (2) Sample size is 3, except as noted.
- (3) Sample size, 1.
- (4) Sample size, 2.
- (5) Final stress levels ranged from 105 ksi to 135 ksi.

Module 0 (2.8.2)

Elevated-temperature notch sensitivity was also evaluated for Inconel 718 (337 ppm boron) and Waspaloy (50 ppm boron) by using a standard acceptance test, in which a smooth/notched duplex specimen must fracture in its smooth section. After irradiation at 1×10^{16} and 5×10^{17} nvt (2 specimens per fluence). Inconel 718 failed the requirement of 23-hour minimum life at 1300°F and 75 ksi, besides failing in the notches. Irradiated Waspaloy passed the requirement of smooth-section rupture, but failure time was less than the required 23 hours at 1400°F and 70 ksi (i.e., 12 to 16 hours).

Effects of cryogenic temperature and radiation were evaluated for aluminum alloy 7039-T61 and T64 plate and for nickel-base alloy Hastelloy-X forgings. Parent metal and weldments of both materials were submerged in liquid nitrogen and irradiated in GTR-21 to a fast fluence of 1×10^{17} nvt ($E > 1.0$ Mev). Preliminary data on yield strength and elongation are shown in Table 10. Elongation decreases were observed for all materials, but in no cases did the reduced values reach the 5% limit. Yield strengths characteristically increased for all materials. Radiation damage to 7039 at 140°R (LN₂) was partially annealed in 1 hour at 440°R and fully annealed in 1 hour at 540°R.

Cryogenic radiation effects on notched and unnotched tensile strength of 7039 are shown in Table 11 and suggest increased fracture toughness due to irradiation. This effect will require verification by special techniques for determining plane-strain fracture toughness K_{Ic} data.

(3) Space Environment

Adhesion tests in vacuum, as performed at Syracuse University, indicated satisfactory performance for both 440-C stainless steel and pyrolytic graphite. Type 440-C against Type 440-C resisted adhesion in

TABLE 10

PRELIMINARY CRYOGENIC TENSILE DATA STRUCTURAL
FOR IRRADIATED ALUMINUM ALLOY 1034 AND HASTELLOY X

Material and Form	Neutron Fluence nvt (E > 1.0 Mev)	Temperature, °R		0.2% Yield Strength			Elongation		
		Irrad.	Test	Cont. ksi	Irrad. ksi	% Change ⁽³⁾	Cont. %	Irrad. %	% Change ⁽³⁾
7039-T61 Plate									
Parent Metal	1 x 10 ¹⁷	140	140	57.4	62.8	+9.4 ⁽⁴⁾	16.8	13.8	-17.8 ⁽⁴⁾
	1 x 10 ¹⁷	140	140 ⁽¹⁾	57.4	60.0	+4.5 ⁽⁴⁾	16.8	15.5	-7.7
	1 x 10 ¹⁷	140	140 ⁽²⁾	57.4	59.3	+3.3 ⁽⁴⁾	16.8	15.6	-7.1
As Welded	1 x 10 ¹⁷	140	140	31.1	41.1	+32.3 ⁽⁴⁾	12.9	12.0	-6.9
As Welded	1 x 10 ¹⁷	140	140 ⁽¹⁾	31.1	36.8	+18.3 ⁽⁴⁾	12.9	11.8	-8.5
As Welded	1 x 10 ¹⁷	140	140 ⁽²⁾	31.1	31.2	+0.3	12.9	12.3	-4.6
Welded, Heat- Treated to 1-61	1 x 10 ¹⁷	140	140	30.3	43.0	+41.9 ⁽⁴⁾	8.7	7.1	-18.4
7039-T64 Plate									
Parent Metal	1 x 10 ¹⁷	140	140	67.8	73.4	+8.3 ⁽⁴⁾	13.9	12.8	-7.9
Hastelloy X Forging									
Parent Metal	1 x 10 ¹⁷	140	140	67.4	89.8	+33.2 ⁽⁴⁾	21.6	16.7	-22.7 ⁽⁴⁾
Weldment	1 x 10 ¹⁷	140	140	69.5	91.3	+31.4 ⁽⁴⁾	16.4	13.1	-20.1 ⁽⁴⁾

Notes:

(1) Annealed at 440°R for one hour after irradiation.

(2) Annealed at 540°R for one hour after irradiation.

(3) Percent change is expressed as percent of control value.

(4) Significant change at 90 percent confidence level.

Module 0 (2.8.2)

TABLE 11

RADIATION EFFECTS ON AVERAGE CRYOGENIC (-320°F)
NOTCHED AND UNNOTCHED TENSILE STRENGTH OF
ALUMINUM ALLOY 7039-T61 AND T64 PLATE

<u>Alloy</u>	<u>Ultimate Tensile Strength, ksi</u>		<u>Notched Tensile Strength, ksi</u>		<u>Notched/Unnotched Ratio</u>	
	<u>Control</u>	<u>Irradiated 1 x 10¹⁷nvt</u>	<u>Control</u>	<u>Irradiated 1 x 10¹⁷nvt</u>	<u>Control</u>	<u>Irradiated 1 x 10¹⁷nvt</u>
1. <u>7039-T61</u>						
Parent mat'l	77.8	78.6	60.0	65.6	0.77	0.83
As - Welded	60.0	58.0	44.0	51.8	0.73	0.89
Welded & heat treated again	57.0	59.0	43.0	52.3	0.75	0.89
2. <u>7039-T64</u>						
Parent mat'l	85.0	85.0	65.1	70.4	0.76	0.83

5×10^{-11} torr at loads near its yield strength and temperatures below 1300°F. A reduction in electrical contact resistance at 1300°F indicated the beginning of adhesion. Pyrolytic graphite resisted adhesion under all test conditions, including temperatures to 2550°F, vacuum to 6×10^{-11} torr, and stresses beyond the elastic limit.

22. Assistance to LASL (2.9.2)

In addition to the normal on-site assistance to LASL, the following activities were conducted in conjunction with the Phoebus 2A and Pewee programs:

- a. Provided NRX-A6 operating data and assisted in use of the data to check out computer programs for Phoebus 2A predictions.
- b. Participated in Phoebus 2A data analysis task unit (DATU) activities, including revision of core cluster and nozzle models necessary to give better prediction.
- c. Assisted in analysis of Phoebus 2A nozzle flange and bolt temperature problems and in re-establishing operating red lines for nozzle flange temperature. Assisted in resolving Phoebus 2A nozzle C_D variance between NRO and LASL.
- d. Provided review, evaluation, and recommendations concerning LASL/NTO interfaces and GSE for the Pewee Program.

23. Program Planning and Control (4.1.2)

Program planning and control activities associated with the CY '68 work program were continued.

The routine biweekly updating, evaluation, and reporting of the active PERT networks was also continued. These included the Aerojet portion of the XECF, XE-1, XE-2, and ETS-1 networks.

Efforts continued during this period in the planning, coordination, and preparation of the NERVA engine program plans and ETS-1 modifications in support of the NERVA engine task force studies.

Support was provided in the preparation of the NERVA management plan.

24. Fiscal Control (4.2.0)

All fiscal reports were transmitted as required.

25. Technical Reports--NASA and AEC (4.3.1, 4.3.2)

During the third quarter of CY '68, the following reports were published:

RN-S-0378	ETS-1 Facility Safety Report	6-20-68
0463	NERVA Material Development - 2nd Quarter 1968	5-31-68
0465	NERVA Management Plan (Preliminary)	5-9-68
0468	Posttest Analysis NRX-A6 Evaluation RTTs Rosemount Model No. 134JA-1	6-13-68
0471	XE-2 Operational Support Plan (2 volumes)(Review Draft)	6-11-68
0400	XE-2 Test Specification - Phase I	4-16-68
0454	ETS-1 Failure Mode Analysis	5-10-68
0455	CY '68 "As Negotiated" Program Plan	4-9-68
0458	2nd Progress Report - Bearing Retainer Materials Development	6-26-68
0459	ETS-1 Data Acquisition System Accuracy Report - Final	4-29-68
0461	Plane Strain Fracture Toughness and Fatigue Tests of a Large Ti-5Al-2.5Sn ELI (Grade) Forging in Liquid Hydrogen	4-25-68

Module (4.4.0)

RN-DR-0150	ETS-1 Modifications for 75K NERVA - Part 1 - Technical Discussion	4-18-68
0135	Dynamic and Steady-State Checkout of XE Common Analog Model	5-9-68
0141	XE Engine Assembly, Failure-Mode Analysis - Rev. A	4-3-68
RN-TM-0564	NRX-A6 Flame Spray Evaluation Test	5-23-68
0560	Development of a TPCV for NERVA	4-68
RN-Q-0045	Quarterly Progress Report No. 45, 2nd Quarter, CY '68, January, February, March	5-3-68
Report 2275	Materials Properties Data Book (First CY '68 Supplement)	4-23-68
2469	Reliability and Quality Assurance Program Plan for NERVA Engine System (Revision D)	6-21-68
RN-TP-0056	NRO Test Plan for Evaluation of Nozzle Coolant Channel End Cap	6-17-68

26. Central Data System (4.4.0)

NRO Central Data Control continued to provide storage and retrieval of all engineering documents initiated in the NERVA project utilizing electronic data processing and microfilming equipment.

The following reports, engineering documents, etc., were updated and delivered on schedule: engineering drawings on 35 mm aperture cards; NERVA drawing list; parts list; specifications on hard-copy and 16 mm microfiche; specifications and standards index; NERVA technical reports on 16 mm microfiche; technical document index; and HE-2, XECF-EP1 and 2 test data on hard copy and 16 mm roll.

NTO documents have been incorporated into the CDSTDI reporting system. In addition, modifications are being made to eliminate truncated title words in the KWIC index.

Module 0 (4.4.0)

Custom modifications to the engineering data identification and control (EDIC) report system to accommodate CEPL report requirements are nearing completion. A where-used index by noun sequence for the NERVA project has been compiled and is available for use at NRO-CDC.

More than 1200 microfiche representing 300 WANL documents were duplicated, indexed, and provided for WANL-Pittsburgh per SNPO-C request. In the future, WANL will be sent a copy of the technical document index.

Activities associated with test data processing, reduction, storage, retrieval and distribution include:

a. NRX Tests

Cal Comp Plots
Channel Data Logs
Steady-State Averages
Oscillograms

b. ETS-1 Tests

Oscillograms from HE-II and ETS-1 Vibration Test
Microfilming of digital listing on NEPN-1

c. XECF, EP-I and EP-II

CRT Plots
Oscillograms
Thinned listings
Events listings

Module 0 (4.5.1, 4.6.0)

Numerous wide-band data requests were processed in support of SPEAR requests.

A master file of all XE and NRX test data is being maintained on microfilm.

The CRT printer/plotter was used extensively in support of XECF test data processing. Over 1700 plots were generated, processed, reproduced and sent to NTO within the 48-hour turnaround time required by the test specification.

27. Program-Management Projects (4.5.1)

Program management was provided as required for the technology program.

28. New-Technology Reporting (4.6.0)

Efforts this quarter included: transmittal of reportable items, including Disclosures of Invention; submittal of backup data in support of reportable items; contributions of computer programs to the COSMIC program at the University of Georgia under contract to NASA; continuation of the NRO T.U. Award-of-the-Month Program and continuation of the NASA T.U. Award Program.

Aerojet was represented at the NASA Technology Utilization Conference at the Langley Research Center during 3 to 5 June 1968 and made a presentation relative to effective management support of the T.U. program.

Module 0 (4.6.0)

The NRO T.U. Award-of-the-Month has been conferred for two contributions: NUC-10335, Rocket Engine Communication and Control System has High Degree of Reliability; and NUC-10339, Line Bellows Restraint by Internal Flexure.

NASA Tech Brief awards have been conferred on the following five AEC/NASA Tech Brief publications during this quarterly period. The identification numbers are: 67-10343, 67-10349, 67-10350, 67-10351, and 67-10352.

Two computer programs listed by COSMIC and requested for the NERVA effort have been obtained. These programs may prove beneficial by upgrading currently used techniques and enabling a cost savings analysis.

Twenty packages of backup data were provided in support of NRO-generated reportable items.

COSMIC received two computer programs via SNPO-C that were developed or modified in support of the program effort.

Module 0 (7.7.1)

NRO transmitted the following eight reportable items to SNPO-C as a result of the total search effort during this period.

<u>NUC-</u>	<u>Title</u>	<u>Date Transmitted</u>
10335	Rocket Engine Communication and Control System Has High Degree of Reliability	4-30-68
10336	Computer Program Determines Ejector Performance	4-30-68
10337	Thermocouple Cable Splice Assembly Improves Reliability	4-30-68
10338	Remote System Accurately Levels NERVA Engine	4-30-68
10339	Line Bellows Restraint by Internal Flexure	6-30-68
10340	High Speed Fluid Control System Designed for Fail-Safe Operation	6-30-68
10341	Control System Designed for Maintaining Cryogenic Turbopump Test Parameters	6-30-68
10342	Finite-Element Analysis of Compressible Solids with Nonlinear Material Properties	6-30-68

29. Engineering Support for Existing NRDS Facilities (7.7.1)

a. Existing NRDS Facilities

(1) Design Modifications

XE-engine test and facilities requirements were coordinated with NRDS on a continuing basis. The development of requirement documents and design criteria and the design and procurement packages for facility changes were initiated or completed and transmitted to NTO for implementation at NRDS as follows:

Module 0 (7.7.1)

(a) Propellant Feed-Line Screen

The design and fabrication of a replacement screen for the main propellant line was accomplished at NRO and the unit was delivered to NRDS for installation. During replacement of this hydrogen feed line filter screen, contamination consisting primarily of fine sand was discovered in the line and the run tank shut-off valve. Successive blowdowns of this line through the run tank were made until there was no evidence of sand pitting on aluminum target plates placed under the open line. The installation of this unit and a leak check of the propellant line was completed on 19 March 1968, but plans were made to replace this filter screen with a finer 100-mesh screen after completion of the XECF testing and prior to XE-1. The design and fabrication of the 100-mesh strainer were completed and proof testing was conducted on 6 May 1968. The 100-mesh propellant line strainer was subjected to 25 cycles of hydrostatic differential pressure of 62 psi with no damage, but the 100-mesh screen had a few small holes due to sharp areas on the structure under the screen and one tear in the screen that occurred during handling. The 100-mesh screen was replaced, and the additional testing consisted of three cycles of immersion in LN_2 and one hydrostatic test at 10 psi, followed by a final dye-penetrant check. The unit was cleaned and shipped to NRDS on 17 June 1968. During shipment, one wooden spacer block used to restrain the screen flange was loosened, allowing motion of the screen, which in turn caused the structural point of the assembly to wear through the plastic bags enclosing the assembly. Inspection of the screen at NTO revealed no structural damage. Two small areas appeared to be polished, and the assembly will be recleaned prior to installation.

Module 0 (7.7.1)

(b) New Steam Line

The design of a new steam line, scheduled for installation prior to XE-1 testing, has been completed. A conceptual design of a new system that had fixed elbows and a water trap had been approved by SNPO-C. Significant design problems were encountered and this concept was dropped. In addition, thermal stress problems associated with the water separator were more complex than had been expected. However, the design effort associated with a new steam line was completed and all drawings were released by 8 May 1968. Procurement action has been undertaken for the delivery of the various steam line components to NRDS, and assistance was given to NTO in development of the required installation design and checkout procedures. The NRO design drawings for the new steam line have been revised to incorporate all changes that were made, and the NTO installation drawings have been signed by NRO. A major effort is being made to coordinate vendor activities and to review and approve vendor-initiated procedures. The current estimated completion date of the new steam line for XE-1 testing is 13 September 1968.

(c) SGS Components Spare

The valve and pressure switch refurbishment program for the SGS components was continued. Marotta valves (PV20C) were refurbished with new O-rings without lubricant, and other Marotta valves (PV28B) were refurbished with new O-rings using lubricant and were shipped to NRDS for comparative operational checkout. On 19 April 1968, a PV28 Marotta valve was received from NTO and sent to the Sacramento valve shop for inspection and testing. The unit was checked for foreign particles, which might cause the valve to hang-up in the open position. Sand particles found in the valve were removed when the unit was refurbished and the valve was returned to NRDS.

Module 0 (7.7.1)

Steam generator malfunctions occurred during NEP-He-1 and 2 testing and during an operational checkout of the steam line that was performed to stress relieve and verify the performance of the line. Partial clogging of the propane line filter resulted in a LOX-rich mixture, damaging the No. 1 injector. The damage resulted from a combination of the decrease in flow of fuel resulting in a LOX-rich, higher-temperature burning mixture and a lack of sufficient fuel, which also cools the injector. These problems indicate the need for an adequate supply of spares for the SGS. On 10 April 1968, SNPO-C approved a program for maintenance of an adequate number of spare components for the SGS, including the fabrication of three new igniters and the rework of two combustion chambers, two injectors, and two igniters.

Fabrication of the three new igniters has progressed on schedule, and assembly of these components began on 10 June 1968. These units are currently scheduled for shipment at two-week intervals starting 2 August 1968.

The rework of the two injectors has been delayed because the delivery of the required nickel face plate material needed for their repair is a long lead-time item. Repair of the two injectors is expected to be completed by 27 September 1968.

The two igniters were sectioned as part of the repair effort. The disassembled first stages were hydrostatically tested to check their mechanical integrity, and an analysis indicated the units are satisfactory for future use. The fabrication and incorporation of the second-stage assemblies are in progress. Repair of these two igniters is expected to be completed on or about 19 July 1968.

Module 0 (7.7.1)

The combustion chambers were cleaned, dye-penetrant checked, and repairs were recommended. Chamber disassembly procedures were generated and approved, and disassembly of the main chambers was completed. New liners were fabricated, and assembly buildup of the units began on 10 June 1968. One combustion chamber is expected to be ready for shipment to NRDS on or before 5 July 1968.

The fabrication of SGS gaskets (24, 36, and 12 each of PN 901726-1, -2 and -3, respectively) was completed, and these items were shipped to NRDS on 8 May 1968.

Engineering support and assistance was provided to NTO for the preparation of preventative maintenance instructions. Applicable checkout procedures, quality control instructions, and maintenance periods are being prepared for the SGS.

(2) Evaluation and Analysis

(a) Modes-of-Failure Analysis

Support was provided to the PMO during the NRO/NTO review of the draft of Report RN-S-0454 ETS-1 Failure Mode Analysis. Support was provided for the resolution of the problems indicated in RN-S-0454. The electrical failure-mode analysis has been revised and informally submitted to the PMO. New relay settings and coordination curves have been developed for the ETS-1 electrical system and were transmitted to NTO.

Module 0 (7.7.1)

(b) ETS-1 Modification Surveillance

NTO activities related to all ETS-1 modifications have been reviewed on a continuing basis and assistance for design was provided as required. Activities requiring significant NRO effort include the following: control drum actuator cryogenic trap installation; ETC latch cylinder modifications; duct vault and pipe chase inerting; heat-shield reinforcement; and permanent cooldown piping.

(c) ETS-1 Activation Support

Support was provided to NTO in the review and analysis of the facility experimental plan data. Support was also provided for the preparation and review of facility experimental plans and procedures and for readiness review.

b. Engineering Support for NRDS Instrumentation System

Information relative to the capabilities and limitations of the ETS-1 instrumentation systems has been provided on a continuous basis as required for the support of the XE engine program and the development of the test stand control system (TSCS). The development of requirement documents and design criteria for system changes was initiated and the following system analyses were conducted:

(1) Data Acquisition System Accuracy Tests

ETS-1 Data Acquisition System Final Accuracy Report,
RN-S-0459, was completed and published on 1 May 1968.

Module 0 (7.7.3)

(2) Zero-Suppression and LVDT Systems Accuracy Tests

A test specification, RN-S-0467, was written and released on 16 May 1968 delineating the requirements for zero-suppression and LVDT systems testing at NTO. The NTO test procedure for conducting these tests was reviewed and approved by NRO on 22 May 1968. Tests were started on 23 May 1968 at ETS-1. Technical problems that arose included severe noise on the zero-suppression channels and other signal perturbations. The zero-suppression equipment is being modified by addition of Burr-Brown isolation amplifiers to break an existing group loop. It is planned to incorporate a dc calibration capability within the zero-suppression equipment prior to XE-1 testing. The LVDT portion of the accuracy test was completed and NRO is reducing and analyzing the data.

(3) General Support

Engineering assistance and support was provided to various NRO design groups and to NTO I&C personnel to resolve instrumentation problems encountered during XECF testing and SPEAR team activity. The problems included wideband tape handling and playback problems; improper grounding configurations in the vibration charge amplifier channels; and starting and switch-over of the digital tape transports. A complete study of the ETS-1 electrical grounding scheme was started to resolve the grounding problems and to document the grounding system.

30. NRDS Instrumentation (7.7.3)

This sub-subtask has been incorporated into Sub-Subtask 7.7.1 as of 29 January 1968. The work performed in this area has been reported in the discussion under Sub-Subtask 7.7.1, Module 0.

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Module 1 (5.3.0)

B. MODULE 1 - REACTOR

1. Reactor Test and Interface Control (5.3.0)

In Sub-Subtask 5.3.0 the interface control drawing was prepared and the preliminary R-1 measurement requirements list Phase 1A was completed.

The R-1 interface control drawing No. 1134509 was prepared, updated to reflect current baseline information, and will be submitted for review early in the next quarter.

Coordination meetings between Aerojet and WANL were conducted to define interface problem areas between the R-1 test article and the test facility and the measurement requirements list.

Work continued on the layouts for the R-1 test article and the preliminary design data information is being prepared for components unique to R-1 and subsequent reactor test articles.

Preliminary R-1 piping layout drawing No. 711J527 and the proposed nuclear subsystem piping layout drawing No. 711J524 have been received from WANL and are being reviewed by Aerojet.

Drawings of the Phoebus-2 facility shield were obtained from LASL and are being reviewed for compatibility with the proposed R-1 test article assembly.

Module 1 (5.4.3, 5.4.5, 5.8.0)

The first WANL-prepared R-Systems test plan documents were received and are being reviewed with special attention to their compatibility with AFSCM 375 and 310 and the NERVA Program requirements document.

Effort relative to the interface control drawing, measurement requirements list, and test Documentation for R-1 is progressing on schedule.

2. Thrust Structure, Nozzle, Skirts, and Lines (5.4.3)

No effort was conducted under this sub-subtask.

3. Pressure Vessel (5.4.5)

No effort was conducted under this sub-subtask.

4. Systems Analysis (5.8.0)

a. State-Point Analysis

Steady-state points for the R test article were developed. The system is similar to a NRX-A subscale system except that the nozzle has a hot-bleed port and the expansion ratio is 12:1. The turbine inlet flow is assumed to be exhausted to atmosphere through a choked nozzle sized to match turbine characteristics at full power. A summary of the full power point is shown in Table 12.

b. R-1 CAM Model

Agreement was reached with WANL on the R-1 and E-1 CAM formats. Basically, the CAM will be in a loose-leaf form to enable convenient

Module 1 (5.8.0)

TABLE 12
R-TEST ARTICLE STEADY-STATE SUMMARY
100% POWER

Engine: $P_c = 450$; $T_c = 4464$; Thrust = 59,170 lb; Impulse = 680 sec;

Power Level = 1550 Mw; $P_a = 12.7$ psia; $\frac{A_E}{A_T} = 12:1$

Turbopump: None

<u>State Point</u> <u>Description</u>	<u>Flow</u> <u>(lb/sec)</u>	<u>(PS) Pressure (PO)</u>		<u>Temp.</u> <u>(°R)</u>
		<u>Static</u> <u>(psia)</u>	<u>Total</u> <u>(psia)</u>	
Engine Interface	91.0		891	53.3
Bolt Coolant	3.0		887	53.3
Struct. Support Outlet	23.7		638	273
Struct. Bypass Outlet	5.0		638	53.3
Skirt Inlet	59.3		887	53.3
Skirt Outlet	59.3		877	85.1
Nozzle Inlet	59.3		877	85.1
Nozzle Outlet	59.3		693	221
Reflector Inlet	59.4		693	215
Reflector Outlet	59.4		649	325
Periph. Shield Outlet	59.4		638	335
Support Plate Inlet	88.1		638	302
Central Shield Inlet	88.1		629	308
Core Inlet	88.1		617	313
Core Outlet	88.1		450	4501
Nozzle Chamber	86.8		450	4464
Diluent Bleed Inlet	2.89		693	215
Hot Bleed	1.31		450	4473
Turbine Inlet (simulated)	4.20		327	1660

Module 1 (5.8.0)

TABLE 12 (cont.)

Engine: $P_c = 450$; $T_c = 4500$; Thrust = 58,925 lb; Impulse = 669 sec;
 Power Level = 1550 Mw; $P_a = 12.7$ psia; $\frac{A_E}{A_T} = 12:1$

Turbopump: None

State Point Description	Flow (lb/sec)	(PS) Pressure (PO)		Temp. (°R)
		Static (psia)	Total (psia)	
Engine Interface	91.0		891	53.3
Struct. Support Outlet	23.7		638	273
Bolt Coolant	3.0		887	53.3
Struct. Bypass Outlet	5.0		638	53.3
Skirt Inlet	59.3		887	53.3
Skirt Outlet	59.3		877	85.1
Nozzle Inlet	59.3		877	85.1
Nozzle Outlet	59.3		693	221
Reflector Inlet	59.4		693	215
Reflector Outlet	59.4		649	325
Periph. Shield Outlet	59.4		638	335
Support Plate Inlet	88.1		638	302
Central Shield Inlet	88.1		629	308
Core Inlet	88.1		617	313
Core Outlet	88.1		450	4501
Nozzle Chamber	86.8		450	4464
Diluent Bleed Inlet	2.89		693	215
Pot Bleed	1.31		450	4473
Turbine Inlet (simulated)	4.20		327	1660

Module 1 (5.8.0)

updating on a page-by-page basis and will include a model summary, derivations, model checks, and nomenclature. The approval and acknowledgment of each revision will be at the end of the table of contents. The R-1 CAM is presently being checked on the TAF program for agreement with WANL. A steady-state check has been completed and a frequency response check is now being made.

Attention was given to the effects on the R series of tests if the engine is changed to a topping cycle. If the R test nozzle skirt is limited to a 6:1 ratio compared with a 29:1 area ratio for the E engine, the energy that would normally be used to drive the turbine could be used to heat the nozzle inlet fluid (Figure 18). Normally, 9.6 Mw of energy are used to drive the turbine in the engine system. The R system simulator would use 8 Mw to simulate the skirt of the nozzle and if an exact match is deemed desirable for the inlet to the core, the remaining 1.6 Mw would be removed by an auxiliary heat exchanger.

Figure 18 - Schematic - Topping Cycle Nuclear Rocket Engine and Test Reactor

C. MODULE 2 - ENGINE

1. Engine-System Design and Integration and Engine-Configuration Documentation (3.1.0)

a. Mission Analysis

Detailed definitions of the missions described by the NERVA Program requirements document have been started. There are four reference missions, two of which have variations, so that there are six reference mission patterns in all. After a study of the NERVA Program requirements document and the making of supplementary assumptions these six mission patterns are described in Table 13. Investigations have been made of vehicle configuration, weight, and performance of suitable launch vehicles and nuclear stages for the six mission patterns mentioned. It is assumed that the chemical rocket launch vehicle for common use in each of the six mission patterns will be a two-stage system described by MFSC for consideration in LMSC studies and referred to as the 1975 Saturn V. The first stage of this system is a Block II S-IC with five F-1 engines that have not been uprated. Only very slight structural modification from the Block II configuration is expected. The second stage will be basically the Block II S-II stage, which has been strengthened for bending loads associated with a nuclear stage and with substantial change in each of the five engines. The engine model is described by the symbol J-2S; maximum thrust in vacuum per engine is about 15% higher than that of the current J-2, to a value 265,000 lb. For suborbital first burn of the nuclear stage, the propellant of the S-IC will be offloaded to establish a near-optimum-payload vehicle configuration. Where the mission pattern requires first nuclear-stage burn from rendezvous orbit, assumed at 485-km altitude, a cryogenic kickstage is projected for the passage from parking orbit, assumed at 100-NM altitude. For each of the six reference mission patterns the stages are currently defined as described in Table 14.

TABLE 13

MISSIONS

<u>Symbol</u>	<u>Title</u>	<u>Payload Nature</u>	<u>Payload Launch</u>	<u>1st Nuclear Stage Burn From</u>	<u>2nd Nuclear Stage Burn From</u>	<u>Nuclear Stage Delivered To</u>
AI	Synchronous-Orbit Ferry	Manned or Unmanned	Integral	Parking Orbit	Transfer Orbit	Rendezvous Orbit
AII	Synchronous-Orbit Ferry	Manned or Unmanned	Separate	Rendezvous Orbit	Transfer Orbit	Rendezvous Orbit
B	Synchronous-Orbit One- Way Trip	Manned or Unmanned	Integral	Suborbit	Parking Orbit	Earth Escape
CI	Jupiter Probe (730 Days, $C_3 = 85 \text{ km}^2/\text{sec}^2$)	Unmanned	Integral	Suborbit	Parking Orbit	Earth Escape
CII	Jupiter Probe (730 Days, $C_3 = 85 \text{ km}^2/\text{sec}^2$)	Unmanned	Integral	Suborbit	None, Direct	Earth Escape
D	Mars Landing (1982 Opposition)	Manned	Separate	Rendezvous Orbit	Heliocentric Orbit	Earth Escape

Module 2 (3.1.0)

TABLE 14

STAGES

<u>Stage Description</u>	<u>S-IC</u>	<u>S-II</u>	<u>Kickstage</u>	<u>S-N</u>
Quantity of Engines	5	5	2	1
Engine Designation	F-1	J-2S	RL10-A-3-3	NERVA
Propellants	LO ₂ /Kerosene	LO ₂ /LH ₂	LO ₂ /LH ₂	LH ₂
Full-Thrust/Engine, lb	1,522,000 (S.L.)	265,000 220,000 (Vac)	15,000 (Vac)	75,000 (Vac)
Full-Thrust Specific Impulse, sec	265.22 (S.L.)	432 437 (Vac)	444 (Vac)	825 (Vac)
Mass Mixture Ratio	2.27	5.5 4.5	5.0	0
Mainstage Propellant Capacity, lb	4,598,260	970,000	Mainstage Propellant Loaded and Burned	Mainstage Propellant Loaded and Burned
Interstage, Ascent Shell, Poison Wires, lb	---	11,450	---	(Typically 22,848)
Ullage and Startup Propellants, Misc., lb	---	4,371	---	2,093/Start 1,660/Restart
Mainstage Propellant Loaded and Burned, lb	4,598,260 (AI,AII,D) 4,216,933 (B,CI,CII)	970,000 (P.M.R.)	15,350	(Typically 170,773)
Thrust Decay Propellant, lb	10,380	360	---	1,015/Shutdown (Cooldown Typically 3,493)
Jettison Wet Stage, lb	342,306	97,203	5,117	(Typically 47,123 + External Shielding)

Module 2 (3.1.0)

Module 2 (3.1.0)

b. Shield-Optimization Program Based on Propellant Tank Heating

The shield optimization program has been revised to reflect the changes required for an earth synchronous orbit ferry mission with a suborbital start. Work has been started on a general shield optimization program in which mission parameters will be input program rather than an integral part of the program. The new program will have the flexibility to be used for any type of mission.

c. Engine Startup, Shutdown, and Cooldown Investigations

Preliminary investigations of the startup, shutdown, and cooldown of the 75K NERVA engine have resulted in the following information which is presented in Figures 19 through 22. The preliminary engine operating map, high I_{sp} startup, high thrust startup, high I_{sp} shutdown, high thrust shutdown, and cooldown propellant requirements vs time following 5, 15, 30, and 45 minutes at full power are presented.

The cooldown effects and requirements for a typical one-way synchronous orbit mission with a suborbital start were also evaluated. Figures 23 through 29 present the results of this study.

These preliminary results are being evaluated by detailed engine systems analysis and will be revised when more accurate information is available.

Figure 19 - NERVA Map 75K Engine, Preliminary

Figure 20 - High I_{sp} Startup

Figure 21 - High I_{sp} Shutdown

Figure 22 - Cooldown Requirements

Figure 23 - Cooldown Parameters, First Burn

Figure 24 - Cooldown Parameters, Second Burn

Figure 25 - Cooldown Parameters, Third Burn

Figure 26 - Cooldown Parameters, Fourth Burn

Figure 27 - Sum of Propellant Usage Requirements for All Cooldown Phases

MISSION PHASE	TOTAL IMPULSE LB-SEC	COOLDOWN IMPULSE LB-SEC	COOLDOWN PROPELLANT LB	COOLDOWN GAS TEMP °R
SUBORBITAL START AND INSERTION INTO 100nm ORBIT	19.69×10^6	$.49 \times 10^6$	1100	1500
DEPARTURE FROM 100 nm ORBIT	65.18×10^6	2.83×10^6	6070	1500
INSERTION INTO SYNCHRONOUS ORBIT	35.35×10^6	1.06×10^6	2270	1500
ESCAPE FROM SYNCHRONOUS ORBIT	11.60×10^6	$.37 \times 10^6$	615	2500
TOTAL FOR MISSION	131.83×10^6	4.75×10^6	10,050	

Figure 28 - Synchronous Orbit, One-Way Trip, Mission-Cooldown Characteristics

Figure 29 - Specific Impulse Change Due to Cooldown

d. Thrust-Nulling Devices

The methods by which thrust-nulling capability can be added to NERVA engine system without excessive weight or performance penalty were investigated. The literature search of the rocket and jet engine technology did not reveal any readily available devices or devices that could be applied directly to NERVA. The following appear to be potential approaches.

(1) Thrust Nulling by Reverse Flow Nozzles

Auxiliary nozzles facing in the opposite direction to the main nozzle could be located in the bottom of thrust chamber on the approximate circumference of the bleed ports. This method relies on splitting sufficient flow to these nozzles during cooldown operation to provide exact thrust counterbalance of the main nozzle thrust. A system of bleed ports and hot valves will be required to provide the flow to the nozzles during cooldown. The large number of nozzles required makes the method unattractive.

(2) Thrust Nulling by Clam-Shell Thrust Reversers

The clam-shell, somewhat similar to the type used in jet engines could be located at the exit from the main nozzle to redirect the flow of cooldown propellant into the radial direction. Complex and cumbersome mechanical structure and hinging appear to be a chief disadvantage of this method.

(3) Thrust Nulling by Elimination of Flow Through Main Nozzle

In this method the cooldown flow could be provided to the reactor structural support passages only. A valving arrangement would

Module 2 (3.1.0)

be required so that cooldown propellant returning to the reactor dome is collected into a manifold, directed outside the pressure vessel, and disposed by radially oriented nozzles. This approach appears to be better than the preceding two methods and assessment of its potentialities will continue. The main drawback is the requirement for internal modifications of the pressure vessel.

e. Determination of Representative Vehicles for Nuclear Shielding Study

A family of representative nuclear-powered vehicles encompassing the wide range of possible NERVA applications to manned flight was devised in support of the nuclear shield study currently under way at WANL and Aerojet.

The mission selection was made on the basis of requirements in PRD and recommendations of LMSC. The assessment of each vehicle performance was obtained from LMSC as well as details of tank construction, insulation, and meteoroid protection and composition of payload and other features pertinent to the study.

The layouts of the vehicles were completed for the following missions:

- (1) Manned Synchronous Orbit Ferry - Drawing 1135173
- (2) Manned One-Way Synchronous Orbit Mission - Drawing 1135169
- (3) Lunar Direct Landing Vehicle - Drawing 1135171
- (4) Manned Planetary Stopover Mission - Drawing 1135167 and 1135170

Module 2 (3.1.0)

f. 75K NERVA Engine Configurations

The engine configurations and planning parts lists (PPL's) that were completed and being prepared during the previous report period were replaced by a new set of documents during the current report period. This was required due to significant changes in design guidelines and component and subsystem envelope dimensions. The following comparison of document numbers of the original and revised drawings and PPL's describes the current status and provides a cross reference of document numbers:

PPL or Drawing Number		Title or Test Article (Revised)	Rev. Doc. Status
<u>Original</u>	<u>Revised</u>		
1134489	1134500	Preliminary 75K NERVA Flight Engine Layout	In process
1134490		Engine Envelope Comparison	
1134491	1134503	Preliminary 75K NERVA Ground Test Engine with Series Flow Nozzle - Flow Schematic	Completed
1134492	1134504	Preliminary 75K NERVA Ground Test Engine with Series Flow Nozzle - Piping Diagram (E-1)	Completed
1134493		Preliminary 75K NERVA Ground Test Engine with Series Flow Nozzle - Layout (E-1)	Not started
1134495	1134505	Preliminary 75K NERVA Ground Test Engine - Series Flow Nozzle Piping Diagram (E-2 to E-8)	Completed
1134496		Preliminary 75K NERVA Ground Test Engine with Series Flow Nozzle - Layout (E-2 to E-8)	Not started
1134498	1134502	Preliminary 75K NERVA Flight Engine with Series Flow Nozzle - Layout	Completed

Module 2 (3.1.0)

PPL or Drawing Number		Title or Test Article (Revised)	Rev. Doc. Status
<u>Original</u>	<u>Revised</u>		
	1134508	Preliminary 75K NERVA Flight Engine with Series Flow Nozzle - Flow Schematic	Completed
	1135152	Preliminary 75K NERVA Flight Engine with Series Flow Nozzle - Piping Diagram (E-7, E-9 to E-16)	Completed
3.1.0	3.1.0A	E-1	Completed
3.1.1	3.1.1A	E-2, 3 and 4	Completed
3.1.2	3.1.2A	E-C	Completed
3.1.3		RADA	(Deleted)
3.1.4	3.1.4A	WEMU	Not started
3.1.5	3.1.5A	E-X, E-5, E-6 and E-8	Completed
3.1.6	3.1.6A	E-7, E-9 through E-16	Completed
3.1.7	3.1.7A	TSA	Completed
3.1.8		TSA Simulator	(Deleted)
3.1.9		E-S (ETS-1 Checkout)	(Deleted)
	3.1.10	NERVA Engine Adapter	Completed

The revised drawings have been released and current work involves preparing A-change drawings of all these documents to incorporate the use of the engine remote plane only during engine development testing and relocating the engine remote plane forward, rather than aft, of the manual engine MPT interface. The revised PPL's previously listed were prepared based on this relocation of the engine remote plane.

g. Engine/Tank Interface Definition

Preliminary interface definition was completed in the form of charts defining fluid state-point conditions, fluid connector sizes, fluid flow times, fluid quantities per test, as well as electrical interface requirements for engine tests in ETS-1 and for S-N stage tests in E/STS-2. These data were supplied as input to test facility design documents.

Preparation of interface control documents for engine tests in ETS-1 was started. Drawings 1135178 and 1135182 are currently being prepared to present the interface definition for E-1 to ETS-1 and E-2 through E-8 to ETS-1 interfaces.

A customer suggestion related to ground remote capabilities was evaluated and found to be acceptable. The major item was relocation of the engine remote plane forward of the manual engine/MPT interface as described previously. Other items included in the suggestion are:

- (1) Use of the XE Test-Stand Adapter for E-1 tests.
- (2) Use of the XE UTSM in lieu of a NERVA engine simulator for checkout of ETS-1 modifications before E-1 tests.
- (3) Destructive remote removal of engines from the E/STS-2 MPT during S-N stage ground tests.
- (4) Use of the engine remote plane only during engine development tests in ETS-1.

Items (1) and (2) require further study, but appear to be advisable based on current knowledge of E-1 test objectives. Items (3) and (4) are acceptable; however, it is advisable to include demonstration tests during the engine development program to ensure that the requirements of Item (3) can be met.

h. Maintainability

Maintainability trade studies were conducted related to the reference engine design as requested by the NERVA Task Force. These studies were limited to: (1) evaluation of existing clearances compared with clearances required to perform the component removal and replacement, and (2) evaluation of the capability of mating and demating the components without removal of other components. The components studied were:

- (1) TPCV, TBV, SSCV, DSAV, CD and PSOV actuators
- (2) TPCV, TBV, DSOV and PSOV
- (3) TPA

The results of this study showed that additional comprehensive study is necessary before meaningful conclusions can be made. TPA replacement seems to be impractical even without more comprehensive study. Further study related to the other components is not feasible until more complete definition of engine and component configuration and dimensions are accomplished. Preliminary observations are that actuator replacement may not be very difficult except for the PSOV and DSOV actuators as presently designed. Redesign of the valve/actuator interfaces may reduce the problem, but with added program costs.

The major maintainability effort currently underway is preparation of a preliminary maintainability program plan. Related reliability analysis is currently in process to aid in definition of component maintainability requirements.

A status report for this trade study was made at the 13-14 June NERVA Task Force Meeting.

Module 2 (3.1.0)

i. NERVA Engine Gimbaling

A trade study was accomplished to evaluate the effect of change of gimbaling requirements from $\pm 1\text{-}1/2^\circ$ and $0.25^\circ/\text{sec}$ to $\pm 4^\circ$ and $0.50^\circ/\text{sec}$. The conclusions of this study were:

- (1) The requirement change increases engine weight by approximately 205 lb.
- (2) The TVS qualification confidence is the same for both requirements.
- (3) TVS design and fabrication are equally feasible for both requirements.

j. Structural Support Cooling System

A trade study is being conducted by Aerojet to evaluate various SS cooling system configurations and various interface configurations and locations for the interface with portions of the system under WANL cognizance. This study has progressed to the point of qualitative and partial quantitative evaluation of five alternate system and interface configurations. Continuation of this trade is awaiting resolution of the SS cooling system flow rate requirements.

k. Assistance in Engine-Shielding Studies for Manned Missions

Assistance in this activity was continued and included:

- (1) Structural and mechanical design of two nuclear radiation shields mounted on the engine external to the pressure vessel.

Module 2 (3.1.0)

- (2) Preparation of engine assembly drawings employing two external radiation shield configurations.
- (3) Assistance in coordination of related thermal analysis, nuclear analysis, structural analysis and component design activities.

The following drawings were completed during this report period:

1134506	Preliminary 75K NERVA Flight Engine Assembly - External Shielded Concept
1135160	75K Shield Layout - Structural
1135162	75K Shield Concept
1135163	75K NERVA Shield Upper Cylinder
1135164	75K NERVA Flight Engine Assembly - External Shield Concept
1135166	NERVA Shield Concept - 2 Assembly

1. AGC/WANL Interface Control Document

The program to define the interfaces between the Aerojet non-nuclear components and the WANL nuclear subsystem components has resulted in the issuance of a set of interface documents, AGC ICD Drawing 1134510, to WANL and Aerojet engineers for proceeding with their studies in support of systems engineering. These interface documents will be informally controlled until the design requirement baseline for the engine is approved, after which it will be controlled by configuration management procedures.

m. NERVA Component Design Data Sheets

A format was prepared for design data sheets to be used in presenting design-to requirements to NERVA component designers. Preliminary

data sheets were prepared for the TPA for the 75K engine. This effort was subsequently discontinued to proceed with systems engineering studies as required by the NERVA Program requirements document.

n. NERVA Program Requirements Document Review

The NERVA Program requirements document was reviewed and comments were submitted for AGC program office coordination on technical requirements.

o. System Engineering Documentation

Efforts were started to develop and prepare NERVA systems engineering documentation. Functional flow diagrams and requirements allocation sheets by SNPO as part of the NERVA Program requirements document are being reviewed. Formulation and preparation of lower level functional flow block diagrams were initiated. Systems personnel organized and held meetings with other organizations within Aerojet and with the WANL representative at Aerojet to outline requirements and procedures.

p. NERVA Propulsion System Specification

Effort was started on the preparation of the NERVA propulsion system specification using the NERVA Program requirements document as authority for requirements.

q. NERVA Engine CEI Specification

Efforts continued on preparation of the CEI specification for the NERVA engine. The engine requirements for performance, design, test

Module 2 (3.1.0)

and qualification were revised to be consistent with the requirements outlined in Aerojet Report RN-DR-0148. Subsequently efforts were initiated to revise the CEI specification to be consistent with the NERVA Program requirements document dated 29 April 1968, issued by SNPO.

r. NERVA Management Plan

Support was continued in the preparation and review of the NERVA Program management plan, RN-S-0465.

s. NERVA Configuration Management Plan

Support was continued in reviewing and supplying revisions to the draft of the NERVA configuration management plan.

t. NERVA Environmental Requirements

The dynamic model of the engine system was partially updated by Aerojet, MSFC and WANL inputs. Progress of the dynamics studies has been hindered by X-engine priorities on contributing engineers. Natural environment definition studies are limited until requirements are obtained as part of systems engineering functional flow diagrams and requirements allocation sheets.

u. NERVA Engine Weight Studies

An accounting has been maintained of current engine weight, by summation of component weights and target weights.

2. Engine-System Test Engineering (3.1.2)

No effort was conducted under this sub-subtask.

3. Thrust Structure, Nozzle, Skirt, and Lines (3.4.3)

No effort was conducted under this sub-subtask.

4. Systems Analysis (3.8.0)

a. Trade-Off Studies

Trade-off studies have been made of the 75,000-lb thrust engine. The current state point for the engine system is shown in Table 15.

One study was made to determine the maximum flow rate possible at a chamber temperature of 4500°F. This would assume that both TPCV's would malfunction to the open position and that no safety action had been taken. It was determined that the pump flow rate could increase to 133 lb/sec with a thrust of 109,000 lb, and turbine inlet temperature would increase to 2108°R. Several components would be subjected to conditions beyond their design specifications. If only one valve fails open and the other is closed, the flow rate would reach 128 lb/sec.

A study was made to show the relationships between internal pressure drops of the NERVA engine system and the turbine inlet flow conditions. Turbine inlet fluid temperatures between 1600 and 1700°R were considered. Figure 30 shows the effects of pump discharge pressure on turbine inlet pressure and flow rate. Other parameters investigated were variations in the nozzle tube ΔP and the core ΔP .

TABLE 15

75 NERVA Engine Steady-State Values TT = 21,

Engine PC = 450.0 TC = 4446. Thrust 75000 lb Impulse 824.72 sec
 Power Level = 1548.2 mw Turbopump = 19000 rpm

Turbopump Overall
 Shaft power, mw 5.4012
 Turbine efficiency 0.5100
 Pump efficiency 0.6900

State Point Description	Flow lb/sec	Total Pressure	Temperature	Enthalpy Btu/lb
Dewar outlet	90.94	29.4	39.3	-101.1
Pump outlet	90.44	935.5	52.7	-44.7
TPA bearing coolant	0.50	935.5	52.7	-44.7
Structure support inlet	5.30	935.5	52.7	-44.7
Structure bypass inlet	15.70	935.5	52.7	-44.7
Nozzle manifold inlet	69.43	900.0	52.7	-44.7
Nozzle outlet	66.43	705.0	200.2	517.4
Skirt outlet	56.03	891.0	84.7	
Bolt coolant outlet	3.00	705.0	52.7	-44.7
Reflector inlet	66.76	705.0	194.0	493.2
Reflector outlet	66.76	652.0	272.4	799.0
Peripheral shield outlet	66.76	643.0	278.7	824.1
Support plate inlet	87.76	643.0	276.2	814.4
Structure support outlet	5.30	643.0	947.1	3237.3
Central shield inlet	87.76	633.0	276.2	814.4
Core inlet	87.76	620.0	281.1	833.8
Core outlet	87.76	450.0	4500.0	17088.7
Nozzle chamber	86.50	450.0	4446.0	16833.6
Main nozzle exit	86.50	450.0	4397.1	16603.1
Diluent bleed inlet	2.67	705.0	194.0	493.2
Hot bleed inlet	1.26	450.0	4446.0	16833.6
Turbine inlet	3.93	306.4	1660.0	5729.8
Main turbine exit	3.93	40.0	1292.8	4428.0
Turbine exit (at collector)	4.43	40.0	1148.3	3923.6
Skirt exten. exit (nozz. in.)	4.43	6.0	1448.3	4971.2

Module 2 (3.8.0)

Nozzle Tube Q = 37358. Skirt Tube Q = 0. Main Nozzle Throat Area 95.972 in.²

Main Nozzle Ideal I_{sp} 869.75, TPCV K/A2 Value 0.312647E 00, Pump Exit Density 4.316

Main Nozzle Actual I_{sp} 845.57 and Turbine Exhaust Nozzle Actual I_{sp} 418.00

Figure 30 - Effects of Pump Discharge Pressure on Turbine Inlet Pressure and Flow Rate

Module 2 (3.8.0)

Also analyzed was the relative performance of the technology engine operating at chamber temperatures of 4307°R and 4185°R, with either an XE turbopump assembly or a NERVA turbopump. An XE engine with an NRX-AG core operates at a chamber temperature of 4185°F, while the same design with reduced periphery cooling should run at approximately 4307°R. Using the NERVA turbopump and the higher chamber temperature, a specific impulse of 811 sec and a thrust level of 65,000 lb could be achieved. With the lower temperature, the specific impulse was 798 sec.

Trade-off investigations were made to meet the 825-sec I_{sp} requirement. Turbine efficiency was increased. The effects of higher inlet temperatures and higher chamber temperatures were investigated.

b. Specific Impulse and Thrust Performance

An analysis was made of the overall specific impulse performance including startup, full-power operation, shutdown, and cooldown for the NERVA engine. This included determination of the accuracy requirements to guarantee a given specific impulse and total thrust. Because of the different missions being investigated, the study considered a short-duration and a long-duration run. The short-duration run was based on approximately 300 sec or 433K Mw-sec of operation, while the long-duration run was for approximately 1 hour at full power or 5671K Mw-sec. This does not include shutdown power generation. Startup was at a rate of 150°R/sec along a high impulse line.

Various operating cycles, including retreats to partial power but full impulse, were considered to give the same integrated power from the time of reaching full power until the time of starting to reduce the chamber temperature. Figure 31 shows power decay, assuming a 1575 Mw reactor

Figure 31 - Fission Product Decay Heat vs Time After Shutdown

Module 2 (3.8.0)

with a 27-sec shutdown to 50% of the steady state. Following the retreat to 50% power at maximum chamber temperature, the power was held constant for various hold times before the reactor was scrammed. Curves 1 through 5 of Figure 31 represent the total integrated power of 438K Mw-sec prior to scram and Curves 6 through 8 represent the total integrated power of 5671K Mw-sec. Figure 31 indicates that after approximately 500 sec from Scram the amount of heat to be removed for a given integrated power is the same.

An overall specific impulse was computed for the time interval from startup until the completion of shutdown, just prior to the initiation of pulse cooldown. This is shown on Table 16 under column (7). The full-power specific impulse reference point for this study was 818 sec. A comparison of Cases I and III indicates the advantage of having the 50% power-level hold before shutdown results in a 3-sec increase in overall I_{sp} . The disadvantage of going to a hold level at part power at full temperature is that the run time related to corrosion in the reactor is increased. For the 1-hour operation, a comparison of Cases V and VII prior to pulse cooldown, shows 0.8-sec increase in overall I_{sp} when the 50% power hold is introduced.

Considering the pulse cooldown period, a 1600°R average chamber exit temperature will give an average I_{sp} of around 475 sec, while if the chamber temperature can be increased to 2000°R the I_{sp} is increased to 535 sec. The effect of this on overall performance, for a total operational period of 24 hours from startup to shutdown, is shown in the last column of Table 16, where for the short-duration runs approximately 6 sec of I_{sp} improvement result from the higher pulse cooling conditions. For the 1-hour run, 3 sec of overall I_{sp} improvement result.

TABLE 16
SPECIFIC IMPULSE PERFORMANCE

Case No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
				Time Until Pulse Cooldown				Pulse Cooling Period				Total for 24 Hours		
	Full Power Run Time, sec	50% Power Hold Time, sec	Pulse Chamber Temp, °R	Time, sec	Flow, lbm	Impulse, 10 ⁶ lbf-sec	I_{sp} , $\frac{\text{lbf-sec}}{\text{lbm}}$	Time, sec	Flow, lbm	Impulse, 10 ⁶ lbf-sec	I_{sp} , $\frac{\text{lbf-sec}}{\text{lbm}}$	Flow, lbm	Impulse, 10 ⁶ lbf-sec	I_{sp} , $\frac{\text{lbf-sec}}{\text{lbm}}$
I	150	300	1600	567	30,995	24.85	801.6	461	1,845	0.88	475	32,840	25.72	783.3
II	150	300	2000	551	30,752	24.67	802.2	377	1,507	0.81	535	32,259	25.48	789.7
III	300	0	1600	443	32,050	25.58	798.2	501	2,005	0.95	475	34,055	26.54	779.2
IV	300	0	2000	419	31,721	25.37	799.9	416	1,662	0.89	535	33,383	26.26	786.7
V	3450	300	1600	4023	334,271	272.88	816.4	1394	5,574	2.65	475	339,845	275.53	810.8
VI	3450	300	2000	3922	333,270	272.51	817.7	1209	4,838	2.59	535	338,108	275.10	818.6
VII	3600	0	1600	3973	335,955	273.98	815.5	1485	5,940	2.82	475	341,895	276.80	809.6
VIII	3600	0	2000	3850	334,719	273.37	816.7	1282	5,127	2.74	535	339,846	276.11	812.5

Module 2 (3.8.0)

c. On-Board Computation of Specific Impulse for Space Vehicles

Knowledge of the specific impulse of a rocket engine system is an indispensable part of any trajectory or mission analysis, since it provides a true measure of performance capability of the spacecraft. A survey of the literature indicates the desirability of computing specific impulse using on-board methods. The procedure is a simple and straightforward technique based on the dynamics of the space vehicle alone (acceleration or velocity versus time). Statistical smoothing of successive observations can further improve the computed data. Two methods that are independent of time and also are capable of providing estimates of the more desirable vehicle system specific impulse rather than the engine specific impulse were found. No additional special instrumentation is needed, since instruments for tracking, measuring the vehicle velocity, or acceleration are an integral part of the guidance system.

Starting with Newton's second law of motion,

$$I_{sp} = \frac{t_2 - t_1}{g \left(\frac{1}{\alpha_1} - \frac{1}{\alpha_2} \right)}$$

where t = time, α = thrust acceleration, and g = gravitational acceleration, it is possible to compute I_{sp} from measurements with only two values of α at two different times. Either ground tracking (ballistic camera and long-range radar) or on-board tracking (optical instrumentation with radio monitoring or stellar monitoring) can provide highly accurate data on the thrust acceleration of the space vehicle. This method has yielded results on Thor, Atlas, and Titan flights with an accuracy of 0.1 to 0.5% at the 95% confidence level.

d. Flight Safety

The results of the technology program have been reviewed for their applicability to the NERVA flight safety system. For the technology program a safety system was developed to provide continued operation where feasible, as well as a system to shut down the engine in a safe manner. There are differences between the technology engine and the flight engine system, such as the inclusion of a new structural support system and certain redundancies in valves, such as the turbine power control valve. However, an evaluation of the technology engine system provides a basis for determining whether to include, delete, or expand the use of inhibits, overrides, or emergency/Scram shutdown systems for NERVA. Table 17 shows the safety system used for the technology engine and the types of malfunctions that were protected against. The steps being taken in performing the NERVA malfunction studies are:

(1) Establish engine and reactor system computer models. These CAM models will be implemented with the E-engine system at Aerojet and the R-reactor system at WANL. Any flight system will be part of the engine system.

(2) Design the necessary control systems. The design of the nuclear subsystem can proceed on the R-1 CAM model and then be integrated into the engine CAM model to ensure compatibility of the two systems. This is consistent with the design goals of the NERVA program to use the same control systems for the R and E systems. The design of the controllers will include the necessary safety systems, such as the inhibits, continued operations from overrides, or the introduction of any emergency Scram shutdown system that might be necessary to protect from a loss-of-flow type of accident.

TABLE 17

MALFUNCTIONS ANALYSIS

1. Safety Circuits Permitting Continued Operation
 - a. Pressure error override
PDVV opens
 - b. TPCV position override
TPCV opens
 P_c demand to 600 psia
 P_c measured to zero psia
 - c. Temperature override
Slow drum roll-out (1.5 to 3 deg/sec)
 - d. Drum position override
Fast drum roll-out (greater than 1.5 deg/sec)
 T_c demand to 5000°R
 T_c measured to zero °R
Temperature loop fails to close at 1100°R
2. Safety Circuits Leading to Scram Shutdown
 - a. Fixed/programmed power
Drum roll-out at 25 to 100 deg/sec (transient conditions at high power)
 - b. Drum roll-in detector
Drum roll-in at greater than 1.5 deg/sec
 T_c demand to zero °R
 T_c measured to 5000°R
3. Safety Circuits Leading to Emergency Shutdown
 - a. Pressure rate detector
TPCV opens (without TPCV position override)
Rapid loss of pump flow
TPCV closes
TBV closes
PSV closes
PDSV closes
 P_c demand to zero psia
 P_c measured to 600 psia
 - b. TPA overspeed

(3) With the completion of the models and design of the controllers, a comprehensive analysis of malfunctions during startup, continued operation, shutdown, and pulse cooling will be made. This analysis will use information supplied from the modes-of-failure analysis of the various components. The analysis is an evaluation of the effectiveness of the safety system design and provides quantitative numbers on the behavior of the system if a malfunction should occur.

Among the items to be evaluated would be various drum roll-in rates, drum roll-out rates, failure of the structural support system valves and bypass valves, failure of the turbine power control valve and the parallel operation of these valves, failure of blocking valve, pump suction valve closing, pump discharge valve closing, failures of the controllers--either the demands to zero or maximum or the measured value to minimum or maximum output of the transducers--in all modes of operation. Other items will come out of the modes-of-failure analysis.

e. Time Spent by the Hydrogen Molecule in the
75K Engine at Design Power

The average time a hydrogen molecule spends in the 75K NERVA engine from the flight engine Dewar to the nozzle throat is shown in Table 18.

Module 2 (3.8.0)

TABLE 18TIME HYDROGEN MOLECULE SPENDS IN
75K ENGINE AT DESIGN POWER

<u>Description</u>	<u>Volume (in³)</u>	<u>Time in Part (sec)</u>	<u>Total Time in Engine System (sec)</u>
Dewar Valve to Pump	5,309	0.1372	0.1372
Pump	1,796.5	0.0487	0.1859
Pump to Struc. Support "T"	906	0.0246	0.2105
Struc. Support "T" to Nozzle Manifold	2,678	0.1081	0.3186
Nozzle Manifold	1,502	0.0606	0.3792
Skirt	3,575	0.1219	0.5011
Nozzle	938	0.0388	0.5399
Reflector Inlet Plenum	5,766	0.0332	0.5731
Reflector	4,768	0.0222	0.5953
Reflector Outlet Plenum	12,245	0.0433	0.6386
Peripheral Shield	1,013	0.0196	0.6582
Dome	10,542	0.0240	0.6822
Core Support Plate	685	0.0017	0.6839
CSP Outlet Plenum	2,951	0.0072	0.6911
Central Shield	1,620	0.0038	0.6949
Core Inlet Plenum	29,107	0.0686	0.7635
Core	17,089	0.0378	0.8013
Plenum (Core Exit to Throat)	28,700	0.0035	0.8048

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D. MODULE 5 - NERVA COMPONENT DEVELOPMENT

1. Pneumatic Systems (1.2.1)

Analysis of the pneumatic system continued during this report period.

The current estimate of the gas required from the pneumatic system storage tanks during a high-impulse engine startup and shutdown transient is 18.0 lb GH_2 , a large portion of which (10 lb) is required to operate the propellant shutoff valve during engine cooldown. The approximate titanium storage tank weight is 2250 lb (including 56 lb required residual gas weight) assuming a minimum recharge pressure of 380 psia (corresponding to 60% power) recharge temperature of 280°R, an actuator supply pressure of 230 psia, and a tank membrane stress level of 64,000 psi. The use of a turbocompressor in the system to boost storage tank pressure would result in a storage tank weight of approximately 570 lb under the preceding conditions, a weight savings of approximately 1500 lb.

Reliability studies to determine the optimum arrangement and quantity of major components within the pneumatic system are being made.

2. Valves (1.2.3)

a. Propellant Shutoff Valve (PSOV)

Preliminary design requirements were established for the 9-in.-dia outlet valve, and a concept layout was initiated based on maximum utilization of X-Engine technology.

Module 5 (1.2.3)

b. Structural-Support Coolant Valve (SSCV)

A detail design layout of the selected SSCV concept was completed (AGC Drawing 1135069). Structural and thermal analyses were initiated.

c. Discharge Check Valve (DCKV), Turbine Power Control Valve (TPCV), Turbine Block Valve (TBV) and Pump Inlet Bellows

No activity due to manpower utilization on XE readiness review action items.

d. Dynamic Rod Hardened Seal Evaluation

The 4.75 and 0.875-in.-dia Vespel piston and shaft seals installed in the 5-in. technology engine butterfly-valve actuator have been subjected to ambient and LN_2 leak and cycle tests. Initial tests disclosed that the application of molydisulfide powder to the electrolyzed cylinder bore and piston shaft was necessary to prevent excessive seal wear. Seal fractures have been the major problem area during the tests. Five 4.75-in.-dia piston seals and one 0.875-in.-dia shaft seal have fractured. The first two piston seal fractures occurred at the seal OD lip and were caused by interference between the seals and a step at the bottom of the actuator bore. The step has been subsequently removed. The second two piston seal failures occurred at the piston seal ID lip on seals that were being tested without the metal internal spring in an attempt to reduce wear and have been attributed to the differential contraction between the Vespel material and the aluminum piston. The fifth piston seal failure occurred at the seal ID lip and is believed to have been caused by a flaw in the seal. This failure is still

Module 5 (1.2.5)

under investigation. The only shaft seal that failed fractured across the entire cross section of the seal and appears to be a differential contraction failure. Additional ambient and LN_2 leak and cycle tests are being conducted. GHe leakage rates of 5 scc/sec ambient and 25 scc/sec LN_2 for the 4.75-in.-dia piston seals and 1 scc/sec ambient and 5 scc/sec LN_2 for the 0.875-in.-dia shaft seals at 500 psid have been achieved.

Ambient and LN_2 leak and cycle tests have been conducted using the 1.25-in.-dia Vespel shaft seals installed in the 5-in. technology engine butterfly valve body. The primary problem encountered during the tests has been the transfer of Vespel material from the seal to the electrolyzed surface of the shaft after an average of 75 ambient cycles at 1200 psid. The test results indicate that a boundary lubricant at the sealing surface is required to prevent gross material transfer. Tests were conducted using M_2S_2 powder as a lubricant; however, the transfer of Vespel material to the shaft still occurred. Tests will be conducted using polyphenyl ether, a fluid that is stable at exposures up to 1×10^{11} ergs/gm(C). The test results also revealed that leakage rates below 1 scc/sec GHe at 1200 psid can be expected if a suitable lubricant is used.

Hardware for the metal lipseal testing is nearly complete.

3. Turbopump (1.2.5)

Extensive turbopump configuration selection studies were conducted. Eight basic candidate configurations and five major mechanical variations of the first configuration were evaluated. The basic configurations considered were:

Module 5 (1.2.5)

- a. Single-spool, centrifugal pump, overhung 3-stage turbine
- b. Single-spool, axial pump, overhung 3-stage turbine
- c. Single-spool, centrifugal pump, straddle-mounted 6-stage turbine
- d. Single-spool, axial pump, straddle-mounted 6-stage turbine
- e. Twin-spool, centrifugal pump, overhung 3-stage turbine, low-speed inducer coaxially driven by single-stage aft-mounted turbine
- f. Twin-spool, axial pump, overhung 3-stage turbine, low-speed inducer coaxially driven by single-stage aft-mounted turbine
- g. Twin-spool, centrifugal pump, straddle-mounted 6-stage turbine, low-speed inducer coaxially driven by single-stage aft-mounted turbine
- h. Twin-spool, axial pump, straddle-mounted 6-stage turbine, low-speed inducer coaxially driven by single-stage aft-mounted turbine

All basic candidate configurations had roller bearing radial shaft support and hydrostatic thrust balance pistons for axial shaft support. Major mechanical variations applicable to the basic configurations included:

- a. Hydrostatic thrust balance incorporated on impeller shrouds.
- b. Supercritical operation (smaller, radially soft bearings for lower DN and ball radial bearings for initial axial-position control.
- c. Tandem ball thrust bearings without thrust balancer.
- d. Partially redundant ball thrust bearings with thrust balancer.

e. Labyrinth seal thrust compensation in lieu of impeller backvanes.

The configurations were weighed on the basis of relative performance (including weight and length); reliability (including design inherent reliability, quality control effects, and programmatic philosophy); and operational flexibility (including throttling requirements, unchilled startup, and engine malfunction modes).

Performance predictions were performed separately for the three major aerodynamic/hydraulic elements of pump, turbine, and balancer/coolant circuit; and were combined and summarized in terms of relative engine bleed ratio. Weight and length were included in terms of relative equivalent specific impulse.

The basis of performance predictions for the aerodynamic/hydraulic elements are shown in Tables 19 through 22. Weight and length were calculated from full-size conceptual layouts iterated for maximum component performance, reliability considerations, practical component arrangement, minimum leakage paths, adequate structural margins, and compatible thermal effects.

The reliability predictions shown in Table 23 are those expected at the completion of the turbopump qualification program. This TPA reliability considered the three elements of the equation:

$$R_{TPA} = (R_D \times R_Q) R_{AR}$$

TABLE 19

BASIS FOR PERFORMANCE PREDICTIONS

CENTRIFUGAL PUMPS

DESIGN POINT

Efficiency from commercial (Worthington Experience Curves) data modified for:

Rocket engine pump experience (Titan, technology TPA).

Size effects.

Inlet effects (suction specific speed correction).

Clearance effects.

Head coefficient from commercial and rocket engine pump data corrected for inlet effects.

OFF-DESIGN

Loss predictions based on technology TPA data modified for improved surface finish, geometry control and inlet effects.

Stall characteristic scaled from technology TPA data modified for improved geometry control and inlet effects.

Module 5 (1.2.5)

TABLE 20

BASIS FOR PERFORMANCE PREDICTIONS

AXIAL PUMPS

DESIGN POINT

Symmetric mean line velocity diagram (50% reaction).

Classical diffusion parameter ("D" factor) limit = 0.5 maximum.

Blade row losses 23 to 40% (function of blade height)

Higher than cascade mean line air data values by Lieblein
(NASA SP-36).

Main-stage flow rate 8% higher than delivered flow for balance piston
and coolant requirements.

Collector losses 36% of entering velocity head based on Rocketdyne
MK-25 data.

OFF-DESIGN

Symmetric loss ratio/incidence half range plots correlated with
NASA pump rotor and M-1 fuel scale pump data.

Module 5 (1.2.5)

TABLE 21

BASIS FOR PERFORMANCE PREDICTIONS

TURBINE

Basic loss analysis similar to Stewart's (ASME 61-WA-37)

But accounting for:

Nonequal work per stage

Proper clearance losses

Stage reheat

Correlated with NASA cold air turbine data (NASA TM X-477).

Additional losses for manifold and collector based on technology
TPA and NRX/EST data.

Module 5 (1.2.5)

TABLE 22

BASIS FOR PERFORMANCE PREDICTIONS

COOLANT/BALANCER CIRCUIT

Labyrinth flow rates pressure drops

$$\dot{W} = CA \sqrt{2g\Delta P\rho}$$

C is based on technology TPA data correlated with Pfleiderer's curves based on number of grooves, width, gap, and Reynolds number.

Balancer capacity from uniform pressure distributions based on above applied to balancer area.

Balancer stability from an extension of work performed for Lerc under Contract NAS 3-7978.

Module 5 (1.2.5)

TABLE 23

PERFORMANCE SUMMARY

BASIC CONFIGURATIONS

$\dot{W}_P = 91 \text{ lb/sec}$ $\Delta P_P = 915 \text{ psi}$ $NPSP = 0$ $T_S = 41.3^\circ\text{R S.S.}$ $P_{ST} = 30 \text{ psia}$
 $P_{TIT} = 300 \text{ psia}$ $P_{TES} = 43.5 \text{ psia}$ $T_{TI} = 1660^\circ\text{R}$ $= 36.5^\circ\text{R T.S.}$

<u>PARAMETER</u>	<u>CONFIGURATION</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
Pump type	C	A	C	A	C	A	C	A
No. turbine stages	3	3	6	6	3 + 1	3 + 1	6 + 1	6 + 1
No. spools	1	1	1	1	2	2	2	2
Shaft speed	19000	19000	19000	19000	25000	25000	25000	25000
Pump efficiency	.69	.74	.69	.74	.72	.76	.72	.76
Turbine tip speed	1200	1200	1200	1200	1150	1150	1400	1400
Turbine efficiency total/static	.52	.51	.63	.63	.52	.53	.72	.72
$\dot{W}_T$ exit	4.44	3.91	3.49	3.33	4.28	4.12	3.31	3.26
$\dot{W}_T/\dot{W}_P$	.0488	.0430	.0384	.0366	.0471	.0453	.0364	.0358
Weight	655	620	760	800	655	700	850	930
Length	29	39	32	39	39	45	47	62
ΔI_{sp} equivalent	0	+2.17	+3.81	+3.83	+.37	+.21	+3.08	+2.08
Failure rate (fails/10000)	2.70	4.07	4.59	5.91	3.27	4.21	5.16	6.10
Reliability	.999730	.999598	.999541	.999409	.999673	.999579	.999484	.999390

Module 5 (1.2.5)

where: R_{TPA} is total turbopump reliability
 R_D is the inherent or design capability of the configuration
 R_Q is the probability of producing that design without reliability -
degrading deviations
 R_{AR} is the probability of not degrading the inherent reliability
by acceptable risks due to necessary programmatic influences.

These effects may be expressed in terms of three questions:

R_D : Can the target reliability inherently be achieved by
configuration selection and design procedures?
 R_Q : Can this design configuration be translated into hardware
without deviation.
 R_{AR} : Is the programmatic philosophy oriented to the prevention
of acceptable-risk failures?

The basis for the R_D predictions was the following sequence:

- a. Selection of a candidate configuration. This was the decision to evaluate each of the eight major cases listed above whereby pump and turbine configurations were varied to achieve maximum turbopump performance (lowest engine bleed ratio).
- b. Completion of modes-of-failure analysis. Modes-of-failure were predicted down to the part level for each of the configurations based on the performance, operational, and malfunction requirements of this engine and applicable historical data from similar machinery.
- c. Calculation of design reliability values at the failure mechanism, part, subassembly and total turbopump level, including weighting of these initially subjective values by stress levels.

d. Application of design decision networks to evaluate alternatives of each of the eight basic configurations (such as the five mechanical variations described for the single-spool, centrifugal pump, overhung 3-stage turbine turbopump). These alternates were investigated to improve either reliability or performance, since it is desirable to maximize both. Adjustment of the R_D value followed this step.

e. Confirmation of the R_D values by comparison to historical data based on comparable parts and assemblies for both turbopumps and turbojets.

f. Calibration of the R_D values by comparison to reliability values calculated from the relationship of nominal stress and its variability to nominal strength and its variability. To date this has been done only on selected parts.

The quality reliability, or R_Q , was predicted based upon the results of other programs such as Gemini, Titan and Apollo, and the expected growth during the hardware evolution of this specific turbopump program. This evolution is a function of having a measurable, inspectable concept, improved documentation and procedure definition, and improved hardware control. The programmatic influence, R_{AR} , was stipulated as 1.0 for the purpose of this study, since it is realistic to expect this for a high-reliability-related program.

Some adjustments to the absolute levels of the reliability values may occur as a given concept progresses through the final design phase because of an improved definition of operating conditions, environments, and stress/strength levels and variability. However, for the purposes of this basic configuration comparison study, the relative levels between configurations are felt to be particularly valid.

Module 5 (1.4.1)

Operational flexibility was compared on the basis of an eight-point grading system for ability to throttle or withstand various off-nominal engine operating modes. The results of this comparison are shown for the eight candidate configurations in Table 24.

The results of the study are summarized in Tables 23 and 25 and 26. Clearly, only the two simplest machines achieve the desired reliability of 0.99967. It is also evident that the more complex machines have the higher performance index. No clear configuration choice can be made until a reliability vs performance trade-off relationship is defined.

4. Nozzle Development (1.4.1)

a. Coolant System Study

The parametric study that was being performed to determine the relative merits of a nozzle/skirt series versus parallel flow system has been completed. The results of the study indicated maximum system performance could be achieved by flowing the cryo-cooled skirt in series with the nozzle and locating the nozzle/skirt interface joint at an area ratio 6:1. These conclusions apply to either 75,000-lb thrust or 106,000-lb thrust nozzle/skirt assemblies. A complete technical discussion of the coolant system study will be presented in NERVA Nozzle Assembly Coolant System Study Report (RN-TM-0567), July 1968.

The results of the cooling system study were submitted to SNPO-C engineering personnel on 2 April 1968. This study will be extended to determine the effects of potentially excluding the use of the turbine exhaust flow as coolant of the skirt extension.

Module 5 (1.4.1)

TABLE 24OPERATIONAL FLEXIBILITY COMPARISON

CHARACTERISTICS	CONFIGURATION							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
	<u>1/C/O</u>	<u>1/A/O</u>	<u>1/C/S</u>	<u>1/A/S</u>	<u>2/C/O</u>	<u>2/A/O</u>	<u>2/C/S</u>	<u>2/A/S</u>
Throttle to 60% thrust	2.5	6.5	2.5	6.5	2.5	6.5	2.5	6.5
Inlet temperature tolerance insensitivity	7.5	5.5	7.5	5.5	3.0	2.0	3.0	2.0
3 σ valve losses insensitivity	7.5	5.5	7.5	5.5	3.0	2.0	3.0	2.0
Tank pressure system malfunction	6.5	6.5	6.5	6.5	2.5	2.5	2.5	2.5
Maximum thrust startup	6.5	6.5	6.5	6.5	2.5	2.5	2.5	2.5
TPCV malfunction	5	1	3	3	8	5	3	3
Throttle to 40% thrust	1	8	1	8	1	8	1	8
Unchilled pump start	3	5	3	5	4	6	4	6
Freedom from vibration No Go zones	1	4.5	3	7	2	6	4.5	8
Emergency shutdown latitude (Stall margin)	1	8	1	8	1	8	1	8
(Axial thrust swing)	4	6	4	6	3	5	3	5
	<u>45.5</u>	<u>63.0</u>	<u>45.5</u>	<u>67.5</u>	<u>32.5</u>	<u>53.5</u>	<u>30.0</u>	<u>53.5</u>

1 = Best

8 = Worst

Module 5 (1.4.1)

TABLE 25

ALTERNATE CONFIGURATIONPERFORMANCE SUMMARY

$W_P = 91 \text{ lb/sec}$ $\Delta P_P = 915 \text{ psi}$ $NPSP = 0$ $T_S = 41.3^\circ R$
 $P_{TIT} = 300 \text{ psia}$ $P_{TES} = 43.5 \text{ psia}$ $T_{TI} = 1660^\circ R$ $P_{ST} = 30 \text{ psia}$

<u>PARAMETER</u>	<u>CONFIGURATION</u>						
	<u>1 (Ref)</u>	<u>1A</u>	<u>1B</u>	<u>1C</u>	<u>2 (Ref)</u>	<u>2A</u>	<u>2B</u>
Pump type	C	C	C.S.	C.S.B.	C	C	C
No. spools	1	1	1	1	1	1	1
No. turbine stages	3	2	3	3	6	4	5
Turbine type	0	0	0	0	S	S	S
Shaft speed	19000	19000	19000	19000	19000	19000	19000
Pump efficiency	.69	.69	.74	.78	.69	.69	.69
Turbine tip speed	1200	1400	1150	1150	1200	1400	1400
Turbine efficiency	.52	.49	.50	.50	.63	.58	.61
$\dot{W}_T$	4.44	4.73	4.36	4.20	3.49	4.08	3.93
$\dot{W}_T/\dot{W}_P$	.0488	.0519	.0479	.0464	.0384	.0448	.0432
Weight	655	655	655	655	760	700	730
Length	29	29	29	29	39	35	37
ΔI_{sp} (From ref)	0	-1.36	+.41	+1.07	0	-2.22	-1.84
Reliability	.999730	.999792	.999725	.999730	.999542	.999665	.999603
Failures/10,000	2.70	2.08	2.75	2.70	4.58	3.35	3.97

Module 5 (1.4.1)

TABLE 26
ALTERNATE CONFIGURATIONS
OF BASE CASE

<u>CONFIGURATION</u>	<u>RELIABILITY</u>	<u>CHANGE IN EQUIVALENT I_{sp}</u>
Bearings and balancer	0.999438	Same as base
Thrust bearings only	0.999428	+ 0.68
Reduced DN roller bearings	0.999752	Same as base
Tandem row roller bearings	0.999681	Same as base
Ball radial bearings	0.999725	Same as base*
Balancer incorporated on impeller	0.999730	+ 1.07
Shrouded impeller	0.999725	+ 0.41
Triple-row ball bearings	0.999287	Same as base

*Reduced operational flexibility

Module 5 (1.4.1)

b. Coolant Channel Design

Design refinements were made in the nozzle coolant channel this quarter to minimize pressure drop, increase fabricability, and smooth wall temperature profiles. Current 8047 computer runs indicate nozzle ΔP could be reduced to 130 psi exclusive of bleed-port bypass-manifold losses, which would be approximately 58 psi. The maximum T_{wg} for this case was 1620°F with a maximum coolant Mach Number of 0.25.

The 8047 computer program was revised during development of the coolant channel design to consider shim thickness in computing the channel geometry and the number of channels. Before this change, it was necessary to input a fictitious number of coolant channels or a fictitious gas-side tube radius to compensate for the thickness of the shims between the channels. The correct tube crown radii or number of tubes would then have to be manually calculated. The revised 8047 computer program will output true values for all coolant channel parameters.

c. Hot-Bleed Port Design

A study to determine the feasibility of using the existing NERVA technology hot-bleed port on the NERVA nozzle was concluded this quarter. The results of the study as applied to the 75,000-lb thrust-engine were summarized in the previous quarterly report. The 106,000-lb-thrust study indicated that the gas-side wall temperatures at 106K conditions would be approximately 70° higher between spacers and 135° higher in line with spacers than the 75,000-lb thrust conditions. A plot of hot-gas-side wall temperature versus diluent flow rate for the 106,000-lb thrust conditions is presented in Figure 32. The results of the study indicated the existing

Figure 32 - 106K NERVA Hot-Bleed Port, Entrance Wall Temperatures Section Between Spacers

Module 5 (1.4.1)

technology bleed port would be subject to higher wall temperatures at both the 75,000-lb thrust and 106,000-lb thrust conditions than were experienced in previous nuclear or chemical simulation tests. It is concluded that use of the technology bleed port, without modification, on the 75,000-lb or 106,000-lb thrust engines would result in marginal operating conditions and decreased engine reliability.

Alternate hot bleed port designs are being prepared that will be operable at the 75,000-lb or 106,000-lb thrust conditions. The following design concepts are being considered:

- (1) A rigimesh hot-gas-side liner to film cool the entrance region.
- (2) An electroformed nickel design to reduce wall temperatures through increased material thermal conductivity.
- (3) An uncooled or semicooled refractory metal liner to withstand hot gas temperatures at the entrance region with minimum cooling.
- (4) Injection of diluent at the entrance region to enable early cooling of the gas-side liner.
- (5) Modifications of the existing technology bleed port to reduce gas-side-wall temperatures at the entrance region.

Additional design concepts will be considered if required to produce a suitable bleed-port configuration.

d. Alternate Nozzle Design Concepts

To enable reduction of the overall nozzle/skirt length, thereby reducing the engine shielding problem, three alternate nozzle design concepts were considered. The plug nozzle shown in Figure 33 enables maximum shortening, but the maximum expansion area ratio is limited to 14:1 with the existing pressure vessel diameter. This area ratio restriction would result in a performance loss of approximately 40 sec of I_{sp} compared with the present nozzle. The plug nozzle was dropped from further consideration because of performance loss, severe throat heating problems, and design problems in supporting and cooling of the plug.

The multinozzle shown in Figure 34, which achieves reduced length through the use of many small nozzles, represents minimum shortening compared with the existing nozzle. This minimal shortening does not appear to be sufficient to compensate for the increased design and development difficulties expected with the multinozzle. Therefore, this design was dropped from further consideration.

The forced-deflection nozzle shown in Figure 35 offers the most promising alternate design concept. It reduces the overall nozzle length by approximately 70 in. with an expected minimal loss in performance. The weight of the F-D nozzle assembly was estimated to be approximately 200 lb less than the conventional Rao configuration. Cooling and supporting the center plug represents a difficult design task. Also the development time necessary to prove the F-D nozzle would be excessive compared with the present nozzle. Because of these expected design and development difficulties no additional work will be done on the F-D nozzle.

Figure 33 - Plug Nozzle Concept

Figure 34 - Nozzle Length Comparison, Multi vs Rao Contours

Figure 35 - Nozzle Length Comparison, Rao vs Forced Deflection

Module 5 (1.4.1)

After consideration of the alternate nozzle concepts, it was decided the present Rao-contoured conventional nozzle is the best candidate nozzle to perform the required engine functions. Alternate skirt materials or other engine system changes appear to offer more advantages in solving the engine shielding problem than changes in the nozzle design.

e. Nozzle Jacket Forging Drawings

NERVA nozzle jacket-forging drawings have been released and fabrication orders have been written. The forging design package was reviewed and approved by SNPO-C on 4 April 1968. The fabrication orders that were written are being held pending release of funding and firm program definition.

f. Bolt Coolant-Bleed Port Diluent Series Flow System

A preliminary design study to determine the feasibility of flowing the bolt coolant system in reverse and using this flow as diluent to the hot-bleed port has been completed. Fluid dynamics calculations indicate the system can be designed within present pressure drop limitations. However, the size and the coolant passages in the nozzle flange and the bolt coolant manifold diameter would have to be larger than were provided for the technology nozzle to maintain an acceptable diluent system ΔP . The reverse bolt coolant system was checked for both the 450 P_c and 625 P_c operations. Bypass holes through the pressure vessel attaching flange to flow approximately 1.6 lb/sec would be required for the 106,000-lb thrust nozzle. The analysis assumed a 100 psi drop through the bleed port assembly, and retained 73 psi for control orificing.

The effects of transient and partial power conditions now under investigation are expected to be evaluated by 19 July 1968.

Module 5 (1.4.1)

g. Nozzle Coolant Channel End Caps

Development effort on the coolant channel end caps to reduce overall nozzle pressure drop was resumed this quarter. Ten sample end caps of different configurations have been fabricated of acrylic plastic, and are being tested. Nine end caps are contoured to reduce pressure drop, while one is flat to serve as a control sample. A complete description of the end-cap designs is presented in Figure 36.

A test fixture was also fabricated from acrylic plastic to enable visual and photographic examination of the flow around the end caps during testing. A photo of the test fixture with instrumentation and fluid lines attached is presented in Figure 37. The test fixture simulates the coolant channel geometry and exit hole at the forward end of the nozzle, except that all sizes have been doubled to enable easier fabrication, higher fluid Reynold's number, and better visual examination. The test fixture is instrumented to enable measurement of absolute and differential pressures at selected locations upstream and downstream of the end cap.

Tests are being conducted in accordance with the NRO Test Plan for Evaluation of Nozzle Coolant Channel End Caps, RN-TP-0056, which was published this quarter. All end caps will be tested by flowing water through the simulated channel in the forward and reverse direction at 10, 15 and 20 lb/sec flow rate. Because of the difference in density and viscosity between H_2O and H_2 , it would be impractical to simulate the nozzle coolant Reynold's number with a water flow test. The flow rates were, therefore, selected to achieve turbulent flow and approximate the calculated coolant channel exit pressure drop. For visual examination of the flow pattern around the end caps, air is injected into the water upstream of the end cap to produce bubbles. A typical flow pattern around a flat end cap is shown in Figure 38. For instrumentation readout the water is flowed without air bubbles.

PART NO.	<u>A</u>	<u>B</u>	<u>C</u>	<u>θ</u>	<u>R</u>	REMARKS
1134688-1	1.50	0.450	0.75	85°	0.25	CYLINDER WITH 0.40 x 0.80 SLOT
1134688-5	1.50	0.450	0.75	85°	0.03	CYLINDER WITH 0.40 x 0.80 SLOT
1134689-1	1.50	0.450	0.64	85°	-	CONE WITH 0.31 x 0.50 SLOT
1134690-1	1.50	0.450	0.64	85°	-	CONE ON STEM
1134691-1	1.40	0.450	0.65	85°	0.10	CONE WITH 0.31 HOLE
1134696-1	1.40	0.450	0.65	30°	-	CONE WITH 0.31 HOLE
1134697-1	1.25	0.450	0.65	30°	-	CONE WITH 0.20 SLOT
1134697-3	1.25	0.450	0.65	30°	-	CONE WITH 0.20 SLOT
1134728-1	0.20	-	-	-	-	FLAT END CAP
1134729-1	1.40	0.550	0.65	85°	0.10	CONE WITH 0.31 HOLE

Figure 36 - Comparison of Sample End Caps

Figure 37 - Test Fixture with Instrumentation and Fluid Line Attached

Figure 38 - Typical Flow Pattern Around a Flat End Cap

Module 5 (1.4.1)

The end cap test series is scheduled for completion in July 1968. A complete test report documenting results of the test series will be published following completion of the tests.

h. Nozzle Instrumentation

The nozzle instrumentation requirements for the R-1 nozzle were determined this quarter. For adequate diagnostic and control information, it was proposed to instrument the nozzle with the following number of channels: 5 accelerometers, 31 pressure, 13 differential pressure, 24 strain, and 43 temperature for a total of 116 channels. This information was transmitted to systems personnel for incorporation into the R-1 measurements requirements list.

i. Metallurgical Investigation

A major metallurgical investigation effort was started this quarter to determine the mechanical properties and brazeability of low aluminum Hastelloy X; the mechanical properties of Hastelloy X and CRES 347 nozzle forging convergent section; and the mode-of-failure of a CRES 347 coolant channel. To accomplish this investigation, the following work is presently being done or will be done in the near future:

(1) Two subscale braze sectors are being prepared with eight coolant channels each. Both sectors will be approximately 50 in. long, and the plates, channels and shims will be fabricated from low aluminum (.020% max) Hastelloy X per AGC-90056D and AGC-90057D. These sectors will be leak tested. Leaks will be repaired and then pressure tested to failure. The sectors will then be sectioned, and the braze joints examined. All materials necessary to fabricate these samples are presently in work. Expected completion date for the braze sector work is 15 September 1968.

Module 5 (1.4.3)

(2) Six forged plates (5 in. x 1 in. x 18 to 24 in.) two each from three different laboratory heats are being prepared with varying amounts of aluminum. The aluminum contents will be $0.50 \pm 0.10\%$, $0.25 \pm 0.05\%$ and 0.020% max. Tensile coupons will be prepared from the plates and tested to determine the effect of aluminum content on the strength and elongation of Hastelloy X at various test temperatures. The testing program will be defined after completion of the tensile test program defined in Item 9.c. below.

(3) Rings have been removed from the convergent section of the Phoebus nozzle, S/N 600, and the technology nozzle, S/N 027. The rings have been sectioned and 100 tensile coupons were machined. These coupons will be tested for ultimate and yield strength, elongation, and reduction of area at six different temperatures from -320°F to 1600°F . This tensile testing program is scheduled for completion by 8 July 1968.

(4) Several of the coolant channels on S/N 027 technology nozzle that failed or showed signs of incipient failure have been removed and metallurgically examined to determine mode of failure. Preliminary examination of microphotographs of the failed area indicate the tube wall melted without large grain growth or intergranular cracking.

5. Thrust Structure and Thrust-Vector System (1.4.3)

Refinement and variations of the concept for the thrust structure/thrust vector system for the 75,000-lb-thrust engine have been made. The lower thrust structure (LTS) design concept has been structurally simplified by providing a separate member for carrying the actuator/ball screw mechanism loads, which eliminates bending moment in the shell of the thrust structure, by incorporating a central stabilizing ring and vertical beam structure to resist deflection of the gimbal hinge units.

Module 5 (1.4.5)

A design study for the upper thrust structure (UTS) was completed featuring 12 back-to-back pairs of sheet-metal triangular trusses stabilizing a light, open structure as shown in Figure 39. The two concentrated loads at the gimbal flexure pivots are spread to lighter components by two support forgings.

A computer program was completed to determine resisting moment and permissible angular deflection for flexure pivots using blades or ligaments of assumed lengths, width, temperatures, crossing angle, and elastic parameters. The program was used to determine preliminary dimensions for a gimbal pivot design study to be made in the next report period. Investigations of possible materials for this application have been started.

A basic LTS concept was completed to incorporate a removable, light structural cylinder between the turbopump and PVARA for unmanned flights, arranged so that the structural cylinder could be replaced by an interchangeable external radiation shield for manned flights. In conjunction with the external shield effort, a preliminary estimate has been made of the temperature effects of radiation on the LTS structure. Preliminary data indicate that aluminum alloy, titanium alloy, corrosion resistant steels, and beryllium-aluminum alloy are suitable structural materials. The aluminum alloy and the titanium alloy, however, require good mechanical contact at the LTS/PVARA joint.

6. Pressure Vessel (1.4.5)

a. Design

The 75K pressure vessel layout was upgraded. Current AGC/WANL design details for the pressure vessel closure ports were incorporated, and support was provided on a continuing basis to update the NERVA interface drawing.

Figure 39 - Upper Thrust Structure Concept: 75K Engine

Module 5 (1.4.5)

b. Material Development Program

Final processing, heat treatment, and inspection of the subscale pressure vessel forgings were completed. The six forgings, representing three chemically different heats of aluminum 7039, will supply material for material development in accordance with Phase II of the pressure vessel materials program plan.* Machining of test specimens from the subscale forged material, in support of the material program plan, has been initiated. Phase II testing will start with a program designed to select the optimum heat treatment for 7039. The -T6 and -T63 tempers will be evaluated. As a parallel effort, stress corrosion susceptibility of 7039 forged material will be investigated under laboratory conditions of accelerated salt-spray environment and Cape Kennedy sea coast conditions. Of particular interest is the establishment of a stress threshold for corrosion cracking.

The first phase of the pressure vessel welding development program, Work Scope 7770:WS:4089, was completed. This initial phase consisted of three aluminum 7039 plate weldments, which were TIG-welded using a double U groove weld joint. The final phase, which entails welding rings parted from the subscale pressure vessel forgings, has been initiated.

The weld program is designed to develop weld procedures for NERVA pressure-vessel girth welds, since a welded vessel is a backup fabrication technique for a one-piece extruded unit.

*AGC RN-66020, Revision 1, NERVA Pressure Vessel Material Program Plan, April 1967

7. Lines (1.4.6)

The NERVA engine line systems are still being studied relative to configuration, material selection, and general suitability. Although a number of drawings have been released during the feasibility study, this does not imply that any specific configuration or components have been selected.

Master layouts of R-1 and E-1 lines are continuing. Pressure drop calculations for four proposed structural support coolant lines (SSCL) configurations in four different line diameters were conducted. Two of the concepts were selected as the most desirable and a qualitative comparison was prepared and submitted to the engine systems group for evaluation. The stress analysis of the R-1 bellowless line system using CRES 347, Hastelloy C, and 6061 Al aluminum are continuing, since analyses show that this concept is feasible. The R-1 propellant inlet line with only one gimbaled bellow located at the horizontal section above the privy roof support was stress analyzed. The single bellows is required to provide for displacement of the flange at the skirt interface, enabling facility checkout in Test Cell C. Available data indicate higher stress in the gimbaled configuration. Sketches of the lines for both single-gimbaled and nongimbaled assemblies were prepared and distributed for comment.

E-2 line analysis is continuing. Sketches and weight estimates of TIL, TDL, and PDL using standard line configuration were completed and submitted to the nuclear analysis group for secondary gamma-emission studies. Nuclear analysis of the manned NERVA engine indicates that the lines are the source of high secondary gamma doses and the shield weight is excessive. The lines model used in the analysis is being updated, and additional analyses have been requested. The nuclear analysis group has released data showing the relative decrease in secondary gamma for possible alternative line materials.

Module 5 (1.4.6)

Engine shielding for man-rating analysis shows that redesign of the lines is necessary to reduce crew dosage. Priority has been given to this redesign effort, which consists of the following:

- a. PDL and TDL materials change or elimination
- b. TIL cooled-line study
- c. Bellowless line stress analysis
- d. Tucked-in lines layout
- e. Bellows material and design change evaluation
- f. Alternative materials properties and fabricability investigation
- g. Alternative materials joining and coupling study

The materials section has completed a preliminary material properties comparison chart identifying suitable alternative materials for line fabrication. Zircaloy-2 for TDL and 6061T6 for PDL were recommended; however, further investigation has shown that the impact strength of Zircaloy-2 decreases as a function of the increasing fraction of hydrogen absorbed and of the maximum allowable temperature limit. Further investigations are required, but studies of the graphite skirt extension have a higher priority. If this concept is feasible it would eliminate the TDL as presently conceived. If the graphite skirt extension proves to be unfeasible, a materials investigation to evaluate Zircaloy-2 or some other suitable material for both the skirt extension and the TDL is required. Use of boral in the PDL is being studied as a possible method of reducing the secondary gamma radiation contributed by the liquid hydrogen in the line.

Heat-transfer analysis of a cooled TIL concept using hot-bleed diluent flow at PDL temperature and pressure was completed. Hastelloy C, 6061T6, and Zircaloy-2 materials were considered. Results indicate that a

nickel-base or stainless-steel alloy is required for the jacketed elbow section of the TIL, because the predicted wall temperatures require use of a high-temperature alloy, which eliminates aluminum and Zircaloy. This analysis also indicates that fluid pressure drop and allowable material temperature limitations do not allow a standard concentric cooled-line configuration even in the straight section of the TIL. Other concepts being investigated include a spiral ribbed tube, which may be analytically feasible, but will entail severe fabrication difficulties. A memorandum is being prepared showing the results of the cooled TIL heat-transfer study. Stress analysis is proceeding.

Preliminary stress analysis of the bellowless line indicates that the concept is feasible and additional analyses are being made. Analyses of the bellowless line and the squashed elbow line to investigate thermal effects are being conducted. A report of the analytical results is being prepared by the stress section. Layouts of different squashed elbow concepts have been prepared and stress analyses of these squashed-elbow concepts using the finite element program have been prepared for computerized analyses. Internal pressure is being considered as the primary load.

Tucked-in line-configuration layouts that move PDL and TDL closer to the pressure vessel have been completed. Tucking of the TIL was not originally considered because of expected fabrication problems, but is being investigated as a possible method of reducing crew dose radiation. The investigation to move TIL closer to the PV has resulted in the TIL centerline being tucked in 5 in. This was accomplished by reducing the length of the flange at the hot-bleed port. Additional tucking in of the TIL by the use of a curved bellows in the jacketed elbow is being considered. The TIL tucking and weight reduction study is continuing.

Module 5 (1.4.6)

Convolution drawings using Zircaloy-2 and aluminum materials have been sent to vendors for feasibility studies. The D&K Co. does not recommend aluminum for the intended operating requirements and favors the use of Zircaloy-2 if three to five plies are allowed. Curved bellows convolution designs (elbow-shaped) have been submitted to vendors for comment. Design layouts have been finished showing double-jacketed line bellows systems made of Zircaloy-2 or aluminum that may be used in the cooled TIL or TDL. Investigation has started of carbon-lined or carbon-(graphite) reinforced lines.

Search for other alternative materials is continuing. To date the only low secondary-gamma-emission materials that are readily available, have been widely used, and have been well documented are the aluminum alloys and Zircaloy. There is limited data for other promising materials and extensive testing would be required to determine if these materials are suitable.

a. Sliding Bellows

Layouts for the 4-in. TIL and 5-in. PDL sizes have been completed in the coaxial sliding mechanism/convolute and the in-line sliding mechanism/convolute configurations. All of these four designs have been studied at review meetings and approved by all contributing departments except the stress group, which is preparing a computerized analysis program.

b. Axial Bellows

The 6-in. TDL drawings have been released.

c. Flexure Bellows

The initial 4-in. TIL and 5-in. PDL (1135260 and 1135150, respectively) have been completed and all drawings released.

Module 5 (1.4.6)

Additional efforts have resulted in simplifying the fabrication methods used in these designs. Drawings reflecting these simplifications have been prepared, and the assembly drawings are being revised. Efforts are continuing to further improve these designs.

d. Translating Flexure Bellows

A new design innovation has been conceived that enables the flexure bellows to be axially compressed or elongated. Drawings have been prepared of this translating flexure bellows.

e. Convolution Assembly Drawings

Five different sizes of convolutes drawings have been finished and are ready for engineering approval prior to release.

f. Bellows-Assembly Manipulator

Two design layouts have been finished for a bellows-assembly manipulator tool that can be used in the shop or field to compress or expand the bellows assembly for assembly or disassembly purposes.

g. Bellows Testing Tooling

Preliminary studies have been started of a bellows testing device that would be capable of imparting axial, angulation, and offset motion to simulate all the possible bellows movement modes.

The weld rust investigation concerning the heat affected zone has been completed, and a memorandum will be issued summarizing the

results. There were a total of 25 tube samples, which incorporated several methods of preweld cleaning, backup gases, weld wire, atmospheres, and the use of a copper backup ring. The most suitable preweld method for rust prevention (no rust after exposure to 100% humidity for 48 hours) is as follows:

a. Polish surface adjacent to joint, or nitric-acid brush passivate or electropolish.

b. Use an internal diffuser to direct backup gas directly on weld area or weld in vacuum chamber back-filled with argon.

These methods did not cause rust formation on the ID; however, rust formed on the OD of the joint except when samples were welded in a dry box that was back-filled with argon.

Welding drop-through control samples are being made. Three types of consumable-weld inserts (Y, A, and J) are to be used in conjunction with different backup gases. The Y and A insert samples have been welded and were X-rayed for joint quality. One of the six samples had two minor gas holes; the other samples had no defects. The J inserts will be welded next.

Preparation of the 0.156 and 0.014/0.017-in. thick Hastelloy C samples for irradiation testing has been started.

The line development plan was revised as of 10 May to include the latest design and test criteria.

Effort on lines for support nozzle and TPA development has been suspended pending program redefinition.

8. Skirts and Poison-Wire Withdrawal Assembly (1.4.7)

The principal areas of investigation for the design of components under this sub-subtask were related to: (a) reduction of contributions to the total gamma-radiation dose at the crew compartment by the skirt assembly; and (b) resolution of unsatisfactory operational characteristics predicted for the R-skirt.

Other activities included investigation of design limits for the turbine exhaust gas-cooled skirt extension and its characteristics during partial power operation; comparison of transient effects on R-skirt and E-skirt coolant; detail design studies of the poison-wire withdrawal assembly; skirt coolant tube braze-joint development studies; and studies to optimize the coolant tube exhaust nozzles of the turbine exhaust gas-cooled skirt extension.

In manned-mission applications of the NERVA engine shielding required to protect the crew from excessive gamma radiation, which is attributed to secondary emissions from various components of the engine system, tends to be excessively heavy. Relative contributions from major engine components were identified and redesign was started of parts where significant emission rates are expected. The skirt/skirt extension assembly was identified as a major contributor, providing about 10% of the total crew dose. Because the skirt extension accounts for most of this radiation, emphasis was given to that component, but skirt design changes were also considered. However, the latter were limited to changes in materials that have low gamma-source strengths or have high strength-to-weight ratios, providing a significant weight reduction with attendant reduction in gamma emission rate.

a. Skirt Extension

Alternative fabrication materials considered for the turbine exhaust cooled skirt extension were Zircaloy-2 for its low cross section and titanium. Although titanium is a higher emitter than stainless steel, the reference material for the skirt extension, its superior strength-to-weight ratio enables a significant reduction in weight with a potential reduction in crew dose. These two materials require a reduction in allowable wall temperature from the 1400° to 1500°F range of the stainless-steel design to about 700° to 800°F. Above this temperature these materials appear to be susceptible to hydrogen embrittlement, which adversely affects low-temperature ductility. The effect on ductility would be a potential source of failure during engine restart.

A method of providing sufficient cooling to maintain acceptable wall temperature would be dilution of the turbine exhaust gas with LH_2 . The coolant flow rate required to achieve an acceptable level of coolant velocity would seriously degrade the performance of the engine system, so further investigation of this approach was abandoned.

Liquid hydrogen cooling was investigated for a skirt extension made of aluminum alloy and of titanium. Zircaloy was ruled out because of low impact toughness at cryogenic temperatures.

Upper wall temperature limits of 300°F for aluminum and 700°F for titanium were established, and coolant tubes were designed accordingly. The coolant circuit was designed so that LH_2 from the pump discharge flowed through the skirt extension, the skirt, then the nozzle. Acceptable operating conditions for skirt extensions using each of the two materials selected were determined. The coolant bulk-temperature rise was increased by about 50°R for each case of a skirt extension with an optimized 70:1 area ratio.

No significant pressure drop from the reference engine case resulted (LH_2 -cooled skirt and nozzle in series and turbine exhaust-cooled skirt extension). However, analysis of the operating characteristics of the nozzle indicated that increased coolant inlet temperature to the nozzle caused an increase in Mach number of the coolant at the nozzle throat.

Without exceeding the gas-side nozzle wall temperature condition of 1620°F and assigning a maximum allowable coolant Mach number of 0.3, the maximum nozzle inlet temperature is about 110°R . This value corresponds to a skirt extension cooled with cryogenic H_2 to an area ratio of approximately 40:1. If the nozzle maximum allowable wall-temperature limit is raised to about 1700°F , the allowable skirt-extension length could be in the 70:1 region before the nozzle-coolant Mach number limit is exceeded.

Operating characteristics of the cryogenically-cooled skirt extension were investigated for a parallel flow scheme, where a portion of the pump discharge is routed to the skirt extension and is reintroduced to the main stream at the nozzle coolant circuit discharge. The data indicate that satisfactory operation will be achieved, but the complexity of the system will be increased.

Three aspects to consider in evaluating the cryogenically cooled skirt extension for use in the NERVA engine are fabrication; simulation of coolant bulk-temperature rise for nuclear subsystems development, limited to the $A_e/A_t = 12:1$; and simulation of coolant bulk-temperature rise in the ground test engine assembly limited to an $A_e/A_t = 30:1$.

Fabrication process development would be required for assembly of the tube bundle. Welding will probably be employed instead of furnace brazing. Heat-treatment of the assembled unit will result in special

Module 5 (1.4.7)

demands on facilities and tooling. Simulation of the coolant bulk-temperature rise for reactor development testing cannot be achieved using the current techniques. The nozzle wall temperature will be adversely affected by the lower coolant inlet temperature in reactor tests with the heat absent that is normally added by the skirt extension. A parallel flow arrangement of the skirt extension with the nozzle and skirt in series is another possibility; however, in reactor tests, the coolant normally used for the extension would be supplied to the reflector inlet plenum as conditioned gas from high-pressure tankage. Operation of the engine in the ETS/-1 modified facility would be even more complicated.

High-velocity gas erosion of the walls of the skirt extension, which is not a problem with steel, may be a mode of failure with aluminum. This will require intensive investigation, with possible support by development tests.

No further work is planned for the cryocooled titanium skirt extension because the weight reduction achieved by the use of this material (compared with the reference component of CRES 347) will not result in a significant reduction in crew dose attributable to the skirt extension.

The most significant materials contribution toward reduction of secondary gamma source strength has been the introduction of graphite material for the skirt extension. Fibre-reinforced graphite is about one-fifth the density of stainless steel with comparable tensile strength. Low ductility and hydrogen-erosion tendencies are problems that must be considered in design. Studies of the erosion problem are being made by several firms.

Hydrogen reaction on carbon results in a slow erosion of material, but depends on the exchange of gas at the surface, the temperature, the pressure, and the impingement angle of the gas stream. The hydrocarbon gas that forms from this reaction is more viscous than hydrogen and tends to build a protective boundary layer on the surface, limiting the reaction effect. The rate of deterioration of material for the skirt extension application is being assessed, and other methods are being investigated to limit erosion of the surface, which include coatings and impregnation of metals into the voids within the graphite structure to form hydrogen-resistant carbides. The low-ductility characteristic of graphite will require design attention to limit flexing and strict fabrication and handling-process controls to protect the part from impact damage.

A preliminary stress analysis is in process using the properties of a fibre-reinforced graphite material developed for rocket-engine application by Aerojet. This analysis is being made to establish the feasibility of this approach and to identify potential problem areas. Data obtained will be applied to detail design and to development of improved material properties where required.

A plan for the development of the reinforced-graphite skirt will be prepared for review during the next report period.

b. Skirt

Materials of construction for the skirt of low secondary-gamma source strength were investigated relative to the effect on engine system performance. The materials considered were Zircaloy-2 and titanium. The conditions for use of these materials, their potential contribution to the

design, and limitations have already been discussed for the skirt extension and are applicable to this component. The results of heat-transfer and fluid-dynamics analysis have indicated that the wall temperature limit requires a significantly greater pressure drop for this component, which will adversely affect engine performance if the reference engine series-flow concept is retained. However, operation of the system with parallel flow is feasible. Should modification of the skirt be required to reduce the total crew dose to acceptable limits, parallel flow should be reconsidered.

The effects of reduction of terminal area ratio on the weight of the skirt assembly and on the performance of the reference engine were investigated, and data were presented to engine systems analysis personnel for trade-off studies of engine performance versus shielding weight requirements. The nozzle-skirt assembly for each terminal area ratio of interest was designed to the optimum Rao contour. Figure 40 presents the results of this investigation.

c. R-Skirt Studies

An 11.07:1 area-ratio skirt simulator was designed for reactor development tests to match the pressure drop and coolant-temperature rise caused by the engine skirt. Analytical studies to determine the side-loading effects during separated flow conditions of partial power operation indicated a coalescence of Mach lines into an oblique shock, even at design-point conditions. This condition was confirmed by an atmospheric subscale nozzle test of this contour. To eliminate this condition (by reducing the adverse gas-side pressure gradient) seven modifications to the contour were studied.

Figure 40 - 75K Engine, Optimum Nozzle Area Ratio

Module 5 (1.4.7)

Upper-boundary characteristics and heat-transfer data were obtained, and the most promising contour relative to least probability of shock formation and bulk temperature rise and pressure drop match to the E-skirt was selected for further study. The design has an exit half-angle of 4° , and interfaces with the nozzle at an area ratio of 5:1. The skirt is terminated at an area ratio of 12:1. A scale model of a nozzle skirt with the modified contour is being fabricated for testing in the ETS-1 scale-model-duct test facility to evaluate the design change and to provide empirical data for the side-load study.

Further analyses of the skirt for nuclear subsystems development (R-Skirt) were made to identify partial-power operating characteristics as related to simulation of coolant-conditioning characteristics of the NERVA engine skirt. Figure 41 shows that duplication of bulk-temperature rise and coolant pressure drop is very close at design-point conditions, and temperature varies by not more than 5°F at lower levels of operation. In this region, actual test results should be even closer than predicted, because in the analysis heat-transfer in the separated flow region of the skirt was set at zero, while in actual practice there will be some degree of unpredictable heat flow to the coolant. Figure 42 also indicates the effect on R-skirt wall temperature as compared with the E-skirt when simulation of pressure drop characteristics is accomplished. This condition is further illustrated by Figure 42 where the effects of interface location are included. As the interface between the nozzle and R-skirt is moved aft, while maintaining the terminal area ratio constant, the ability to simulate the E-skirt approaches a limit characterized by the wall temperature. This condition can be modified by selecting a lower design wall temperature for the E-skirt at the expense of pressure drop.

Figure 41 - Operating Characteristics of Skirt Under Partial Power Conditions

Figure 42 - Operating Characteristics of Skirt, Nuclear Subsystem

d. Turbine Exhaust Gas Cooled Skirt Extension Studies

Three studies of the turbine exhaust-cooled skirt extension were completed to evaluate capacity for adjustments in operating conditions. The first study was made to identify the lower limits of coolant conditions under design-point conditions. Figure 43 shows turbine exhaust conditions in terms of pressure, temperature, and flow rate with a limit line for skirt-extension operation. Any set of conditions below the skirt extension coolant Mach number line of 0.4 will result in operating wall temperatures in excess of 1500°F. Operation of the skirt extension at off the design point was analyzed to detect any unacceptable circumstances that might exist. The data presented in Figure 44 illustrate a trend of decreasing thermal severity as lower power levels of engine operation occur. An apparent inconsistency exists as the operating conditions are extended past the design point ($P_c = 450$ psia). The partial power and design-point data are based on turbine exhaust conditions for machinery designed for engine operation at a chamber pressure of 450 psia; the uprated data show the skirt extension reaction to conditions of a turbopump designed for $P_c = 625$ psia.

The third study of the skirt extension was concerned with evaluation of the effect on engine performance of variations in coolant tube exhaust nozzle design. The basic design consists of a 15° exhaust cone terminated at any area ratio of interest. Up to the tube-exhaust nozzle area ratio of 4:1, the material of construction is CRES 347. Beyond this point, wall-temperature conditions necessitate the use of high-temperature materials.

Performance of a nozzle design using a Rao contour was compared at various terminal area ratios with the basic type. Nozzle performance as a function of expansion ratio is presented in Figure 45 corrected for weight. Optimization of the design was continued by eliminating

Figure 43 - NERVA Skirt Extension, Design Point Limit Conditions

Figure 44 - NERVA Skirt Extension, Operating Characteristics

Figure 45 - 75K Skirt Extension, Coolant Tube Exhaust Nozzle Performance

the gas-side wall of the two configurations aft of the $\epsilon = 4:1$ point, enabling the entire nozzle to be constructed of CRES 347, with resultant reductions in weight. The interactions between the engine exhaust stream and the coolant tube exhaust in this region are not accounted for in the curves of Figure 45 representing this change, but negligible effect is expected. Selection of a turbine flow exhaust nozzle has not been made to date. The performance gains for each concept must be evaluated relative to fabrication complexity and reliability to make a logical decision.

e. Braze Development Studies

The skirt-braze development program described in past reports was resumed in this report period. The first portion of the brazing program includes tube-to-tube braze specimens and will be known as Section 1.

Section 1 is divided into the following five phases:

Phase I. Selection and evaluation of commercially available brazing materials compatible with nuclear environments and other characteristics unique to the NERVA engine.

Phase II. Fabrication, brazing, and examination of vertical flow specimens using braze materials selected in Phase I.

Phase III. Fabrication, brazing, and examination of full-length tube sections, using alloys and temperatures selected from Phase II.

Module 5 (1.4.7)

Phase IV. Fabrication, brazing, and examination of a simulated full-skirt section; one half to be brazed with 82 Au-18Ni alloy and the other half with alloys selected in Phase III.

Phase V. Selection of the braze alloy for development skirt fabrication and writing of specifications and brazing procedures for skirt fabrication.

Phase I is completed. For Phase II, specimen fabrication with 20 braze alloy combinations have been completed, and furnace brazing is completed. The brazed specimens have been returned to Aerojet and have been sent to the materials laboratory for evaluation. The full length tubes for Phase III have been obtained and requisitions for welding, brazing, and inspection were written and submitted to the Purchasing Department. Requisitions for the Phase IV brazing and inspection have been written. Phase V is dependent on the previous phases.

Section II of the program will establish procedures and the tube-end design for brazing the coolant tubes to the forward flange as shown in Figure 46 using braze materials selected from Section I of the braze program. Type, shape, and flow characteristics of the braze material will be determined. The braze assembly will be leak-tested and a repair procedure will be established.

Manifolds (simulating a portion of the skirt flange) were designed to receive the three tube designs being considered.

Material and fabrication requisitions for all of the component parts of the test specimens were submitted to purchasing. Most of the parts are on order.

Figure 46 - NERVA Skirt Forward Flange Detail

Module 5 (1.5.1)

f. Poison Wire Withdrawal Assembly Design

Study was resumed of the poison-wire withdrawal assembly during this report period. An assembly layout, Drawing No. 1135432 was completed. This design differed from previous designs in that the PWWA is locked into the skirt at its aft end instead of at the nozzle throat.

As a result of an engineering review of the preceding drawing, a new layout is in progress that will incorporate all the recommendations from the review, plus changes necessitated by new poison wire information furnished by WANL. The new layout and the details of this design are being considered simultaneously. Some of the major changes resulting from the engineering review are: lengthening of the wire storage cylinder; removal of the entire forward structure; supporting the cylinder bearing from a plate locked to the skirt aft end; redesign of the withdrawal piston and the energy spring-latching mechanism; and change of the piston actuator mechanism from a drum and cable to a tape and sheave.

The assembly layout is approximately 25% completed. Preliminary stress analysis and a weight study are continuing.

9. Control System Design and Analysis (1.5.1)

The E-1 Common Analog Model was updated to reflect the 75K line geometry, the series nozzle design, and the latest steady-state engine-balance conditions. The CAM specification was issued to WANL.

A revised format for issuing CAM equations was agreed to in a coordination meeting with WANL and will be incorporated in a CAM revision now under preparation. Work has been started on the derivation and numerical constant sections that were not included in the original issue.

Module 5 (1.5.1)

The 360 TAF version of the E-1 CAM was completed and used to provide steady-state and frequency response at the design point. Work is now in progress to obtain similar data at a low power point.

The NERVA E-1 equations have been scaled and are currently being patched for the analog computer. Checkout is expected to be performed after the computers are reinstalled.

R-1 Common Analog Model equations have been programmed on the 360 TAF program. Steady-state and frequency response performance data of the model have been compared with results obtained at WANL. An excellent agreement of data exists for all runs when systems are identical. Additional runs with the Aerojet model have shown the effect of the pump bypass and heat exchanger valve dynamics on the engine response. Also, it has been shown that the fixed load representation of the nozzle and reactor has no significant effect on the frequency response of the feed system.

An analytical model of the NRX-A6 system has been written as defined by the final CAM equations. Checkout of the model is in progress. The objective of this effort is to verify performance data of the system against results obtained at WANL.

Integral-pulse-frequency modulation has been investigated as a possible information processor in the NERVA pressure control loop. Work included analysis and simulation on the analog computer of the stability characteristics of the modulator in a closed-loop configuration. Using a simplified transfer function for the plant, results show that the system is asymptotically stable with a limit cycle at 7 cps and amplitude of 11 psi.

10. Electronic Development (1.5.4)

New circuits were developed and components associated with the new circuits for use in the flight-engine control system and other associated NERVA controls programs were evaluated. Significant engineering effort was directed toward evaluating microminiature and integrated circuits suitable for use in engine control applications.

The pulse-interval control-system concept study continued. A study model of a comparison device for two positive pulse trains was constructed and operated. This study model generated a pulse train that was one polarity of the difference between the two pulse trains. In a servo-loop application of this comparator, the other polarity of the difference would be provided by an identical device with the two input pulse trains interchanged. The comparison device was constructed of basic cells with a single level for simplicity; it is possible to construct this device in three levels for redundancy in a manner similar to that demonstrated for the sequence control loop. The comparison device operates by detecting the second pulse in one pulse train without an intervening pulse from the other pulse train. Following this rule, it is possible to generate a pulse train whose pulse rate is the difference between the two input pulse trains. This result can be demonstrated graphically and was the result obtained from the tests of the comparison device.

The detailed operation of the device is as follows. The first pulse in one pulse train is called the set pulse train and is received, stored, and recirculated in a basic cell loop. When a pulse is recirculating in this loop, a switch is opened to allow the next pulse in the set pulse train to become an output pulse. When a pulse from the other pulse train called the reset pulse train is received, it cancels the pulse circulating in the basic cell loop, thereby closing the switch to prevent gating a set

pulse to the output. The squelching of the circulating loop pulse by a near-coincident set pulse must be prevented. This is done by inhibiting set pulse inputs to the loop whenever a loop pulse is circulating.

11. Control Actuators (1.5.5)

A preliminary specification, AGC 90201, defining the performance, design, test, and design verification requirements for a rotary electropneumatic actuator meeting the proposed 75K NERVA engine TPCV, SSCV and TVS control requirements has been released. Copies have been sent to WANL and SNPO for comments and input relative to using the actuators defined on the SSCV. Procurement of actuators meeting these new requirements is being delayed until authorization to proceed has been granted pending resolution of funding and scheduling problems.

Draft copies of the WANL ganged-drum drive system, control drum actuator system and structural support coolant valve (SSCV) actuator system have been reviewed, and comments relative to engineering integrity and compatibility with the overall NERVA engine system have been prepared for transmittal to WANL and SNPO.

WANL design concepts for the ganged drum drive system and the control drum actuator system were jointly reviewed by SNPO and Aerojet personnel. Comments and recommendations for further action to be taken have been submitted to WANL.

Alternative pneumatic servo valves for the TPCV actuator are being evaluated to develop one that will withstand the expected NE-induced vibration environment. Procurement has been initiated of a selected engineering evaluation unit for environmental (except radiation) and functional integrity development tests. Delivery and testing are scheduled for August 1968.

Module 5 (1.5.7)

Several manufacturers of linear variable differential transformers (LVDT) have been contacted and evaluated as potential sources for a rotary variable differential transformer (RVDT) to replace the potentially radiation-sensitive and vibration-sensitive rotary potentiometers now used for position feedback on the XE TPCV actuator.

Procurement of RVDT evaluation units has been initiated and candidate units are expected to be available for evaluation in September 1968.

12. Engine Flight-Programmer Development (1.5.7)

The initial system functional design conceptual diagram for the E-engine control system was completed for the 75K engine configuration. In conjunction with the design, functional requirement documentation and preliminary design data sheets were completed to define elements of the controls system. This documentation is being reviewed relative to engine system compatibility to provide the necessary data for the control system contract end item specification (CEI). The initial data also enables an E-engine controls development plan that provides definition of design, fabrication, and test requirements for electrical and control system mechanical elements of the engine system.

Consistent with the overall E-engine program plan, efforts were made to provide the foregoing long-term development plan for the engine controls. This plan is intended to include details relative to controls development; data for development of interfaces between central electronics and connecting elements (e.g., instruments, TSCS, NSS, power, signal conditioning, actuators, etc.); joint scheduling data and design review points; test planning information; and basic research requirements.

The NERVA Program requirements document was reviewed to ensure that the controls system preliminary functional design meets engine and program requirements.

Development of flight-packaging criteria was continued in support of the flight ECS configuration.

13. Control System Fluidic Chamber Pressure Control NERVA
Component Development - Phase I (1.5.9)

Work was initiated in the areas of component designs, component analysis, system performance analysis, and test facility planning and activation.

Component designs of a full-scale vortex valve (TPCV) and various subscale driver amplifiers were completed.

The full-scale vortex valve (Figure 47, AGC Drawing 1135319) was designed with the capability of varying the ratio of control-port area to exit-port area. This will enable examination of the trade-off capability of control pressure and flow gain. The valve chamber can be 2-in. or 4-in. thick, which will enable examination of chamber and control jet-width effects on performance.

The NERVA full-scale (30 in. dia) vortex valve was designed with a center tie bolt (Figure 48) to minimize weight (wall thickness). To verify this concept, subscale tests with gaseous nitrogen were performed with a 3-in. vortex valve and a 0.125 in. rod insert. Summary of test results are shown in Figure 48 for equivalent exit areas, both with and without the center rod. Change in performance was slight.

A stress analysis of the test vehicle full-scale vortex valve is now being performed. Combined with this study is a weight-reduction analysis for application to a flight-engine design.

AK 21				WELD JOU		MIL R 5051	
AK 21						CLAS 216	
AK 21				UNPAIND			65
212 PP	9600	70180 W		CAUSKET			67
212 PP		56180 55		CAUSKET			64
214 PP		56015 611		CAUPLING			63
214 PP	9600	56015 3 HT		CAUPLING			62
212 PP	61400	56000 W		SEAL			60
614		56000 W		SEAL			59
412		56000 W		BOLT			58
412		56000 W		BOLT			57
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412		56000 W		BOLT			37
412		56000 W		BOLT			36
412		56000 W		BOLT			35
412		56000 W		BOLT			34
412		56000 W		BOLT			33
412		56000 W		BOLT			32
412		56000 W		BOLT			31
412		56000 W		BOLT			30
412		56000 W		BOLT			29
412		56000 W		BOLT			28
412		56000 W		BOLT			27
412		56000 W		BOLT			26
412		56000 W		BOLT			25
412		56000 W		BOLT			24
412		56000 W		BOLT			23
412		56000 W		BOLT			22
412		56000 W		BOLT			21
412		56000 W		BOLT			20
412		56000 W		BOLT			19
412		56000 W		BOLT			18
412		56000 W		BOLT			17
412		56000 W		BOLT			16
412		56000 W		BOLT			15
412		56000 W		BOLT			14
412		56000 W		BOLT			13
412		56000 W		BOLT			12
412		56000 W		BOLT			11
412		56000 W		BOLT			10
412		56000 W		BOLT			9
412		56000 W		BOLT			8
412		56000 W		BOLT			7
412		56000 W		BOLT			6
412		56000 W		BOLT			5
412		56000 W		BOLT			4
412		56000 W		BOLT			3
412		56000 W		BOLT			2
412		56000 W		BOLT			1
412		56000 W		BOLT			0

223

Figure 48 - Vortex Valve Performance Curves

Module 5 (1.5.9)

Alternate vortex valve-design concepts, other than the initial breadboard design, are being explored. Emphasis will be given to weight reductions and integral designs compatible with the turbine inlet manifold.

Several subscale designs of the unvented driver amplifiers have been completed. These are various momentum and jet deflection (secondary injection) concepts. Initial manufacture is now in progress using photo-sensitive plastic. Trade-offs between pressure and flow gain will be studied with these subscale devices; the more promising designs will be scaled up in size for initial manufacture and test at design conditions.

A study is now in progress in support of both vortex valve and driver amplifier designs to determine the applicability of establishing digital computer steady-state analyses programs for design support. Extension of the vortex valve analytical approach of Prof. Wormley, MIT, to include temperature effects is now planned as an initial step. Various analytical procedures are being studied for possible application to the driver amplifier design.

System performance analysis indicates that the high pressure recovery characteristic of the vortex valve will increase the available turbine inlet pressure (torque margin) above that available with the present mechanical TPCV. This should offset any increase in weight or loss in available enthalpy due to the performance of vortex valve. When test data become available, a complete trade-off study relating specific impulse, control gain, and engine performance will be made.

Various manufacturing methods available at Aerojet are being surveyed for possible application to the design of metallic unvented driver amplifiers. Among methods being studied is diffusion bonding.

Module 5 (1.5.9)

Specialized constant-temperature hot-wire anemometry equipment has been ordered to support the test programs. This equipment will be calibrated in the Azusa test facility with hydrogen gas at test conditions.

To simulate the actual type of flow impedance that the vortex valve exit will be subjected to, an XE turbine inlet manifold with the first-stage nozzles inserted will be connected for each test.

Module 7 (2.5.1)

E. MODULE 7 - NRDS

1. Ground Operations Safety (2.5.1)

a. General

Audits accomplished during this report period included: (1) effectiveness of REECO medical response to emergency calls; and (2) the support contractor's Scott Air-Pac servicing facility, including units received in May.

Refresher training was initiated on the purpose and use of respiration equipment. Training also was provided for radiation safety and fire personnel concerning cryogenic hazards, industrial hygiene problems, and radiation hazards.

b. Criticality

A-6 fuel-dust from R-MAD sawing operations was shipped to E-MAD.

XE-1 radiation-monitoring requirements were reviewed with Pan Am radiation-safety personnel and a formal support-requirement document is being prepared.

The collision of the R4 and the R8 units in the RMSF was investigated. Several pieces of KIWI B-4D fuel spilled from a cask insert. However, a criticality problem did not arise, and re-railment and cleanup were accomplished.

Module 7 (2.5.1)

One violation of the criticality control manual was discovered at E-MAD during postmortem operations.

Arrangements were made with Pan Am and EG&G to provide a neutron source and "popper" prior to the arrival of the XE-2 reactor at E-MAD.

A survey of NTO shipping casks was completed for SNPO-N. At the request of SNPO-C, more permanent criticality-zone signs were directed to be placed in E-MAD hot cells.

c. E-MAD

An investigation of the derailment of the F-5 flatcar was made and recommendations were issued for corrective action.

Arrangements were made to supply in-cell fire suppression equipment for post-operative cells.

Accounting of NRX-A6 nuclear materials continued with transfer of scrap fuel to RMSF.

Personnel entry to the hot cell service area was made several times to maintain equipment. Although radiation fields were in excess of 5R/hr, stringent personnel control maintained exposures at acceptably low levels.

d. ETS-1

An investigation was made to determine acceptable replacement clothing for liquid oxygen operations. The present equipment is unsatisfactory because of its rapid deterioration.

Module 7 (2.6.3)

An inspection of the scissor-lift work platform revealed that the equipment was unstable in the raised position. Its use was limited to locations where stability can be provided.

Duct-removal stress calculations were reviewed from a safety aspect. It was determined that Broloc slings will possess a 5.1 safety factor when manufactured. They will be accepted after proof testing by the manufacturer and installation by the contractor.

e. R-MAD

A study of face velocities of ventilation systems was made and a report issued.

With the LASL safety representative, an investigation was made of fire control measures. Discrepancies were noted and corrected.

f. Test Cell C

Borated-water flow-test of reactor shields revealed no major leaks at 25 psi with flow-rates of 5700 gpm.

A review was made of proposed specifications and of the standard operating procedure for poured-in-place rigid urethane foam.

2. Quality Assurance - NASA (2.6.3)

a. General

The format for XE logs was approved for use on XE-1 and subsequent engines.

Module 7 (2.6.3)

Procedures to govern control of nonconforming material were approved and issued.

Quality-reliability instruction 8.5 (product assurance interface with test specification and procedure review, and test review board) was initiated, coordinated, and the final draft transmitted for approval.

b. ETS-1

A workmanship audit of all racks and terminals was completed. As a result, a more exacting control of work performed at ETS-1 is being maintained.

A post-inspection of the test stand adapter was completed in accordance with NTO-I-0477.

All drawings for pipe-chase and duct-vault catwalks and ladders were reviewed and approved.

A preliminary portion of the unit-list audit was completed and corrective actions were submitted to channel engineering.

c. E-MAD

Cleaning of the upper structural line was accomplished in accordance with NRO Procedure 7770-WS-4568.

Inspection services were provided during the installation and checkout of XE-1 instrumentation, in accordance with the requirements of XE-1-P4 and NTO data log-sheets.

Module 7 (2.6.3)

Inspection services were provided during XECF post-test inspection and checkout, as required by P-18.

Inspection was provided of XE-1 UTSM-line deviations, as reported and dispositioned on QRDR 2830. Adjustments were made and verified.

d. Reliability

A failure-mode analysis of the railroad transport system track switches is being performed.

The final review of the ETS-1 failure-mode-analysis was completed and comments transmitted.

A review of all ETS-1 discrepancy/failures was performed to determine if effective corrective action was taken.

An evaluation of the QRDR as a reporting document was made, resulting in modifications both to the form and to the instructions for its initiation. The modified forms were received and training sessions initiated.

An instruction to define the procedure for discrepancy/failure analysis, specifying the method to be used to determine the prevention of problems, was initiated and transmitted for final review.

Module 7 (7.0.0)

3. General Support (7.0.0)

a. ETS-1

The following piping stress analyses were completed to verify existing designs and to determine the acceptability of required system modifications:

- Survey of ETS-1 and E-MAD piping and supports for seismic loading
- Steam line installation
- Helium purge diffuser S-3 platform modifications
- Cooldown piping modifications
- Cryotrap installation
- Pipe-chase catwalks and ladders
- Water-system additions

The following engineering packages, drawings, and specifications were completed:

- Generators #1 and #2 cooling fans
- Generators #1 and #2 battery replacement
- Cooldown-system modifications
- Pipe-chase GN₂ manifold
- Duct-vault inflatable seal
- Helium-purge diffuser S-3 platform modifications
- Duct-exhaust cooldown filter proposal
- S-2 cable pylon
- General civil improvements
- Water-system additions
- Overheat protection for data-acquisition system

Module 7 (7.0.0)

Cryotrap installation
New steam-line installation
Pipe-chase catwalks and ladders

b. E-MAD

The following engineering packages, drawings, and/or specifications were completed:

Postmortem-galley service hoist
Actuator-checker gas supply
Lateral pipe-supports
Lifting-fixture modification kit
PM HOCMTS emergency tow-bar
RTS brake redesign study
RTS coupler redesign study
200-PSI air system (preliminary)

c. Test Cell C

General support was provided to LASL for the scrubber development and test program. The primary effort was devoted to scrubber testing.

d. NTO Counting Laboratory

In support of NTO/LASL test operations, the following tasks were performed:

Comparison of lithium fluoride TLD's
Preparation of XE-1 dosimetry packets

Preparation of the XE-1 P-12 procedure

Preparation of NRX-A6 dosimetry report on cobalt-glass data

d. Documentation and Reporting

The following reports were issued:

Volume I, NRX-A6 Disassembly Report

XE-1-P26, XE-1 Modification to the Test Stand Adapter

XE-2-1, NTO Operating Procedure for Reactor/Pressure Vessel Assembly (PVARA) Receiving and Storage

NTO-SOP-0109, ETS-1 LN Converter Operations

NTO-SOP-0100, ETS-1 Propane Storage Tank Fill

XECF-P18, NTO Operating Procedure for Post-Test Inspection of XECF

XECF-P17, Transfer of XECF from the Hot Bay to the Cold Bay

XECF-P14, Remote Leak and Electrical Checkout of XECF after Remote Replacement of UTSM in E-MAD

XECF-P11, Manual Realignment of Engine Replacement Stand (ERS) for XECF, Remote UTSM Replacement and Transfer of XECF from ERS to EIV

XECF-P10, Remote Transport of XECF from ETS-1 to the E-MAD Hot Bay and Removal Using the OPS

NTO-I-0477, XECF Post-Test Inspection

NTO-G-0001, Interim Fuel Element Processing System

NTO-G-0002, Checkout of the Fuel Element Processing System

NTO-A-0022, Organization and Responsibilities of NTO Health and Safety Staff

NTO-A-0030 - Section 033, Instrumentation Equipment Re-Inspection Requirements at ETS-1

NTO-G-0004, ETS-1 Electrical System and Equipment Preventative Maintenance Procedure

Module 7 (7.1.0)

NTO-I-0447, NTO Operating Instruction for TIE Activation

NTO-I-0465, NTO Procedure for Installation and Removal of the Simulated Cooldown System for FEP-V

NTO-SOP-0075, NTO SOP for Setup and Operation of Passive Signal Conditioners at ETS-1

NTO-SOP-0081, NTO SOP for Setup and Operation of Active Signal Conditioners at ETS-1

NTO-A-0001, NTO Procedures and Reports Manual

4. Test Cell C Operations (7.1.0)

a. General

Support to LASL in preparation for the Phoebus-2A test series included all sub-system checkouts and participation in Experimental Plans I, II, III, and IV. Significant facility work accomplished or in progress during this reporting period included:

b. Data Systems

(1) Thermocouple Reference Oven

Because of the limited number of earth-well reference junctions available and the high noise-level associated with these junctions, 32°F Pace reference ovens were used for all previously earth-referenced channels. The chromel/alumel calorimeter thermocouples were the only cart channels referenced to these ovens.

Failure modes of the ovens were investigated and data taken during induced power-failures. A complete power loss causes the effective junction temperature to decay about 0.14°F/min. Data were taken

for copper/constantan junctions, relating the change in effective junction temperature from 32°F to the drift in high and low block-temperatures. The linear equation

$$T_{\text{REF}} - 32^{\circ}\text{F} = 2.30 (T_{\text{LB}} - 150^{\circ}\text{F}) - 1.26 (T_{\text{HB}} - 255.7^{\circ}\text{F})$$

was found to give the best fit. A similar equation is now being developed for chromel/alumel thermocouples. A program also is being written whereby data can be corrected for reference drift. It will use the above equation to make point-by-point corrections.

(2) DDP-116 Hardware, Software, Programming

A real-time clock was installed on DDP-116 for use during the Phoebus-2A test series as a backup time-source. Also, the MAD unit was modified to increase its speed and to make it compatible with disc unit input/output data transfers. These two items were checked out and were operational during testing.

Programs were written for DDP-116 which provide far more efficient use of input/output equipment. These included a system-monitor program to permit the operator to write and read programs on the disc using the ASR-33 keyboard as the requesting device. This provides instantaneous access to system programs.

All Phoebus-2A application programs, subroutines, and interrupt drivers were prepared: all are checked out except the time-history and parameter-display application programs, the new CRT input/output subroutines, and the real-time clock interrupt-driver.

Module 7 (7.1.0)

(3) Data-System Hardware Modifications and Checkout

Twelve new microphone channels were installed in connection with the study of sound pressure-levels during power tests. They are variable-reluctance devices usable over a sound pressure-level range of 110 to 180db re 2×10^{-4} μ bar. The system has a frequency range of less than 0.1 Hz to kHz. All channels were calibrated at sound pressure-levels of 160, 150, 140, and 130db with pure tones of 250, 500, and 1,000 Hz immediately before operation, and as soon as possible after a run. A photocon PC-125 acoustic calibrator was obtained for this purpose. Six accelerometer channels were also installed to observe acoustically excited accelerations of certain facility structures.

Installation and checkout were completed on 50 new channels of telememory, 100-channel vacuum alarm system, a new wide-band calibrator, and a time-code decoder for the LCR.

c. Mechanical Systems

(1) New Turbine Installation

As the result of difficulties encountered with the Mark-25 turbine rotor blades, new rotors were fabricated by Rocketdyne, and the turbines containing them installed between EP-IIB and EP-III. The acceptance and qualification test was performed as part of EP-III operations. Turbopump instrumentation revealed no problems associated with the new rotors.

(2) Mechanical Blocks for Valves

Malfunction of some test-cell valves could have an adverse effect during a reactor run or the subsequent cooldown period.

Wherever possible, mechanical blocks have been incorporated to prevent a malfunction. Mechanical blocking has been accomplished in several ways: (1) blocking or limiting actuator travel; (2) blocking or limiting valve-stem travel; and (3) plumbing the actuation fluid directly to the valve actuator to hold the valve either open or closed.

(3) Modifications as a Result of Acoustic Studies

In conjunction with the joint Marshall Space Flight Center (MSFC) and LASL J-17 acoustic study, several modifications to the test-cell structures were necessary to protect against anticipated acoustic loading. Several physical inspections of the test cell were made, and the resonant modes and damping factors of many structures measured. MSFC personnel performed calculations to determine material-failure probabilities and also evaluated and approved design modifications as proposed by J-17 and J-5.

The corrugated metal housings on Dewars 1, 2, and 3 control-valves were strengthened. The unsupported panel size was reduced, panels braced, and housing support structures strengthened. The shear pins on the blow-out panels in the pump room were modified to withstand 16 in. of water pressure. Improved bracing and latching were installed on test-cell building doors. The Dewar 1 and 2 flare-stack was guyed to prevent swaying. All tubing which had been attached to light metal-panels was removed and rerouted so their attachment was made only to support members.

A separate study was conducted on the cart to ensure that critical channels were not in danger as a result of vibration induced by rocket noise. The resonant frequencies of the privy panels and instrumentation ladders were determined and analyzed. A number of modifications resulted, and these now have been implemented on the cart as well as on components in the shield annular-space.

Module 7 (7.3.1)

d. Test Operations

(1) Local Tests

A series of "local tests" were performed to insure the readiness of those subsystems which were not tested during the pre-reactor experimental plans.

(2) Experimental Plans

Experimental Plan I of the Phoebus-2A test series was conducted 22-23 May. Experimental Plan II was conducted 29 May. Experimental Plan III was conducted on 8 June. The full-power run, Experimental Plan IV, was conducted on 26 June. Although full-design conditions were not reached, many experiments were completed at higher power levels than ever achieved before, and the test series was considered a success.

5. MAD-Building Reactor Operations (7.3.1)

a. NRX-A6

Hardware examinations included both nuclear and non-nuclear components. The following were the major areas of interest:

Sectioning of the core-support-plate into specimen blanks for testing was completed.

Sectioning of the control-drum-housing was completed and samples shipped to WANL.

Leak-testing of the reflector instrumentation installations was completed

Wrapper examination was completed.

Module 7 (7.3.2)

Fuel air-flow impedance measurements were completed.

Examinations were completed of beryllium reflector, control drums, filler strips, seal segments, cluster hardware, support plugs, side-by-side actuator, nozzle, core wrapper, propellant-feed-line, and instrumentation.

b. PEWEE

The PEWEE test car was transferred from R-MAD to E-MAD for diasssembly. Preparation of the PEWEE test bed is continuing.

Planning is currently in process to establish the support equipment, procedures, and manpower requirements at E-MAD needed for disassembly and post-operative examination of the PEWEE test article.

6. MAD-Building Engine Operations (7.3.2)

a. HVAC/PA/CCTV

Operation of the HVAC console and surveillance of the system was provided.

Repair and checkout of the J-11 air compressor was completed. Reworking of the shielding door guides in the E-MAD hot bay (doors 122-1 and 122-2) was completed.

b. Wall-Mounted-Handling-System (WMHS)

Mechanical problems encountered with the WMHS have been resolved.

Module 7 (7.3.2)

c. Floor Mounted Handling System (FMHS)

The FMHS was load-tested and the data forwarded to NRO for possible modification to improve system reliability.

d. Emergency Power System

The emergency power-system is operational and has been turned over to Pan Am for periodic maintenance and checkout under NTO surveillance.

e. XE-1

The UTSM pump discharge and cooldown lines were removed, cleaned, and reinstalled. External PVARA instrumentation installation and flame spraying was completed. Pressure testing of the turbine-exhaust-line closures was completed. On-Mark connector realignment was completed. LTS leak testing was completed.

f. XECF

After testing at ETS-1, the XECF was transferred to the E-MAD cold bay for external UTSM modification. After completion of the work, the test article was transferred to the hot bay for remote cycle demonstration. Additional vibration testing, however, may delay the availability of the XECF shield for XE-2. Work-around programs are currently being formulated to eliminate XE engine constraints at ETS-1.

Module 7 (7.4.0)

7. Engine Test Operations (7.4.0)

a. General

The XECF test program, including posttest operations, was conducted during April. Removal of XECF from ETS-1 was completed 30 April and the assembly returned to E-MAD.

Activation and test schedules for ETS-1 were revised to reflect: (1) cancellation of NEP-VI; (2) addition of facility modifications; and (3) rescheduling of activities to circumvent problem areas having an adverse impact on the initiation of FEP-V and the XE-1 test program.

Facility modifications and subsystem checkout tests were in progress in accordance with the ETO scheduled program plan, with emphasis on the cooldown system, test-stand control system, and the data-acquisition system in support of FEP-V.

b. Facility Checkout

(1) XECF Cold Flow Tests

EP-I was conducted 2 April and completed through Run No. 1. This was the first test of an engine system at ETS-1 to demonstrate that all facility systems and procedures were satisfactory for engine testing.

The EP demonstrated successfully the interaction of ETS-1 facility systems with an engine. Only one of the planned bootstraps was conducted. A malfunction of the pump-discharge shutoff valve limited the testing to dry-pump bootstraps. An adverse wind caused test-stand-wall

temperatures to be exceeded after one bootstrap operation. Anomalies encountered are described in Report RN-DR-701, XECF EP-I.

EP-II was initiated and conducted 11 April with two bootstrap runs successfully completed. The first was with a dry pump, the second with a chilled pump. The third run, liquid-hydrogen insertion tests, also was completed. However, the test objective was not met because it was not possible to step-increase the liquid-hydrogen flow rate. Although several minor facility discrepancies were encountered, the performance of the facility was considered to be satisfactory. Report RN-DR-702 describes EP-II test results.

(2) XECF Posttest Operations

The requirement for EP-III was cancelled 23 April. In the meantime, EP-II posttest operations were conducted in accordance with Procedure P-18 and completed 24 April. Remote removal of XECF with the EIV was initiated on 26 April. On 30 April, removal of the test articles was completed and XECF was returned to E-MAD.

(3) Data-System Accuracy Test

The LVDT/VR tests were completed and test data processed for evaluation.

c. Facility Modifications

The following facility modifications and activities were completed or are in progress in support of scheduled experimental plans.

Module 7 (7.4.0)

(1) FEP-V Modifications

Flushing of the TSA cooldown line was accomplished after XECF testing to verify cleanliness of the gimbal bellows. The duct-vault-door pipe-chase inflatable seal was installed to complete the duct vault and pipe chase GN_2 inerting system. Installation of the XE-1 cooldown simulator system and permanent cooldown piping is in progress, including installation of the hydraulic actuation-system, test-stand control system, console modifications, instrumentation, and signal-conditioning modifications.

(2) XE-1 Program Modifications

Modifications which were completed included:

(1) reinforcement of the test-stand heat shield to withstand anticipated wind and thermal loads; and (2) addition of outdoor facility lights to aid night operations.

The correction of engine test compartment (ETC) punch-list items was continued, including: (1) repair of an eutectic alloy leak; (2) cleaning of the seal blades; and (3) installation of lines for drainage of water from the pits housing the side-shield limit switches. Overhaul of the ETC side-shield-latch actuation cylinders, however, did not eliminate excessive GN_2 leakage. Further corrective actions were initiated.

Refurbishment of the steam-generator system is in progress, including removal of the existing steam line to the NES duct prior to installation of a new line and water separator to correct existing structural line deficiencies. Cleaning of the propane storage tank and supply line to the steam generator is in progress to remove contaminants which would clog filters and adversely affect operation of the steam generator.

Module 7 (7.4.0)

Radiographs taken of the vent-line bellows of LH_2 run tank V-5001 indicated the presence of contaminants. Provisions are being made to conduct blowdown tests for vent line flushing.

Other activities and modifications in progress include: (1) remote operation of the 42-inch diameter main water-supply valve; (2) inch-mode operation for ETC side shields and the S-3 shield as they approach their parking and test-position stops, respectively; (3) provision of an auxiliary steam-heating system as backup for melting eutectic alloy ETC trough-seals; (4) replacement of stainless-steel guides with bronze guides to prevent galling of the valve-stems located in Area 32; (5) installation of the hydraulic-pump assembly from Test Cell A to provide an adequate supply of actuation fluid to the test-stand valve; (6) design of a system for flushing NES duct cooling-water passages with demineralized water following test operations to prevent mineral-scale deposits; and (7) preparation of a design for reinforcement of the corrugated duct-vault wall which vibrated excessively during the experimental plans which used the NES duct for GH_2 cooldown modes-of-operation.

Installation of TSCS/ECS modifications resulting from changes in engine operational requirements are approximately 60% complete. Installation of TSCS/ECS modification kits in support of safety requirements associated with engine operations will be initiated following the completion of FEP-V.

Installation of the water-deluge system in the test stand and vault areas to provide cooling and decontamination water was resumed upon receipt of the 12- and 14-inch valves. Upon completion of FEP-V, work will resume on: (1) remote control of the LN_2 vaporizer; (2) ATD-console modifications for display of critical parameters during the XE test program; and (3) installation of actuator cryo-trap for removing condensible elements from the hydrogen gas supplied to engine system actuators.

Module 7 (7.4.0)

Data-link system software design was continued for XE-1 requirements. Modifications to the Redcor decoder units were completed. Modifications to the test diagnostic center are pending receipt of XE final requirements.

(2) Computer Programs and Data Handling

Work was continued on programming the CDC 3200 for real-time data processing for display both in the ETS-1 test diagnostic center and the A&E building. A revised program was utilized during XECF EP-I and EP-II. A loss of data on the digital-data system recordings at ETS-1 resulted in a limited capability to record redundantly at the A&E building. Programs for XE were being prepared by Computer Applications, Incorporated, following development of a schedule and PERT chart describing XE requirements.

Preparation of the new calibration program covering "average", "slope", "noise", "nonlinearity" and "drift" data was continued.

Data from XECF EP-I and EP-II were processed, including the preparation of plots and other special data presentations for SPEAR-team evaluation. Oscillograms and strip charts were microfilmed and the original records stored.

(3) Channel Engineering

The I&C audit of existing termination and cabling systems was completed. Updating of the I&C unit-list terminations to agree with the audit is in progress.

ETS-1 Operational Document Change Procedure, Report NTO-A-0030, and ETS-1 Transducer Inventory Update Procedure, Report NTO-I-0495, were issued. Preparation of ETS-1 T&C Unit List Update Procedure, Report NTO-I-0496, is in progress.

Module 7 (7.4.0)

Other functions which were performed included updating of the master-channel list, transducer inventory, spare-channel list, power-distribution listing, XECF Data-Log, and publication of the FEP-V patch list.

d. General

(1) Underground Event "Boxcar"

Prior to "Boxcar", which was conducted 26 April, precautionary safety measures were taken at ETS-1. Surveillance of the facility was provided during the event. Posttest inspection revealed no structural damage to the complex.

(2) Documentation

ETS-1 test operating procedures and posttest check-out procedures for XECF were issued. The FEP-V test description was revised to incorporate changes in the cooldown concept. Preparation of the FEP-V control-room operating procedure was in progress, as was the test description and test operating procedure for LN_2 cryo-shock testing of the cooldown system modification.

The XE-1 P-8 and P-9 procedures for installation and checkout, respectively, at ETS-1 were issued for review. Procedure XE-1 P-28, covering modification and checkout of the test stand adapter (TSA) preparatory to XE-1 testing, was submitted for review. This initial issue covers replacement of a leaking PSV and installation of the 100-mesh-screen filter in the TSA propellant supply line.

Module 7 (7.4.0)

Preparation of the XE-1 support operations requirements document and review of the recording display and control requirements are continuing.

ETS-1 component service history and preventive maintenance/inspection program, Procedure NTO-A-0036, was prepared and issued for review. Procedures for implementing the preventive maintenance program are being prepared for equipment and systems operated by ETO.

The ETS-1 facility operating procedures are being revised and then certified by dry-run checkout.

(3) Operations Analysis

Assistance was provided in preparing XECF SPEAR-team reports. The 36-day report for XECF EP-I and EP-II was issued.

Coordination was provided for the analog studies covering ETS-1 cooldown system modifications.

The temporary control requirements for the performance of FEP-V were defined.

(4) Program Control

Monitoring and updating of the ETO activity schedules in support of FEP-V and XE-1 test programs were performed continuously. Action items resulting from schedule analysis were defined to expedite the resolution of problem areas. Configuration control of the ETS-1 facility also was maintained.

Module 9 (1.3.5)

F. MODULE 9 - SUPPORT

1. Reactor Development (1.3.5)

Activities in this task included review of NERVA reactor development work for consistency with engine requirements and facilitation of WANL-NRO interchange of information necessary for the integration of reactor-engine hardware, test planning, testing, and data interpretation. The following activities were carried out:

Reviewed WANL configuration management plan, CEI and ECC specifications, and provided comments to WANL.

Provided technical review and evaluation of WANL proposals and program plans.

Analyzed performance potential of EPY 500 resin for a secondary stand-off element support system and recommended that WANL not use EPY 500.

Attended WANL shield study progress meetings and reported recommended actions to NRO systems division.

Reviewed proposed NERVA flight shield criteria and recommended changes required to meet engine design requirements.

Performed technical reviews of WANL facility procurement requests.

.2. Facility Engine-Control System Design (1.5.8)

Effort was continued to define the test stand control system (TSCS) modifications required at ETS-1 to support E-engine testing. Changes that will result in TSCS design modification are being defined. In addition, effort to identify equipment problem areas and operator inconveniences with the existing equipment for possible correction during the modification program was continued.

3. Instrumentation and EPIC Development (1.7.6)

a. Thrust Chamber Thermocouple

Design studies were started to determine the optimum location, diameter, and shape of the thrust chamber thermocouples for the proposed 75K engine, taking into account NRX experience and the recently perfected Elox machining techniques. At this time the best configuration appears to be an elliptical probe (0.160-in. by 0.320-in. with a 3-in. penetration length) located 9-in. up from the throat. An analysis of a probe extending 4-in. into the gas stream revealed a latent natural frequency of 228 Hz. The first bell-mode vibration frequency of the nozzle torus for NRX-A2, -A3, and -A5 was in the 240 Hz range; therefore, significant excitation could occur to overstress the 4-in.-long probe. Effects of tapering the probe are being investigated.

Module 9 (1.7.6)

Calibration curves were computed using the third-through seventh-order equations to fit the experimental data points. Of these equations, the sixth-order with a forced fit at the reference temperature produced the minimum deviation from the least squares fit of the data points at each calibration temperature. The seventh-order, which would be expected to be still better, had a tendency to oscillate up and down between the least squares fit rather than extrapolate smoothly between them. Calibration curves for the XE-1 thrust chamber thermocouples, originally computed to a fourth-order equation, were recomputed to this sixth-order equation.

The eight thrust chamber thermocouples built for XE-2 have successfully passed acceptance tests for speed of response, gas tightness, pressure, and electrical continuity. High and low temperature calibrations are now in progress.

b. Control Pressure Transducers

The rough draft of RN-S-0453, NRX-A6 Evaluation Test of Engine-Mounted Pressure Transducers, was completed. The AP150.6. portion was rewritten, since the actual heating-rate value as a function of power level during the test was unknown. Previously, a predicted heating value was used to provide a temperature-correction curve of the AP150.6. data but, all it did, essentially was to change the algebraic sign of the raw data maximum deviation, and it is guesswork to apply assumed heating values to see how close one can come to the actual reference measurement. The performance of AP150.6. during NRX-A6 demonstrated the ability of this type of transducer (Statham Model P-812, PN 50390-1) to survive and operate satisfactorily in the NERVA engine environment.

Module 9 (1.7.6)

The rough draft of the instrumentation portion of RN-S-0449, ASTR 23/R512A Pressure Transducer Test Report, has been completed. The four Statham Model P-812, PN 50390-1, pressure transducers were tested for nuclear rate effects in the ASTR Reactor, Fort Worth, Texas. These candidates for the NERVA control pressure transducer (serial numbers 47, 50, 61, and 63) all survived the test: SN 50 experienced a permanent zero shift. The maximum deviations during the test were as follows:

SN 47 $\begin{matrix} +9.0\% \\ -2.5\% \end{matrix}$ of full scale

SN 50 $\begin{matrix} +4.4\% \\ -12.8\% \end{matrix}$ of full scale

SN 61 $\begin{matrix} +1.3\% \\ -3.9\% \end{matrix}$ of full scale

SN 63 $\begin{matrix} +2.3\% \\ -3.9\% \end{matrix}$ of full scale

This test demonstrated the ability of the NERVA candidate control-pressure transducer, which utilizes the Statham vacuum-deposited thin-film strain-gage principle, to withstand severe nuclear fields. Applying temperature corrections will improve the data significantly. Development effort is being directed to the improvement of performance without having to correct the data for temperature.

c. Sheathed Cable-to-Transducer Attachment

(1) Sheathed-Cable Vaporizing

Experiments to strip sheathed cable by vaporizing the sheath were unsuccessful. The process tried made use of a low-voltage, high-current, dc power source in series with the cable to be stripped. One lead to the power source was attached to a metal vessel containing molten tin,

the other was attached to the cable sheath. The cable was then lowered to make contact with the molten tin, thereby striking an arc and causing the sheath to vaporize. The process removed the sheath; however, there were two undesirable results: (a) the sheath balled-up or grew in size, preventing further integration into other assemblies, and (b) the conductors became excessively oxidized by the heat, increasing the difficulty of brazing. No further experiments of this type were tried.

(2) XE Station 119 Terminal Strip Moisture Proofing

Problems were encountered during the attempt to provide a moisture-proofing material for the XE terminal strips. Although a suitable material and process were developed for the purpose (General Electric G6205 sprayable silicone insulating grease), the material was not acceptable because of the chlorine content in the solvent (methylene chloride). WANL reactor personnel were concerned about the possibility of the reactor purge loss during the moisture-proofing operation, which could result in contamination of the fuel elements by the chlorine. Therefore, attempts were made to provide an acceptable substitute solvent that would meet both the application and contamination criteria. In this instance additional problems resulted from changing solvents, i.e., solvents other than methylene chloride and Freon are flammable and have much slower evaporation rates. Using slower evaporation-rate solvents resulted in the following: the Glyptol seals on the terminated sheathed cables have a tendency to dissolve because of the prolonged presence of solvent; the application is not controllable; the grease/solvent combination has a tendency to run and pocket; too much time is required between applications to allow complete solvent evaporation, which prolongs the explosion and fire hazard; the solvents are toxic and attack the spray container seals. These problems were resolved by the use of duPont's Freon 113 (a fast-evaporating, noncombustible, nonchlorinated solvent).

Module 9 (1.7.6)

(3) XE-1 Flame Spray

Cabling on the XE-1 engine was flame sprayed through the period of 20 May through 29 May 1968. A total of 581 ft of cable was sprayed, which required 23.5 lb of aluminum. The total time required to complete the operation was 160 manhours. The elimination of the aluminum weld clamps and the addition of new masking techniques resulted in a more professional job than was achieved on NRX-A6.

(4) Sheathed-Cable Seal Assemblies

Seven AGC PN 1134533 sheathed-cable seal assemblies have been returned from Aeroquip Corp., Jackson, Michigan. The initial induction brazing tests performed there were only partially successful. Welding to the seal alloys was acceptable, but suitable welding could not be made to the 347 stainless steel sheath material. As a result, additional seals and sample lengths of 304 stainless steel had to be supplied, together with a Palladium-bearing silver-copper braze alloy. This combination of materials appears promising and is being further evaluated by Aeroquip Corp.

(5) NERVA Station-Zero Electrical Disconnects

Terminating to the station-zero disconnects both directly by sheathed cable and through the use of spliced sheath to flexible organic insulated cable is feasible at this time. Terminating with sheathed cable will necessitate the use of a modified AGC PN 1134533 seal assembly that is being developed for this purpose. Terminating with flexible cable will necessitate the use of organic insulating materials that are compatible with all ground tests and space environments. In the organic insulating materials investigation, it has been determined that cable and connectors insulated with Polyimide would be compatible with the known environments at or near station zero of the NERVA engine.

Module 9 (1.7.6)

d. Differential Pressure Transducers

Development work was limited during this report period because it was necessary to devote engineering time to the support of other sub-subtasks.

Re-evaluation of performance requirements and design constraints, based on the latest concepts of NERVA, were initiated.

A survey was started to determine if readily available transducers will satisfy the NERVA requirements.

The deposited-film strain-bridge sensing device has a significant development history in this program since it is used in the absolute pressure transducer currently being developed for NERVA. Therefore, several conceptual ideas for applying this device in a wet-wet differential pressure transducer were studied and discussed with the manufacturer.

e. Resistance Temperature Transducers

Six redesigned resistance temperature transducers (RTTs) were installed in various locations in the propellant feed system of the NRX-A6 engine for a nuclear evaluation test. These transducers were similar to Model 134EB used previously on all NRX tests, except that the electrical connector had been removed and replaced with integral cable.

Two evaluation transducers, AT100.6. and AT102.6., were located on the propellant feed line outside the engine shield. AT103.6. was located at the nozzle manifold inlet beside AT101.6., the standard model transducer; and AT120.6., AT121.6., and AT123.6. were located on the nozzle

Module 9 (1.7.6)

manifold. Channels AT103.6. and AT123.6. were ranged in the normal manner of 35 to 540°R. Channels AT100.6., AT102.6., AT120.6. and AT121.6. were ranged from 35° to 65°R for improved data resolution and system accuracy.

The two wide-ranged channels showed no anomalies throughout the test series and, because of the reduced resolution, changes in temperature caused by changes in the propellant system operating parameters and other causes were barely discernible through the system noise of $\pm 5^{\circ}\text{R}$.

The narrow-ranged channels provided data with a noise level less than $\pm 0.5^{\circ}\text{R}$ and with a resolution capability of discerning changes in temperature caused by propellant system changes during the ramps to power. Channels AT100.6. and AT102.6. indicated a steady-state propellant temperature of 47.5°R throughout the run. The neutron fluence at the transducer location was less than 1×10^{14} nvt, and no detectable radiation-induced error was predicted or observed.

Channels AT120.6. and AT121.6. indicated at 2°R temperature rise throughout the EP-IIIB run. The temperature rise exceeded the system uncertainty prediction of $+0.7^{\circ}\text{R}$ and is attributable to radiation-induced error and changes in the propellant system operating parameters. The neutron fluence at the RTT location was approximately 4×10^{16} nvt which, applying the GTR-18 irradiation test results, is sufficient to cause a 1.7°R error in a platinum RTT at liquid-hydrogen temperatures. No failures or other anomalies were noted.

The complete test results are reported in RN-S-0468, Posttest Analysis of NRX-A6 Evaluation RTTs, Rosemount Model 134JA-1.

Module 9 (1.9.2)

f. Development Reports

Instrumentation development progress reports were submitted to SNPO-C on a monthly basis.

g. Instrumentation Reports

Reports released and written during the report period are as follows:

<u>Report</u>	<u>Title</u>	<u>Status</u>
RN-S-0392	Qualification/Evaluation Test Results of Metal-Sheathed, Ceramic-Insulated, Radiation-Resistant Electrical Cables	Being held for additional information
RN-S-0449	ASTR 23/R512A Pressure Transducer Test Report	Rough draft in review
RN-S-0453	NRX-A6 Evaluation Test of Engine-Mounted Pressure Transducers	Revised rough draft in review
RN-S-0462	NRX-A6 Posttest Instrumentation Report	Being published
RN-S-0468	Posttest Analysis of NRX-A6 Evaluation RTTs, Rosemount Model No. 134JA-1	Published
RN-TM-0564	NRX-A6 Flame-Spray Evaluation Test	Published

4. Radiation Effects Integration, Analysis, and Documentation (1.9.2)

a. Coordination

In April, Aerojet and WANL representatives reviewed WANL plans for the GTR-20 tests. In June, a NERVA radiation-effects coordination meeting was attended by representatives from SNPO-C, WANL, GD/FW, and Aerojet.

Module 9 (1.9.2)

Agenda items included the GTR-19 test report, flux distribution, and new irradiation capabilities resulting from the recent ground test reactor modification, detailed planning for the GTR-20 test, and NRX-A6 posttesting.

An AGC-GD/FW task force meeting was held at Fort Worth to review GTR-19 strain-measurement methods and data. The results of the task-force study will be implemented by modifications of the test report.

b. Analyses and Support

(1) Analyses

In-house radiation-effects analyses were made for three applications: (a) an epoxy adhesive for support of R-1 fuel elements; (b) silicone as a moisture barrier for terminal strips in the XE-1 thrust structure; and (c) a rust-resistant lubricant for the NES duct slings.

A study was made in support of the proposed irradiated TPA bearing test at the Aerojet-Sacramento facility. The study showed that the activity of irradiated bearings would not significantly affect the Sacramento inventory of radioactive material and that dose rates were tolerable. Some minor handling problems, however, will require resolution.

(2) Data Treatment

Procedures for treatment of radiation-test data to be used for design and reliability assessments of NERVA materials and components were reviewed at meetings with NBS, WANL, SNPO-C, and GD/FW. Following is an outline of the procedures: (a) raw-data acquisition with application of process-control methods; (b) introduction of standard specimens into each

Module 9 (1.9.2)

testing system; (c) determination of probability distributions relative to mechanical-properties test parameters; and (d) statistical analyses and evaluation, as applicable, to environmental testing.

The trend-data computerized retrieval program was tested and found operable. Information about Inconel 718 and aluminum 6061, 7039, 7075, and 2219 has been entered on 1000 IBM cards. A tab print-out of this information is now available. Computerized regression and distribution analyses are programmed for both original and transformed data. These include probability limits for means, individuals, and populations.

c. Documentation

The following documents were issued.

<u>Report</u>	<u>Title</u>
-	NERVA Radiation Effects Program Plan for CY '68
RN-S-0401A	Statistical Correlation of GTR-19 Liquid Hydrogen and Liquid Nitrogen Irradiation Data for Structural Materials
RE-EDP 10	Experimental Design Plan for Bearing Cage Materials Test
RE-EDP-11	Experimental Design Plan for Bearing Cage Test
RE-EDP 12	Experimental Design Plan for High-Temperature Materials Test
RE-EDP 13	Experimental Design Plan for Engine Seals
-	Status Report, Bearing Cage Materials Test 37R107
-	Test Specifications for AGC Materials Test, GTR-20 (Preliminary)
-	Radiation Effects Program Plan for CY '68

5. Radiation-Effects Support for Reactor Development (1.9.3)

Effort under this sub-subtask is reported under Sub-Subtask 1.9.2.

6. Instrumentation, Components, and Subsystem Radiation Effects (1.9.4)

A review draft of an addendum to the final GD/FW report on the pressure transducer test 23R512A has been received and is being analyzed by Aerojet. This addendum corrects the heating rate data published in previous test reports. Additional refinement of the uncertainty analysis on nuclear heating is in process.

7. Materials Radiation Effects (1.9.8)

a. GTR-19 Materials Test

The preliminary GD/FW test report on GTR-19 was reviewed. Release of the report was recommended, subject to the accomplishment of various changes, including the addition of a section dealing with the accuracy of reported strain values.

b. GTR-21

(1) Thermal Conductivity and Electrical Resistivity
37R201

Review of test results is in process. Particular emphasis is being placed on an evaluation of the magnitude of system bias and imprecision. Table 27 provides a preliminary summary of results obtained from electrical resistivity measurements made during the thermal conductivity test.

TABLE 27
 PERCENT CHANGE FROM CONTROL VALUE
 CHART ELONGATIONS, GTR-21 HIGH TEMPERATURE TEST⁽¹⁾

Material and Boron Content	Strain Rate Min ⁻¹	Test Temp °F	Average Elong. Control %	Percent Change Due to Irradiation ⁽²⁾ Thermal Neutron Fluence, nvt < 0.48 ev		
				1 x 10 ¹⁶	5 x 10 ¹⁷	5 x 10 ¹⁸
Inconel 718, 37 ppm	.0013	1050	11.3	-15	-32	-38
	.0013	1125	5.6	-	-25	-
	.0013	1200	4.6	-35	-57	-72
Inconel 718, 0.6 ppm	.0013	1200	3.6	-	-28	-96
Inconel 718, 46 ppm	.0013	1200	9.4	-	-52	-70
Rene' 41, 50 ppm	.0013	1200	10.1	-42	-57	-65
	.0013	1400	6.0	-61	-83	-
Waspaloy	.0013	1100	29.2	-	-20	-
	.0013	1200	24.6	-23	-27	-45
	.0013	1400	19.5	-55	-65	-80
Inconel 718, 37 ppm	.13	1200	12.6	-	-36	-
Waspaloy	.13	1200	21.9	-	+1.3	-

(1) Data are preliminary.

(2) Percent change is $\frac{\text{irradiated value} - \text{control value} \times 100}{\text{control value}}$.

(2) High-Temperature Structural Materials Test 37R018

Tensile and stress rupture tests were completed. Results showed that candidate materials for high-temperature service in the NERVA engine were subject to significant decreases in high-temperature ductility as a result of exposure to radiation. Table 28 shows the effect of radiation and operating temperature on the ductility of the materials tested. The loss in ductility is strain-rate dependent as shown in Table 29. The stress-rupture properties of Inconel 718 were drastically affected by exposure to radiation, while the properties of Waspaloy were significantly less affected. Table 30 summarizes the results of the stress-rupture testing at 1200°F. Figure 49 shows typical behavior of Inconel 718 specimens during stress rupture testing.

(3) Bearing Cage Materials Test 37R107

A special posttest mapping run was performed in June to obtain a more accurate estimate of the gamma dose received by the bearing cage materials. Preliminary results show that the TPA bearing cages received a dose of 6×10^{10} ergs/gm(C), approximately six times that expected for the NERVA TPA in an unshielded configuration. One of the irradiated cages has been operated under NERVA design loads in a bearing tester for 3 hours with no detectable change in performance. Test 37R107 is scheduled for completion early in CY '69.

d. GTR-20

At the June Radiation Effects coordination meeting, tentative plans were made for two successive reactor runs: one for bearing cage materials and metals that require high thermal neutron exposures and the other for metals and shield materials that require high fast-neutron exposures.

TABLE 28
EFFECT OF STRAIN RATE
ON ELONGATION

Material and Radiation Environment	Percent Elongation	
	Strain Rate .0013 min ⁻¹	Strain Rate .13 min ⁻¹
Inc 718		
Control	4.6	12.6
5 x 10 ¹⁷ nvt < 0.48 ev	2.0	8.1
Waspaloy		
Control	24.6	21.9
5 x 10 ¹⁷ nvt < 0.48 ev	16.6	22.2
Rene' 41		
Control	10.1	--
5 x 10 ¹⁸ nvt < 0.48 ev	3.5	10.9

TABLE 29

PRELIMINARY 1200°F STRESS-RUPTURE TEST SUMMARY

MATERIAL	Thermal Neutron Fluence nvt < 0.48 ev							
	Control		1×10^{16}		5×10^{17}		5×10^{18}	
	Time to Rupture, hr	Chart Elongation, %	Time to Rupture, hr	Chart Elongation, %	Time to Rupture, hr	Chart Elongation, %	Time to Rupture, hr	Chart Elongation, %
Inconel 718, 37ppm Boron								
Ave value	69.0 ⁽¹⁾	6.9 ⁽¹⁾	56	3.9	36	1.3	11.0	0.3
Range	-	-	1.7	0.5	12	0.6	5.1	0.3
Waspaloy								
Ave value	≈ 100 hr ⁽²⁾	14.3	70	6.5	65	7.4	56	5.0
Range	-	3.1	13	0.3	25	1.0	25	1.7

NOTES:

Stress levels were 110 ksi for Inconel 718 and 105 ksi for Waspaloy, except as noted. Sample size is 3 except as noted.

(1) Sample size, 1.

(2) Final stress levels ranged from 105 ksi to 135 ksi.

TABLE 30

CHANGE IN ELECTRICAL RESISTIVITY AT -320°F VS NEUTRON FLUENCE (PRELIMINARY)

Material	Initial Resistivity (ρ_0) $\mu\Omega\text{-cm}$	Final Resistivity (ρ_0) $\mu\Omega\text{-cm}$	Resistivity Change ($\Delta\rho$) $\mu\Omega\text{-cm}$	Percent Change $\frac{\Delta\rho}{\rho_0} (100)$	Neutron Fluence (ϕ) $10^{17} \text{ nvt} > 1 \text{ Mev}$	Damage Rate, $\frac{\Delta\rho}{\phi} \text{ (avg)} \frac{\Omega\text{cm}}{\text{nvt}}$
Be (NBS)	1.067	1.844	0.777	72.8%	10.0	7.8×10^{-25}
Be (WANL)	0.678	1.580	0.902	133.0%	12.1	7.4×10^{-25}
Al-7039-T61	2.038	2.187	0.149	7.33%	5.0	3.0×10^{-25}
Graphite P-03	2324.0	3530.0	1206.0	51.9%	9.2	$13,100 \times 10^{-25}$
Ti-5Al 2.5 Sn ELI	138.56	139.50	0.94	0.68%	5.0	20×10^{-25}

Module 9 (1.9.8)

Figure 49 - Typical Results (Preliminary) Stress-Rupture Test - 1200°F,
Inconel 718, 37 ppm Boron

Module 9 (2.1.1)

8. Mechanical Ground Support Equipment (2.1.1)

a. General

The following activities were carried out during the quarter.

(1) Completed a list of AFSCM/AFLCM-310-1 data items recommended for the NERVA GSE Program.

(2) Initiated the preparation of GSE input for AFSCM/AFLCM-310 Data Item S-52-6.1.

(3) Performed a study and submitted comments on the effect of the topping-cycle engine vs the hot-bleed-cycle engine on NERVA GSE requirements.

(4) The preliminary NERVA engine and subassembly fabrication and shipping configuration and logistics document was reviewed and comments were submitted.

(5) Completed and submitted the GSE data pertinent to the NERVA engine transportability study.

b. NERVA Mechanical Equipment

A meeting was held with NERVA engine projects to discuss and interchange information on configuration, interface, handling requirements and shipping requirements relative to the R and E-1 nozzle/skirt assemblies.

Module 9 (2.2.1, 4.2.1, 4.5.0)

c. Other Tasks

Engineering was completed, including all support data, for the slings and sling attachments associated with the NES duct removal preparatory work. This work was integrated with the other facets of the task at NTO and presented to the customer at the critical design review.

9. Electrical GSE (2.2.1)

Investigation and coordination of R and E checkout requirements for incorporation in the checkout equipment CEI specifications were continued.

10. Material Inventory (4.2.1)

See Sub-Subtask 4.2.0 in Module 0.

11. Program Management (4.5.0)

The NERVA Management Plan (NMP), RN-S-0465, was mailed to SNPO-C on 22 April 1968 for review and approval. A presentation of the plan was subsequently made in Cleveland to SNPO-W and -C personnel.

The Aerojet configuration management plan was partially updated to reflect the NERVA management plan logic. After completion of this updating plus incorporation of additional requirements forthcoming from SNPO, the configuration management plan (CMP) will be submitted to SNPO by the end of July for review and approval. Detailed configuration-control procedures have been under preparation for the initiation of a NRO change board activity, the details of which will be incorporated in the CMP.

Module 9 (6.2.0)

Support was supplied in the preparation of detailed PERT networks relative to the logic delineated in the NMP.

Target specification trees were prepared for the engine, facilities, and AGE items.

Data items and other required documents that were referenced in the PRD, Appendix A, were reviewed for applicability to the NERVA Program. Review is continuing, since many of the referenced documents are not yet available at Aerojet for review.

Assistance was provided for the development of the management procurement logic diagram and for the preparation of the NASS specification for the NERVA Program in conformance to the AFSCM 375-1 format. Program management, as required, was provided for the ETS-1 modifications for the NERVA Engine.

12. Other Test Zones and Laboratories, Sacramento (6.2.0)

Bids for the installation of a LH_2 transfer piping system were opened on 9 April.

The request for quotes had given the bidders the alternative of bidding on the cost of a line made of all new materials or the cost of a line fabricated in part using material salvaged from the old line. However, the four bids received considered the use of all-new materials only, and even the lowest bid exceeded the estimated cost for the job by a significant margin. The scope was subsequently reduced in an attempt to make the cost more compatible with the budget. This was done by deleting two of the vacuum-jacketed

Module 9 (6.3.0)

pipng spools. The requirement for the deleted piping will be met by reinstalling the original pipe spools, which have not had a history of failure.

Although the bids for LH₂ transfer piping had been received in early April, award of the subcontract to accomplish the job did not occur until SNPO-C approval was received on 24 June. In the interim, a series of letters were exchanged between Aerojet and SNPO-C; initially to clarify a misunderstanding of the effort described in the bid package and, then, to reduce the scope of work to meet funding restrictions. Clarification resulted in award of the 75-day subcontract to PMI Corp. on 25 June.

In expectation of the start of contractor activity on the LH₂ transfer piping, the cryogenic laboratory LH₂ system was deactivated early in April and the valving was removed for inspection and service. Subsequently, the requirement for a demonstration and a proof test of the technology engine 8-in. PSV necessitated a test setup employing trailers as the source for LH₂. The system modifications necessary to accommodate the temporary LH₂ supply were accomplished and testing was started on 12 June. Three tests were conducted on PSV S/N 880102.

Testing activity in the cryogenics laboratory will be handicapped until the LH₂ transfer piping system is completed in early September. Materials wear testing is expected to start about 2 weeks after the completion of the line.

13. Test Zone H, Sacramento (6.3.0)

The XE-1 readiness review revealed an apparent need for redesign and additional testing of the technology engine TBV and TPCV. This unforeseen requirement caused reassessment of the plans associated with the full-flow and temperature-demonstration tests of the GH₂ heater in Test Zone H.

Module 9 (6.3.0)

To meet the earliest possible test date for TBV and TPCV testing, some of the modifications and the full-power tests proposed for the GH_2 heater have been deferred. The deferred heater modifications included the installation of movie cameras for recording the burner flame patterns and the installation of kits to provide a modified burner configuration.

During activation of the NERVA test facility in Test Zone H for TBV/TPCV testing on Test Stand H-4A, a GH_2 heater-temperature profile test of standing burners was conducted on 13 May, which was followed by a satisfactory heater proof test on 15 May. These tests demonstrated the readiness of the heater for the then forthcoming valve tests for which warm GH_2 was to be used as the testing media.

Following the receipt of TBV S/N 025 on 21 May, activation efforts continued until 28 May, when the first TBV bearing evaluation test was conducted. This test was terminated when the valve failed to cycle satisfactorily during the test.

A satisfactory test of the TBV was conducted on 5 June after return of the valve from the NRO components laboratory using ambient GH_2 as the test media. The substitution of ambient gas for warm gas was approved when an inoperative ultra-violet flame sensor for a heater burner prevented heater operation.

On the morning of this test, inspection of the GH_2 high-pressure gas storage area revealed a leak in the GH_2 high-pressure vessel, V-E4. Since all six of the A. O. Smith, laminated-wall GH_2 vessels are connected to a common manifold, the failed vessel was isolated from the other vessels by closing the manual ball valve on the forward end of the vessel. The GH_2 cascade was then available for the TBV bearing evaluation test that

occurred later in the day. After the test had been completed, the GH_2 cascade was vented to atmosphere and purged to allow the failed vessel to be removed from service.

On 10 June, a third TBV bearing evaluation test was conducted with the GH_2 heater supplying warm gas. Subsequent disassembly and inspection of the valve revealed a scored shaft retainer ring. The scoring was attributed to excessive axial shaft loads, which were present when opening the valve under pressure, when the valve is cycled during a Zone H test. To preclude excessive shaft loads during the opening cycle, another block valve has been installed upstream of the test valve to isolate the test item until it has reached the open position. At that time the second block valve will open to introduce GH_2 flow. During the closing sequence, gas trapped in the pipe spool between the test item and the other block valve will be vented through a small orifice.

While the H-4A test setup was being modified to accommodate an additional valve, another heater flow test was conducted on 13 June using the heater main burners to achieve a heater outlet temperature of 850°F . The firing rate for the heater was varied by regulating the burner propane supply with a flow control valve that had been installed as part of the heater activation effort. A posttest inspection of the heater firebox revealed no serious abnormalities.

Concurrent with the testing activities that followed the discovery of leakage from vessel V-E4, the leak was also investigated. Since this vessel was one of a type not having a manway, visual access to the vessel interior was initially limited to the use of a boroscope, which revealed little of interest. An attempt was also made to pressurize the space between the laminations that form the vessel wall with GN_2 at 10 psi. This was accomplished by plugging all but one of the weep holes in the forward course of the vessel's outer shell and using the remaining weep hole as the inlet

for the pressurization source, expecting the gas to migrate through the laminate and emerge inside the vessel through the failure. However, this attempt was also unsuccessful. Therefore, a jig for guiding a cutting torch was obtained, and a circular hole large enough for a manway was cut in the aft end of the vessel.

The vessel wall was again subjected to reverse pressurization using helium at 10 psi. This attempt was successful in that a leak was discovered in the 1-in. drain nozzle located at the bottom of the vessel in the first or forward course. Dye-penetrant and magnetic-particle checks disclosed the failure was caused by a crack in the nozzle. No further activity associated with V-E4 is expected until the total GH_2 vessel situation is investigated.

Installation of movie cameras in the roof of the GH_2 heater had been scheduled for the last two weeks in June and the first two weeks in July. This interval was expected to be available between the first set of TBV/TPCV tests and the second set of tests. However, program progress has negated this plan and the camera installation is now planned following the valve testing. Burner modifications if necessary will now be accomplished at that time. Full-flow and temperature demonstration testing of the heater will follow the camera installation and burner modification. This testing is now expected for the first quarter of CY '69.

14. NRO Laboratories, Sacramento (6.4.0)

Testing and system checkout in support of engine controls, instrumentation and the ETS-1 test stand control and test simulation systems (Subtasks 1.5 and 1.7.2) were continued during this report period. Activity is reported under those subtasks.

Module 9 (7.7.5)

15. Engineering Support for ETS-1 Nuclear Exhaust System (7.7.5)

a. Engineering Support for ETS-1 Nuclear Exhaust System (E-1)

Fabrication of the scale model E-1 primary nozzle (12:1 area ratio) with turbine exhaust and approximately 50% of the proposed testing have been completed. Testing, however, was interrupted due to indications of gas separation in the nozzle skirt. A new gas-side contour has been received and this configuration is in fabrication. An 8-week delay in testing is expected due to this problem.

b. Engineering Support for NASS (E-2 and Subsequent Engines)

(1) NASS

A conceptual layout of the full-scale NASS has been completed and is shown as Figure 50. Also completed was the NASS full-scale ejector. Predicted performance for a high- I_{sp} engine ramp is shown in Figure 51. This configuration requires approximately 1200 lb/sec of steam without the necessity of throttling. The detail values for the high-specific-impulse engine startup ramps have not been defined by the NERVA PRD. Therefore, NRO is continuing with the NASS program using the E-2 engine ramps as shown in Figure 52. The dates associated with each ramp indicate when these conditions were first assumed. The high- I_{sp} engine ramp reflects NRO's consensus consistent with the steam system economics and the engine performance requirements. Increasing the slope of the startup ramp requires a corresponding increase in the steam flow rate to maintain system performance. The requirement for 1000 lb/sec of steam to satisfy the high-specific impulse (I_{sp}) engine ramp requires that the steam be throttled at the higher engine chamber pressures to preclude flow interference and subsequent choking of the hydrogen and diffuser dropout. More recent investigations disclosed that with an inefficient

Figure 50 - ETS-1 (E-2) NASS Exhaust Duct Configuration

NOTES:

- (1) 0 PLENUM LOSS AT 0 P_c
 2 PSI PLENUM LOSS AT 450 P_c

(2) $\left(\frac{P_c}{P_2}\right) = 23$
 STARTING PRESSURE RATIO

- (3) HIGH I_{SP} START-UP RAMP

Figure 51 - Ejector Performance, Centerbody Ejector

Figure 52 - Estimated 75K Engine, Startup Ramps

Module 9 (7.7.5)

throttling process the single ejector could not provide the desired performance. However, a centerbody ejector nozzle together with an annular ejector nozzle, each properly sized, will meet the 1000 lb/sec steam requirement. This method requires that each ejector nozzle be individually controlled and programmed to maintain the proper system performance. A sketch of the multiejector configuration is provided as Figure 53, and the corresponding performance curve using 1000 lb/sec of steam for the high Isp ramp is shown as Figure 54. A predicted E-2 NASS performance curve is provided as Figure 55 and is the same for either ejector configuration.

(2) E-2 Scale-Model NASS

Design of all scale-model hardware associated with the full-scale duct configuration for the E-2 engine, (Figure 56) has been completed. Fabrication of the scaled nozzle and of the diffuser has also been completed. Fabrication of the remaining components is in process.

(3) High-Temperature Water-Penetration Tests

The first series of tests, consisting of two pressure tests conducted to obtain a Mach number profile at the exit of the J-4 diffuser, have been completed. In the first test, the Mach number distribution was found to be higher than desired. In the second test, by varying the secondary-ejector steam-flow rate, and thus back pressure on the diffuser, a steam-driving pressure necessary to establish the desired Mach number flow field was determined.

Fabrication of the temperature rake to be used in the remaining four tests has been completed. The high-temperature water-penetration pretest prediction document is being compiled and will be published

Figure 53 - NASS Multi-Ejector Concept

Figure 54 - Ejector Performance, Parallel Ejector

NOTES:

- (1) 0 PLENUM LOSS AT 0 P_c
 2 PSI PLENUM LOSS AT 450 P_c

(2) $\left(\frac{P_c}{P_2}\right) = 23$
 STARTING PRESSURE RATIO

- (3) HIGH I_{SP} START-UP RAMP

Figure 55 - E-2 NASS Performance

Figure 56 - Subscale Duct Hardware for E-2 and Subsequent NERVA
Ground-Test Engines

Module 9 (7.7.6)

prior to the initiation of the four remaining temperature tests. These are expected to be completed during the first part of August 1968.

(4) NASS Specification

The NERVA altitude simulation system (NASS), Specification SS-90204, covering the performance and design requirements for this system was revised to be compatible with the Air Force Systems Command Manual (AFSCM) 375-1) presentation format and reworked to incorporate review comments and additional required information.

Twenty-five copies of this preliminary NASS specification were transmitted to SNPO-C on 31 May 1968, in accordance with the deadline established during the 8th and 9th of May 1968 meetings held at Sacramento between SNPO-C representatives and NRO personnel.

This preliminary specification was given a detailed review during a series of meetings held in Cleveland on 11, 12 and 13 June 1968, attended by SNPO and NRO personnel. As a result of these meetings, some official guidelines and specific written comments were obtained from the various government personnel. The NASS Specification is in the process of being revised in accordance with these SNPO review comments and a corrected updated version is expected to be ready for final review on or about 17 July 1968.

16. Engineering Support for Existing NRDS Facilities (7.7.6)

a. Engine System Task Force Support

Support was provided to the Engine System Task Force Facilities and Operations Committee during the first two quarters of the

contract year to identify modifications of ETS-1 required to accommodate a variety of engine programs. This effort was concluded with the issue of the NERVA Engine Systems Task Force Facilities and Operations Committee Summary Report published on 15 April 1968.

b. 75K NERVA Conceptual Study

Following the review of preceding conceptual approaches, SNPO prepared and issued criteria for Conceptual Study ETS-1 Modification for 75K NERVA on 8 March 1968. Based on these criteria, a budgetary study of eight alternate combinations of ducts, steam generators, and exhaust scrubbers was conducted. The results of this study were reported in RN-DR-0150, ETS-1 Modifications for 75K NERVA Conceptual Study, dated 8 April 1968.

c. Duct Removal Modifications

Based on the concept presented in RN-DR-0150 a detailed design was initiated for Phase I of the duct removal modifications. These modifications consist of jacks, slings, and appropriate attachments to the duct and jack-mounting pads. This design package was submitted to SNPO on 14 June 1968 for the critical design review. Review comments are being incorporated into the design for final SNPO approval. Long lead-time components for this modification are being procured with the approval of SNPO.

d. LH₂ Topping

The design for an LH₂ topping system to provide for the transfer of propellant from the storage Dewar to the run tank during engine testing has been initiated based on the concept presented in RN-DR-0150. This effort is approximately 30% complete, and the 30% design review meeting is scheduled for the first week of July 1968.

Module 9 (7.7.8)

17. Engineering Support for NRDS Instrumentation System (7.7.8)

This sub-subtask was incorporated in Sub-Subtask 7.7.6 as of 29 January 1968. The work performed in this area has therefore been reported under Sub-Subtask 7.7.6.

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