NUCLEAR DIVISION

REPORT NO. RN-Q-0049

To AEC-NASA Space Nuclear Propulsion Office
QUARTERLY PROGRESS REPORT NO. 49

For Second Quarter, CY 1969
Covering the Period of
January, February, and March 1969

NERVA Program

Contract SNP-1

MAY 1969

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XE-Prime at ETS-1 EP-IIA Run

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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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I. INTRODUCTION

This document, which covers the progress of the NERVA Engine Development Program and its associated tasks, is submitted in partial fulfillment of Project 234 of Contract SNP-1. This report covers the second quarter of Contract Year 1969 (1 January through 31 March 1969). 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. OVERALL PROGRAM HIGHLIGHTS

Work continued in three broad areas: the technology program, the NERVA flight-engine program, and various support activities. The highlight of the period in the technology area was the successful performance of low-power mapping tests with the XE-Prime engine in ETS-1.

The XE-Prime testing program continued with the accomplishment of EP-IB, EP-II, and EP-IIA. The engine was checked out through drum and power calibration tests and successfully demonstrated three bootstraps, reaching a peak reactor power of 204 Mw.

The steam line modification was completed and the line was successfully tested. Numerous other facility and control modifications were performed.

Studies relating to future seismic events and means of facility and engine protection have been made. The XE-Prime report, RN-S-0493 Malfunction Analysis has been issued.

A group of proposed mission plans has been determined and work is proceeding in the analysis. Results have been tabulated for ready comparisons.

Reference engine and piping layouts, have been made available for review. This design includes dual TPA's, incorporates thrust nulling and contains a brim shield.

A task force was formed for the purpose of performing engine trade studies. A total of 43 studies is now in process.

Bearing cage wear tests were conducted during the period. An unirradiated PBI-graphite 50-mm roller bearing cage test was extended to 6 accumulated hours. Prototype TPA bearing cages irradiated in GTR-20A (General Dynamics, Fort Worth) were processed for testing at Sacramento.

Tests were conducted on the 30-in. vortex valve. Pressure recovery at full-flow conditions appears to be at least equal to the present mechanical TPCV in the XE-Prime.

Support was provided for twin-spool TPA tests conducted in January.

The Nuclear Altitude Simulation System (NASS) continued to show progress with the publication of numerous documents, continued design work, and scale-model testing. The NASS Management Plan was published, which defines organization and the responsibilities of the interface between the NASS and the facility. The 1/8 scale-model testing continued with a series of correlations successfully completed.

B. TECHNOLOGY PROGRAM

The XECF Final Test Report was completed and issued as document RN-S-0496, dated February 1969.

The XE Prime was reinstalled in ETS-1 in January. EP-IA was performed 20 February 1969 and consisted of drum and shield worth measurements, thermal power calibration, and irradiation determinations through dosimetry.

EP-IB was performed 27 February 1969 and consisted of the steam generator system checkout test and the engine interaction test. EP-II was initiated 13 March 1969 and was aborted due to adverse wind conditions. EP-IIA was performed 20 March 1969. There were three successful engine starts and bootstraps. The first two reached peak powers of 201 Mw and 204 Mw, respectively. The third successful bootstrap reached a peak power of 126 Mw. Run data were analyzed following each EP. The EP-III results indicated that each of the three bootstraps would have resulted in a successful run if continued to higher power.

Additional installments were published of the document, XE-P Test Predictions. Steady-state performance maps were constructed for various engine parameters vs chamber pressure with lines of constant chamber temperature. Predictions were made for the transfer function tests. Comparisons made with actual EP-II run conditions used in the computer codes gave results within the measured tolerances of the actual run.

The XE-Backup upper and lower modules were mated in March 1969. Modifications that have been incorporated in the prime engine have also been incorporated into the backup engine. All assembly and checkout work on the backup engine is expected to be complete next quarter.

An evaluation of all XE aluminum 7075 components was made to determine a probability of failure due to stress-corrosion cracking. Results indicate that the probability of failure of the six suspect components is minimal.

C. NERVA PROGRAM

A design review meeting early in this period resulted in a change to the reference engine design. The present reference design (layout #1135222, piping #1135223) includes a dual TPA concept with a brim shield, incorporating

a thrust-nulling concept. A prerelease layout is now available for in-house use. This concept provides the baseline configuration for studies and analyses.

Mission analysis effort continues as the systematic generation of requirements for NERVA engine design. Report RN-S-0506, NERVA Mission Data Book has been issued, which indicates the analysis effort to date. A general data section documents all of the assumptions that entered into the analyses. Six reference missions have been studied, five in detail. Results have been tabulated for ready comparison of trajectory, mass, and performance.

Engine and reactor systems analysis work continued. A reference design with component tolerances for a dual turbopump 75K thrust, brim shield system was established. The values of a nominal chamber temperature of 4613°R producing an Isp of 831 sec with a power level of 1660 Mw are included for the system. A baseline pneumatic gas subsystem was also established. Other trade studies have been conducted and computer models have been developed and improved.

A total of 43 new trade studies was initiated during the report period: 15 engine system studies, 10 nuclear subsystem studies, 1 pneumatic subsystem study and 17 I&C studies.

A considerable effort has been applied to engineering analyses of the engine concept, subsystems, and components. Studies and design work have been applied to TPCV actuation, hot-bleed port design, the nozzle design, poison wire withdrawal techniques and hardware, and shielding designs. Effort has been applied to the dual TPA design, and the full-flow design. Reliability analysis of representative hot-bleed and full flow engine turbopumps was completed in sufficient depth to define their relative failure potential.

Documentation for planning activities progressed during the quarter with the definition and publication of Functional Flow Diagram (FFD) and Requirements Allocation Sheets (RAS) for the NERVA development program.

RAS's have been completed through the third level of definition. Required Data Items (AFSCM 310-1) have been identified and responsibility established for their preparation.

An ROM budget plan was prepared and submitted to the customer. This presented a plan for the development of a nuclear engine through qualification testing.

Numerous meetings have been held to discuss and plan System Engineering activities relating to mission planning, documentation, and item definition.

The Aerojet Change Board began operations and changes to the SNPO-NPRD-1 and the engine specification have been processed by the Board.

Shielding studies conducted have established comparable data listings for the brim shield and the uncooled disk shield configurations and their influence on total system weight. Results have been documented in RN-PA-0016, Status of NERVA Shielding Requirements Trade Study. Studies have also been made to define an experimental program with associated facilities required to obtain radiation data for design of flight engine shielding.

Management documents and program plans in various areas have been devised and some were released. Work continued on the NERVA data and document management plan, as well as the configuration management plan. Two procedures related to configuration management were drafted and distributed for internal review. The NRO Product Assurance Program Plan for the NERVA engine system was revised to include the latest comments received from SNPO-C personnel. Work has continued on the Materials Property Data Book.

Planning and scheduling effort during the quarter included development work on PERT networks leading to Preliminary Design Review (PDR). PERT logic was developed for 11 major trade studies. The engine system network is

being revised to show the development process for FFD's and RAS's for the various missions.

D. SUPPORT PROGRAMS

Modifications of ETS-1 for the XE test program were identified and accomplished. This required support from NRO relative to design criteria, completion of design and procurement packages, and the installation and checkout of the modifications at NRDS.

Modifications of the ETS-1 facility included work to restore the facility after preparations for the seismic event, replacement of Area 32 stainless-steel valve guides with bronze guides, modifying the LH₂ run vessel vent system, and installation of fail-safe features for the V-5002 cooldown vessel pressurization system. Many changes were made in the control system, including work to improve the reliability and controllability of the turbine pump control valve. Improvements were made in the steam generator system and the instrumentation systems to upgrade their performance and to improve reliability.

The ETS-1 steam line was successfully tested during EP-IB. An early anomaly of line positioning after a test was investigated and the line was considered acceptable to support further testing.

Activation of the Sacramento Cryogenics Laboratory was completed and bearing-cage wear testing was initiated in January. Six NERVA bearing-cage wear tests have been conducted with satisfactory results.

Component vibration testing of a TBV and TPCV actuator continued.

Twin-spool TPA tests conducted in January were supported. The test vessel, V-H76 was modified for further tests and was proof-tested in February. Hubless-inducer TPA tests have been deferred until the next quarter.

Engineering for the ETS-1 NASS program continued. The preliminary design of the wet duct was initiated during this quarter together with the associated analyses and documentation. A study of the duct collar requirements was started, with emphasis on deleting the collar or using an uncooled collar. A materials survey was initiated to determine a suitable material for the fabrication of the plenum-ejector portions of the duct. Stainless steels were found to meet all of the criteria specified in the duct design requirements document.

Eight biweekly SNPO-NRO design review meetings were held during this quarter to review the status of the NASS duct design and supporting documentation.

Scale-model testing was continued with the NASS duct scale-model diffuser. Aero-thermodynamic evaluation testing was completed the week of 7 February. The scale-model system evaluation program was started to determine the overall system response and performance.

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III. TECHNICAL DISCUSSION

A. NUCLEAR ROCKET SYSTEM ANALYSIS AND INTEGRATION

Project 101 - Mission Studies and Analysis

Suffix f - NERVA

1. NERVA Data Items Vehicle and Trajectory Analysis

Detailed descriptions of reference missions and planned trajectories presented in the previous quarterly report remain essentially unchanged; the following information is supplementary. The purpose of the mission analysis effort remains the systematic generation of requirements for NERVA engine design.

a. Mission Analysis Presentation

SNPO and Aerojet considered the mission analysis effort to be at a stage of development that merited a full-scale presentation of the data. Accordingly, a first status report on NERVA Mission Studies was prepared and presented to SNPO by Aerojet in Germantown, Md., on 12 and 13 February. Several of the significant items from the presentation are included in the following material, together with additional information.

b. Mission Data Book

Much of the mission analysis effort to date is presented in Report RN-S-0506, NERVA Mission Data Book. A General Data section in this report documents all of the assumptions entering into the trajectory analysis for the various reference missions. Each of several additional sections present tabular data on trajectory, mass, and performance for one of the reference missions.

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c. Reference Mission Summary Performance

Reference missions are identified in Table 1, and key parameters are given in Table 2. Mission D data were not completed, although some preliminary work has been accomplished. This mission has now been eliminated. Satisfactory evaluations of payload and other parameters were obtained for both the Synchronous-Orbit One-Way-Trip Mission B and the Jupiter Probe Missions C-I and C-II. Unless there is major redefinition of these three missions, required effort consists of updating and refinements, mainly those pertaining to the launch vehicle, nuclear-stage tank and equipment design, radiation shielding, and flight-vehicle configuration. The results for either version of the Synchronous-Orbit-Ferry Mission A were less satisfactory relative to flight performance, because there was insufficient mass at the end of a cycle from low circular orbit to Earth-synchronous orbit and back again to provide for both a reasonably massive manned re-entry vehicle with adapter and deorbit propulsion system attached and the predicted inert mass for the nuclear stage itself. Possible remedies, full or part, include uprating of the F-1 engines of the S-IC booster stage, use of zero-stage solid-propellant strap-on engines for the S-IC booster stage, sub-orbital start of the nuclear stage, and release of the manned system prior to the fourth burn into circular rendezvous orbit. However, it appears that study of the Mission A operation will be helpful in establishing significant engine requirements, and work was continued to expand the ferry operation to include a re-ascent phase to synchronous orbit after the initial round trip.

d. Nuclear Stage Masses

The accuracy of mission payload predictions is highly dependent on the accuracy of predictions for the nuclear-stage masses. Table 3 indicates the level of detail in mass prediction included in computations to date. This level is believed to be adequate only for early effort, and not for updating as the project continues, so two supplementary analytical

TABLE 1
SELECTED REFERENCE MISSIONS

<u>Mission</u>	<u>Description</u>	<u>Payload</u>	<u>First Nuclear Burn</u>	<u>Nuclear Burns Per Engine</u>
A1	Synchronous- Orbit Ferry	Manned Integral	Orbital (185KM)	4
A11	Synchronous- Orbit Ferry	Manned Separate	Orbital (485KM)	4
B	Synchronous- Orbit One-Way Trip	Manned	Suborbital	4
C1	Jupiter Probe	Unmanned	Suborbital	2
C11	Jupiter Probe (Direct)	Unmanned	Suborbital	1
D	Mars Landing (4, 2, 1)	Manned Separate	Orbital (485KM)	1

TABLE 2

REFERENCE-MISSION SUMMARY PERFORMANCE

<u>Mission</u>	<u>Ascent Shell, lb</u>	<u>Nuclear Stage Length, ft</u>	<u>Total NERVA Steady- State Burn, min</u>	<u>Nuclear* Stage Mass, lb</u>	<u>Total Hydrogen Loaded, lb</u>	<u>RV Payload, lb</u>
A-1	26,500	106.23	29.13	69,430	187,130	$\frac{22,970^{**}}{0}$
A-11	26,300	105.68	28.49	69,300	185,400	$\frac{22,970^{**}}{0}$
B	29,800	119.71	37.42	68,060	230,500	$\frac{34,450}{66,200}$
C-1	33,000	132.30	45.84	61,450	271,000	$\frac{0}{67,600}$
C-11	33,500	134.35	47.69	62,000	277,580	$\frac{0}{60,380}$

*At end of terminal cooldown with instrumentation unit.

**Predetermined, not currently realized.

TABLE 3

NUCLEAR-STAGE MASS SUMMARY, MISSION B

	<u>Mass, lb</u>		<u>Mass, lb</u>
At Launch	<u>434,989</u>	At Synchronous Orbit	<u>185,315</u>
Launch Escape System	8,579	Residence Cooldown	985
Ascent Shell	29,843	RV	34,450
		RV Separation	500
First Burn		Payload	66,167
Chilldown	238	Payload Separation	500
Start	2,188		
Steady State	110,962	Fourth Burn	
Shutdown	1,001	Ullage Rockets	300
		Chilldown	238
Coast in Elliptical Orbit	4,475	Start	1,205
		Steady State	10,204
Second Burn		Shutdown	857
Ullage Rockets	300		
Chilldown	238	Terminal Cooldown	1,851
Start	1,205		
Steady State	38,095	At End of Terminal Cooldown	<u>68,058</u>
Shutdown	1,001		
		Residual Dry Stage	30,338
Coast in Transfer Orbit	3,920	Nerva Engine	16,000
		Internal Shielding	2,500
Third Burn		External Shielding	10,000
Ullage Rockets	300	Instrumentation Unit	4,700
Chilldown	238	Residuals	2,260
Start	1,205	Reserves	2,260
Steady State	44,885		
Shutdown	1,001		

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efforts were partially completed before the end of the report period. The results of these analyses will be incorporated in the General Data section of the Mission Data Book.

The objective of one of the two efforts is to identify and evaluate in detail the non-engine hardware masses of the stage. Two items are jettisoned before the steady-stage portion of the first nuclear-engine burn: the ascent shell and chillover propellant for suborbital start. Eight items remain after the last cooldown:

1. Tank and Baffles	5. Tank and Actuator Pressurization
2. Forward Skirt and Tank Support	6. Telemetry and Communications
3. Thrust Structure	7. Equipment Environmental Control
4. Purge, Fill, Drain, Supply,
and Vent	8. Electrical Equipment and Cables

Most of these items have already been represented indirectly in the trajectory analysis by the use of an LMSC-developed equation. While the equation may be adequate in most cases, greater knowledge of the elements is required to assure exploration of all nuclear-engine-related matters, as well as to compute a realistic payload. Sufficient LMSC and NAR data are available to support evaluation of the item masses; however, these data do not always permit direct reference, and the numbers sometimes vary by a factor of nearly two. Study of the indicated mass elements include preparation of required detailed equations for lengths, areas, and volumes of the tank with 75°-modified-conical bottom.

The second analysis, which is nearly complete, is the prediction of inert and propellant masses for a liquid-propellant chemical-rocket Reaction Control System (RCS), which is presently assumed to account for all secondary propulsion requirements of the nuclear stage. These requirements include vehicle stabilization after lower-stage separation (with

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assistance as available from the nuclear engine), propellant settling, nuclear-stage separation, and stage orientation during rendezvous and docking. Consideration of RCS requirements for changes in vehicle orientation during pulsed cooldown has been left to Trade Study No. 6 on post-burn operations, since this is a significant requirement and will be affected by any decisions relative to thrust nulling. To support Trade Study No. 6, in separate analyses, the computing program capability has been developed to show the effect on trajectory and vehicle mass of spatially controlled thrust during pulsed cooldown.

e. Vehicle Length

Although no length constraint has yet been applied to the computation of payload mass, it may be difficult to house the vehicle assemblies. Figure 1 shows the relationship of assembled vehicles for the various missions to the limitations on length in terms of handling within the vehicle assembly building at Complex 39 of the Kennedy Space Center. The Mission B vehicle exceeds the maximum allowable height; however, the launch escape system could probably be installed off the VAB roof, to permit all other assembly within the VAB. For the Jupiter Probe Mission C the vehicle height is close to the allowable maximum. Mission A vehicles present no height difficulties.

f. Mission Mode Comparisons

To obtain a necessary perspective, comparisons were made between different modes of achievement of common mission objectives. Table 4 shows one comparison, where the objective is the delivery of an unmanned payload to Earth-synchronous orbit, together with a manned reentry vehicle, which later returns to the Earth's surface. One column shows the Synchronous-Orbit One-Way Trip Mission B. Data in the last column are a composite of those for the reference Mission A-I Synchronous-Orbit Ferry

Figure 1 - Vehicle Configuration - MFSC 75° Tank Bottom

TABLE 4

SYNCHRONOUS-ORBIT MISSION COMPARISON

		<u>B</u>	<u>A-1</u>
<u>Reference Missions</u>			
<u>RV</u>	<u>1b</u>	<u>34,450</u>	<u>22,970**</u>
Payload	1b	66,220	0
Nuclear Stage Mass After Cooldown, 1b		68,060	69,430
Total Hydrogen Loaded, 1b		230,500	187,130
No. Starts/Burns/Shutdowns/Cooldowns		4	4
Steady-State Duration (min)	1st	20.34	12.50
	2nd	6.98	6.69
	3rd	8.23	5.06
	4th	<u>1.87</u>	<u>4.88</u>
		37.42	29.13
<u>Second Phase A-1 (2nd S-V Launch)</u>			
<u>RV</u>	<u>1b</u>	---	<u>34,450</u>
Payload	1b		50,500
Nuclear Stage Mass After Cooldown, 1b		0	65,200
Total Hydrogen Loaded, 1b		0	135,400
No. Starts/Burns/Shutdowns/Cooldowns		0	3
Steady-State Duration (min)	5th	0	12.90
	6th	0	7.00
	7th	<u>0</u>	<u>2.02</u>
			21.92
Unmanned Payload, 1b		66,200	50,500
Total Payload, 1b		100,650	107,920

**Predetermined, not currently realized

and of additional computations referring to the continuation of Mission A-I (after refueling) by flight to synchronous orbit and then, after payload separation, to nuclear stage disposal at Earth-escape velocity. Total payload is roughly the same for the two cases, and each case involves the expenditure of one nuclear engine and associated shielding, but the ferry mode requires two Saturn V launch vehicles compared with only one for the immediate-disposal mode. It is concluded that the ferry mode of synchronous-orbit-station supply is less feasible economically than the disposal mode and will remain so until reusable launch vehicles are available.

Table 5 shows a mode comparison for the unmanned Jupiter Probe Mission between the two-burn case C-I, and the single-burn direct-ascent case C-II. Since ascent paths are the same for C-I and C-II up to the point of first shutdown for C-I in safety-optimized elliptical parking orbit, there is no payload advantage in the single burn associated with the flight angles at which velocity increments are gained, as is sometimes the case with non-nuclear vehicles. The Mission C-II has an advantage in requiring only terminal engine cooldown. However, the listed payload for C-I does not reflect any geometrical constraint on the point in the elliptical coasting path at which the second burn can start; consequently, this point has been selected near perigee to achieve maximum payload. The associated greater efficiency in obtaining a predetermined hyperbolic excess velocity is the controlling factor. Also, Mission C-I is advantageous relative to minimizing limitations on launch opportunities, since even an elliptical parking orbit can be useful for phasing.

g. Payload Sensitivities to Engine and Stage Parameters

Significant mission analysis progress has been achieved relative to payload sensitivity to parameter changes. Table 6 shows, for one mission, the computer gradients of payload to four basic parameters, the steady-state specific impulse, the steady-state thrust, the system mass dropped before first burn, and the system mass remaining until after last

TABLE 5

JUPITER-PROBE MISSION COMPARISON

Δ <u>Interplanetary Injection</u>	<u>C - 1</u>	<u>C - 11</u>
° Parameter C_3 , km/sec ²	85	85
° Altitude, km	5,245	7,945
° Velocity ft/sec	40,660	38,910
° Flight angle, Theta s, deg	45.36	50.50
° Elapsed time from launch, min	202.50	56.50
° Coast before injection, min	150	0
Δ Payload, lb	67,600	60,380
Δ Nuclear stage mass, after cooldown, lb	61,450	62,000
Δ Total hydrogen loaded, lb	271,000	277,580
Δ No. starts/burns/shutdowns/ cooldowns	2	1
Δ Steady-state duration, min	20.44/25.40	47.69
Δ Launch window	Flexible	Critical
Δ Launch profile	Identical to SOPO	

TABLE 6

PAYLOAD SENSITIVITIES,
MISSION C-II, DIRECT JUPITER PROBE

	<u>Gradient</u>	<u>Units</u>
Specific impulse, 825 sec	+176.44	<u>lb payload</u> sec
Thrust, 75,000 lb	+ 0.416	<u>lb payload</u> lb
Ascent shell mass, 33,494 lb	- 0.2165	<u>lb payload</u> lb
Stage inert mass, 61,994 lb	- 1.00	<u>lb payload</u> lb

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cooldown. These gradients are valuable to engine designers in the evaluation of the relative merit of various subsystem designs. Additional data of this type are being obtained. For Mission C-II, with a single, suborbital startup, the influence on payload was calculated for a variety of pressure-temperature ramps. The difference in payload between the high-specific-impulse and the high-thrust starts was found to be 320 lb.

h. Improvements in Mission Analysis Program Capability

(1) Engine Cooldown

A method of adding engine cooldown pulses to Program TRAJ (now being used for trajectory calculations) has been devised. This will be used for the next computation cycle.

(2) Data Retrieval for Documentation Purposes

A data-retrieval routine has been added to program TRAJ to facilitate acquisition and reproduction of mission data for the Mission Data Book. In addition, the routine provides position data that were not available before.

(3) New Trajectory Program

An IBM IBSYS 7094 trajectory program, "A Trajectory Code for Maximizing the Payload of Multistage Launch Vehicles", was acquired from NASA-Lewis. The program has been converted to operate on IBM 360-65. The program uses a Newton-Raphson method combined with the calculus of variations to optimize stage propellant loadings and upper phase thrust attitude time histories for desired trajectory end conditions. In the present form of the program, the trajectories are limited to motion in two dimensions in the upper phases. Limited three-dimensional capability and logic for proper phasing for synchronous equatorial orbit closure are being incorporated into the program.

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(4) Propellant Tank Heating

To correctly represent the propellant tank weights in flight analysis the problems associated with long-term storage of cryogenic propellants in thermal environments and pressurized discharge of propellants from storage tanks are being studied. The Lockheed "Asymmetric Propellant Heating Computer Program" (LMSC-A 794909-A) is being modified to include solar, planetary, and nuclear radiation, as well as operation under zero-acceleration conditions.

With the modifications made to date in this program, it can be used during ascent, orbital coast, and first-burn phases of the NERVA engine. Since the program cannot handle zero acceleration conditions at this time, a limitation value of $\frac{a}{g} = 10^{-4}$ has been used during the orbital coast period. When fully modified, the program will predict the propellant tank gas pressurization and venting requirements, temperatures of the liquid, ullage, and tank wall, etc., during any phase of a given mission. Additional modifications to include pulse-cooling operation after engine shutdown are also being made.

(5) Flight Contingency Studies

Trajectory analyses in support of flight contingency studies have been started. A simulation of off-design thrust and I_{sp} operation, initiated at various points along the nominal trajectory for Mission B to the 118-N.M. orbit injection point, was started. This work is being continued and will be extended to points further along the trajectory, as well as to the other missions being considered.

B. ENGINE SYSTEM

Project 111 - Engine Systems Analysis

Suffix b - Technology

Technology system analysis efforts were primarily directed toward providing the supporting documentation and analysis required prior to XE testing and the data reduction and system analysis support following each engine and facility test.

Data reduction and analysis were provided for EP-1A, conducted on 20 February 1969; EP-1B, 27 February 1969; EP-II, 13 March 1969; and EP-IIA, 20 March 1969. In addition a formal data system checkout test was conducted to evaluate the XE-Prime data acquisition system.

1. XE-Prime Test Predictions and Post-Test Analysis

Additional installments of RN-S-0418, XE-P Test Predictions, were issued in support of Phase II and Phase III testing. Section 5 was issued presenting steady-state maps for the XE-P test article. The steady-state performance maps were based on computer runs made on the AGC NETAP engine transient analyses program and the WANL TNT program. The maps were constructed for various engine parameters vs chamber pressure with lines of constant chamber temperature. The instrumentation channel numbers used to monitor the various parameters are shown on the plots.

Section 10 was issued presenting the predicted performance for transfer-function tests. The XE common analog model (CAM) was used to provide predictions for the transfer-function tests. The frequency-response measurements were obtained by implementing the CAM model on the time and frequency (TAF) digital computer code. The code computes the desired steady-state conditions and solves sets of simultaneous first-order, nonlinear differential and algebraic equations. The measured drum and measured TPCV

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positions were perturbed and the open-loop frequency responses of twenty-two engine variables were measured.

Utilizing the CAM, NETAP and TNT computer models a parametric engine startup study was conducted to provide a more reliable procedure for the Phase II low-power flow tests. Based on the results of this study, the engine startup sequence was changed as indicated in AGC Modification No. 15 to RN-S-0400. A supplement to the test prediction report was then issued to provide the engine operating characteristics predicted for the three startup runs to be conducted during Phase II in accordance with AGC Modification No. 15.

In addition, alternative startup procedures for EP-II were analyzed on the CAM. The computer runs consisted of fixed drum starts based on various combinations of power levels, drum positions, run tank pressures, and chilldown times.

The Phase II low power flow tests were conducted during EP-IIA on 20 March 1969. During the three bootstrap tests there was some inconsistency in the times at which TPA shaft rotation and bootstrapping began. Based on the results of XECF EP-II and the test predictions, it was expected that the characteristics following the beginning of TPCV opening would be the same. The first test agreed fairly well with the predictions. In Run 2, however, there was a significant delay (16.5 seconds compared with 1 second in Run 1) between the beginning of TPCV opening and the start of TPA rotation. Run 3 also showed a significant delay (10.4 seconds), although not as long as in Run 2. In all cases, bootstrapping proceeded smoothly with no hesitation following the initiation of TPA rotation. Figure 2 in SPEAR Memo No. 3 of EP-IIA shows the variation in chamber temperature, chamber pressure, and drum position for the three XE-P EP-IIA runs and the pre-test prediction. In general the predictions lie within the spread of the measured data.

The NETAP digital program was rerun in an attempt to match startup results of EP-IIA Runs 1, 2 and 3. Previous predictions had not

Figure 2 - Comparison of Chamber Temperature and Pressure and Control Drum Position; EP-IIA

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allowed sufficient time for engine chilldown, which resulted in higher overall engine temperature conditions. Program reruns were made for each run with initial temperature conditions adjusted to actual test data. Turbine inlet and diluent line material temperatures were also lowered to match test data for Runs 2 and 3. The program reruns compared well with actual test data after necessary temperature adjustments were made.

An analysis of the EP-IIA test data was also made to determine if the various starts of EP-IIA would have been suitable for a direct start to intermediate power. The results indicated that all three runs would have been successful engine starts to intermediate power and that Run 3 showed the best approach to the operating line for a start-to-power. This analysis is documented in Memo No. 25 of the EP-IIA Spear report.

Test predictions were issued to support Run 1 of Phase III - Initial Startup to Intermediate Power which will be conducted during EP-III. These predictions are currently being revised in accordance with AGC Proposed Modification No. 18 to the XE test specification, RN-S-0400. This modification includes the following changes to EP-III.

- (a) The power schedule during engine startup was modified slightly based on EP-IIA post-test analysis.
- (b) The steady-state hold points were revised.
- (c) Shutdown was changed to checkout the emergency cooldown system.
- (d) Incorporation of Phase III Run 4 - Engine Restart.

In addition, analysis efforts were started for prediction of the engine autostart systems and for pulse cooling after intermediate and full-power tests.

2. XE CAM Model Development

Several modifications of the XE CAM model have been made to obtain better agreement with EP-II and previous test data.

The chamber-temperature profile during chilldown was adjusted to match a particular test profile by a modification of the inlet hydrogen enthalpy. In addition, a slight offset of the log to linear power conversion was necessary due to analog equipment limitations under the conditions of very low power during chilldown.

The chamber temperature profile during bootstrap was made to match test data by modifying the core heat transfer until bootstrap occurs.

A change in the nozzle coolant tube resistance under conditions of low density and a modification in turbine efficiency at very low pump speed enabled agreement of the bootstrap timing with test data. The efficiency modification is adjustable for matching different test data. This adjustment appears to be a function of chilldown time.

The chamber pressure profile during bootstrap was made to match test data by increasing the flow coefficient of the TPCV by 70%. This change will have to be reevaluated when test data at higher flows are obtained on EP-III and subsequent tests, since it is probably excessive for high-flow cases.

All of these modifications, with the exception of the TPCV coefficient change, are effective only during chilldown and the early part of bootstrap. After temperature loop closure, as well as during shutdowns and restarts, the normal CAM equations apply.

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As a result of these adjustments, good agreement with EP-II test data for bootstraps 1 and 3 was obtained. Agreement with bootstrap 2 was not as good.

A procedure was developed for obtaining engine restart conditions on the XE CAM. This procedure involves a TPCV closure and a switch to log power control to close the control drums. After the chamber temperature reaches the desired level, the restart is initiated by starting the desired period ramp in log power, and opening the TPCV to allow bootstrap at the desired power level.

Specific data channels required for XE transfer-function measurements in position control were defined. To aid in scaling the zero-suppressed channels, the maximum expected signal amplitude for each channel was specified. The maximum expected amplitudes were based on TAF frequency response data and the transfer function input amplitudes specified in Report RN-S-0400.

The digital program, COMFR, to be used in correlating CAM dynamics with XE transfer function test data, was revised to fit the SDA Sigma 5 computer. A test case was successfully run on the revised program.

3. Data Coordination and Analysis

A data system checkout test plan was established to evaluate the XE-Prime data acquisition system and related reduction procedures to insure that the data met XE-Prime requirements. The data system checkout test was made on 5 February 1969. Three data evaluation teams were established at WANL (Large, Pa.), AGC (Sacramento), and NRDS (Jackass Flats). All applicable data were assessed by each team and the anomalies detected were reported. Where possible, the anomalies were corrected and results were sent to NRDS.

4. Narrow-Band Data Analysis

The main and plot programs were used to support the XE-Prime calibration test run on 5 February 1969. The NTO test data tapes were run successfully on machines No. 1 and No. 2. The plots obtained from tapes run on both machines were identical.

A plot input tape was successfully generated. This tape includes all calculation name changes requested.

The main program was upgraded with additional XE-P calculations prior to the test run 20 February 1969.

XE-P-1A test was conducted on 20 February 1969 and data accumulated during the run was processed through the narrow-band data analysis program. Multiplots for sixteen time slices were requested. Twelve time slices were obtained; four were lost because the data did not exist on the NTO tape. Both the Computing Sciences and Test Area versions of the programs were used and plots were generated on the CRT and Cal Comp plotters.

The Computing Sciences and Test Area narrow-band data analysis programs were used to reduce data acquired during the XE-P 1-B test conducted 27 February 1969. Seventeen time slices of data were reduced and plotted via the CRT and Cal Comp plotters and returned to the site. One time slice could not be handled because of a coincidental time-data gap on the DN-3 tapes.

The narrow-band data analysis programs (both Computing Sciences and Test Area versions) were used to support the XE-EP-IIA test. Approximately 40 time slices of data were obtained and Cal Comp and CRT plots were generated.

The turbopump and best-estimate programs have been upgraded and are in the final phases of checkout. The program will be used to evaluate steady-state data obtained during EP-III.

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From an overall standpoint, significant improvement in the entire ETS-1 data acquisition and data processing system was demonstrated, compared with XE-Prime EP-1 data results. Only one major problem area, the unsatisfactory operation of charge amplifier channels, existed at the conclusion of the evaluation phase.

Following the data system checkout test, a calibration computer program was completed for evaluating transducers requiring charge amplifiers. The charge amplifier calibration is performed by introducing a 200 cps square wave at two different amplitudes. The method of analysis is to select 20 successive cycles and statistically evaluate each group of data. This procedure is repeated to result in four sets of data for each amplitude.

Other demonstrations of improved data handling were as follows:

- (a) The tape input system was completed and used in XEP EP-I for the first time.
- (b) The capability of plotting curves from the TDC tape has been demonstrated with XEP-EP-IA data for the first time.
- (c) The tape playback capability by ETS-1 was demonstrated for XEP-EP-IB for the first time.
- (d) The charge amplifier calibration is operational and was applied to the sound transducers AT 803 and AT 806 in the XE-Prime EP-1B test.

The charge amplifier calibration program now permits every wide-band channel to have an automatic computer calibration analysis as well as a Visirecord visual portrayal for each test of XE-Prime.

5. Wide-Band Data Analysis

Expanded plots of the displacements in the steam line elbow section during the XE-P SL-2 were obtained for further analysis.

To accomplish a smooth, rapid processing of the wide-band data (transfer functions, acoustics, accelerometers, etc.) at Aerojet-Sacramento for the XE-Prime test data analysis and SPEAR requirements, a format that specifies the type of plots and listings required from the wide-band data analysis and for SPEAR requirements was prepared.

Data from the EP-I frequency-response test were evaluated to determine if the narrow-band data can be used as backup for the zero-suppressed wide-band data in obtaining transfer functions. Results indicated that sine input from the narrow-band data can be used as backup for the wide-band data with reasonable confidence in obtaining transfer functions.

Wide-band data from XE-Prime EP-IA test were processed at Aerojet-Sacramento and sent to the SPEAR team at NRDS. Data included the frequency response tests for drum position control (sine input) and power control (step, pseudo-random, and sine inputs) and pre- and post-test calibration data analysis. Essential data were sent to the SPEAR team by R + 3 and the remainder was delivered by R + 5.

Wide-band data from XE-P EP-I-B on 27 February 1969 were processed at Aerojet and sent to the SPEAR team at NRDS by R + 4. Data included the frequency response tests for TPCV and drum perturbations (GH_2 to the actuators), TPCV torque motor current, and pre- and post-test calibration analysis. All channels that were used to obtain transfer functions were in good condition. EP-IA and IB wide-band data in book form were sent to SNPO-C and WANL.

XE-P EP-IIA wide-band data, which included acoustic vibration and strain data, were processed by Aerojet. Essentially all of the data were

sent to the SPEAR team at NRDS by R + 3. These data in book form were sent to SNPO and WANL.

Suffix f - NERVA

1. Reference Design Engine

Steady-state design point performance characteristics for the NERVA 75K reference engine system with dual turbopumps have been calculated. A steady-state parameter schedule is shown on Table 7. In accordance with the engine sensitivity and design tolerance requirements study, the design requirements for the components that comprise the reference engine have been computed to assure that NERVA engine performance will meet NPRD requirements. Component operating conditions and component design tolerances are presented in Table 8.

2. Effect of Diluent Injection Angle on Component Influence Coefficients

A study was made to determine if the diluent injection angle could be changed to lessen the component influence coefficients. Influence coefficients were calculated for the nozzle tubes, reflector, and core pressure drop relative to specific impulse and turbine inlet temperature for pre-design (turbine-inlet temperature = 1660°R) and engine-to-engine (turbine-inlet temperature floating) conditions. These coefficients were calculated for 0° diluent injection (present design) and 90°. A list of the influence coefficient obtained is shown in Table 9. Results indicate that the influence coefficients are not significantly affected by the diluent injection angle.

3. Preliminary Brim Shield Analysis

This study was made to determine the effect on operational conditions of adding a brim shield to a NERVA engine after design completion, and conversely, removing the brim shield from an engine that has the shield as an integral component. For this particular analysis, the location of the

TABLE 7

STEADY-STATE PARAMETER SCHEDULE,
REFERENCE ENGINE

(Per Layout Drawing 1135222)

Engine: $P_c = 450$ psia; $T_c = 4613$ °R; Thrust = 76,137 lb;

Impulse = 831.2 sec; Power Level = 1600 Mw

Turbopump:	<u>No. 1</u>		<u>No. 2</u>	
	<u>Pump</u>	<u>Turbine</u>	<u>Pump</u>	<u>Turbine</u>
Shaft Speed, rpm	26,916	26,916	26,916	26,916
Power, Mw	2.93	2.93	2.93	2.93
Efficiency, %	66.8	55.5	66.8	55.5
NPSP, psia	5.3	---	5.3	---
TPCV Gate Position, °	39.98		39.98	

<u>State Point Description</u>	<u>Flow, lb/sec</u>	<u>Pressure, psia</u>	<u>Temperature °R</u>
Propellant Tank	91.5	30	40
Pump No. 1:			
Inlet	45.75	29.5	39.3
Leakage to Turbine	0.3	989	54.5
Outlet	45.45	989	54.5
Pump No. 2:			
Inlet	45.75	29.5	39.3
Leakage to Turbine	0.3	989	54.5
Outlet	45.45	989	54.5
Brim Shield Inlet	90.9	959	54.5
Structural Inlet	5.1	954	54.7
Bypass Inlet	15.9	954	54.7
Brim Shield Outlet	69.9	949	60.7

Table 7 (cont.)

<u>State Point Description</u>	<u>Flow, lb/sec</u>	<u>Pressure, psia</u>	<u>Temperature °R</u>
Bolt Coolant PV Flange	3.0	944	60.7
Skirt Inlet	66.9	944	60.7
Nozzle Inlet	66.9	930	90
Nozzle Outlet	66.9	737	217
Reflector Inlet	67.1	737	212
Reflector Outlet	67.1	686	307
Struc. Support Outlet	5.1	686	1153
Bypass Outlet	15.9	686	54.7
Extension Shield Inlet	88.1	686	311
Dome Baffle Inlet	88.1	670	314
Central Shield Inlet	88.1	653	314
Support Plate Inlet	88.1	634	316
Core Inlet	88.1	621	320
Nozzle Chamber	86.9	450	4613
Diluent Bleed Inlet	2.82	706	212
Hot Bleed Inlet	1.23	450	4610
TPCV #1 Inlet	2.025		1660
TPCV #2 Inlet	2.025		1660
Turbine #1 Inlet	2.025	216	1660
#1 Outlet	2.325	30	1110.8
Turbine #2 Inlet	2.025	216	1660
#2 Outlet	2.325	30	110.8
Skirt Extension Inlet	4.65		110.8
Skirt Extension Outlet	4.65		1490

TABLE 8

COMPONENT OPERATING CONDITIONS AND DESIGN TOLERANCES, REFERENCE ENGINE

Component	Inlet Conditions			Design Requirements				
	Pressure, psia	Temp, °R	Flow, lb/sec	Pressure Drop, psia	Temp, °R	Flow, Efficiency, lb/sec %	$\Delta H/N^2$	
Pump Inlet Line (each unit)	30	40	45.75	0.5 ± 0.5	0 ± 0.1			
Pump (each unit)	29.5	39.3	45.75	$959.5 \pm$	9.05 ± 1	66.8 ± 5	4.35×10^{-5}	
Bearing Coolant (each unit)	989	54.5	0.3			0.3 ± 0.1	$\pm 0.016 \times 10^{-5}$	
Pump Discharge Line (each)	989	54.5	45.45	30 ± 2	0 ± 0.1			
Brim Shield	959	54.5	90.9	10 ± 2	6.2 ± 1			
Structural Support Assembly	954	54.7	21.0	268 ± 34.5	220 ± 66			
Line, Brim Shield to Skirt	949	60.7	69.9	5 ± 2	0 ± 0.1			
Skirt	944	60.7	66.9	14 ± 3	29.3 ± 6			
Nozzle	930	90	66.9	193 ± 14	127 ± 15	(Throat Area $97.398 \pm 1.43 \text{ in.}^2$)		
Bolt Coolant	944	60.7	3.0	207 ± 2.07	0 ± 0.1	3 ± 0.3		
Reflector	737	212	67.1	51 ± 4.5	95 ± 25.2			
Extension Shield	686	311	88.1	16 ± 1.6	3 ± 1			
Dome Baffle	670	314	88.1	17 ± 1.7	0 ± 0.1			
Central Shield	653	314	88.1	19 ± 2.1	2 ± 1			
Support Plate	634	316	88.1	13 ± 1.13	4 ± 1			
Core	621	320	88.1	171 ± 44.4	4293 ± 119			
Diluent Line to HBP Mixing Chamber	706	212	2.82	263 ± 26.3	0 ± 4	2.82 ± 0.13		
Turbine Inlet Line	450	1660		224 ± 2.2	0 ± 4			
Turbine (each unit)	216	1660	2.025			55.5 ± 6		
Turbine Exhaust Line (each)	30	111	2.325	2 ± 1				
Skirt Extension	28	111	4.65	22 ± 2	1379 ± 60			

TABLE 9
INFLUENCE COEFFICIENTS; 75K, SINGLE-TPA, NERVA ENGINE

<u>Description</u>	<u>Complex HBP</u>	
	<u>Injection Angle</u>	
	<u>0°</u>	<u>90°</u>
$\left(\frac{\partial I_{sp}}{\partial P_{nozz}} \right) T_{11} = 1660^{\circ}R$	-0.0141	-0.0151
$\left(\frac{\partial I_{sp}}{\partial P_{nozz}} \right) T_{11} = \text{floating}$	-0.0177	+0.00045
$\left(\frac{\partial T_{11}}{\partial P_{nozz}} \right) T_{11} = \text{floating}$	+1.2477	+1.2508
$\left(\frac{\partial I_{sp}}{\partial P_{refl}} \right) T_{11} = 1660^{\circ}R$	-0.0125	-0.0330
$\left(\frac{\partial I_{sp}}{\partial P_{refl}} \right) T_{11} = \text{floating}$	-0.0767	-0.0755
$\left(\frac{\partial T_{11}}{\partial P_{refl}} \right) T_{11} = \text{floating}$	-4.5850	-4.686
$\left(\frac{\partial I_{sp}}{\partial P_{core}} \right) T_{11} = 1660^{\circ}R$	-0.0121	-0.0134
$\left(\frac{\partial I_{sp}}{\partial P_{core}} \right) T_{11} = \text{floating}$	-0.0614	-0.0623
$\left(\frac{\partial T_{11}}{\partial P_{core}} \right) T_{11} = \text{floating}$	-2.738	-2.672

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brim shield was considered at two locations: at the pump exit and at the reflector exit.

The steady-state reference engine with no brim shield was calculated with the same engine data as used in calculating the operating conditions of an engine with a brim shield. The main operating difference between this design and the previous design is the slight increase in engine thrust and decrease in specific impulse. This was the result of an increase in turbine flow caused by the 21.5 psid increase in pressure drop through the system. This pressure drop increase was mainly due to the additional flow resistance of the brim shield and the increased pressure drop through the nozzle tubes that resulted from the increase in inlet temperature at that component.

The brim shield was added at the pump exit after the design of the engine was completed. Although there is an increase in pump-head rise resulting from the additional component, the system specific impulse increases 0.5 sec over the base case as a result of a substantial increase in turbine inlet temperature. This not only decreased the flow rate required for turbine operation, but also increased the skirt extension specific impulse contribution.

In contrast to the preceding run, another calculation was made to demonstrate the operational results for an engine designed to incorporate the brim shield but built without it. As expected, there was a decrease in turbine inlet temperature that ultimately resulted in a decrease in system specific impulse. A decrease of 300 lbf thrust also occurred.

Analysis of an engine system designed with the brim shield at the reflector exit showed the operational difference between this engine and one with the brim shield at the pump exit to be a 35-psid addition at the pump outlet. This pressure increase is due to the increased pressure drop through the brim shield located at the reflector exit because of the difference in fluid state conditions (lower density). This increase results in a 2.3% increase in turbine flow and an additional 30 lbf thrust.

By adding the brim shield to the reflector exit after engine design, the turbine inlet temperature was decreased. This resulted from the additional pressure at the reflector inlet and a greater diluent flow. As a consequence, the skirt extension contribution to overall specific impulse is greatly reduced. While the increased turbine flow serves to maintain an engine thrust level comparable with that of other designs, the overall system specific impulse was reduced 2.45 sec from the base case.

If the engine is designed with a brim shield at the reflector exit and this shield is removed later without modifying any other component in the system, the turbine inlet temperature increases to 1820°R, with a corresponding decrease in turbine flow rate, which in turn results in an increase in overall specific impulse to 829.26 sec.

In each case where the brim shield was either added to the engine, or removed from the engine after design completion, Table 10, a change in turbine inlet temperature was noted. There are two ways to control temperature in these cases. The first is to change the size of the diluent orifice so that the desired turbine inlet temperature is maintained with the component change. The other is to add a diluent control valve to the basic system design, which would serve as a temperature controller.

This analysis was made to show the magnitude and direction of changes of the fluid conditions in the individual components as affected by the addition of a brim shield. The brim shield used for the analysis was a preliminary design and further refinements to this component design would modify the results of the engine operation study.

4. Engine/Stage Pneumatic Gas Requirements - Trade Study No. 8

An Engine/Stage Pneumatic Gas Requirements Trade Study was started, the basic objective of which is to establish the design concept of the pneumatic subsystem (PSS). The function of the PSS has been defined as

TABLE 10
DESIGN OPERATIONAL EFFECTS OF BRIM SHIELD

	<u>Pump Discharge, psia</u>	<u>Specific Impulse, lbf</u>	<u>Thrust</u>	<u>Turbine Inlet Temp, °R</u>
Reference Engine	932.4	827.55	75,202	1660
Brim Shield at Pump Exit	953.9	827.23	75,211	1660
Brim Shield at Pump Exit After Design	957.8	828.09	75,206	1733
Engine designed with brim shield at pump exit shield removed	928.8	829.96	74,888	1598
39 Engine designed with brim shield at reflector exit	988.6	827.15	75,241	1660
Engine designed without brim shield and shield added at reflector exit	988.3	825.1	75,220	1502
Engine designed with brim shield at reflector exit and shield removed	931.1	829.26	75,163	1820

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follows: To provide pneumatic gas requirements during all phases of the NERVA Reference Missions (as defined by SNPO for engine requirements studies) to pressurize the main propellant tank, to operate engine valves including PSOV, TBV, TPCV, SSCV, TVS, NSS, and to satisfy any miscellaneous stage or leakage requirements.

Mission A-1 was determined to be the most demanding mission for PSS; therefore, the work was concentrated on this mission. A baseline system has been established that can be used to compare alternative systems. The criteria that will be used to judge the candidate systems will include vehicle payload weight, flight safety, reliability, and compatibility with the overall engine design.

The PSS gas is obtained from gas storage tanks during early startup, late shutdown, and engine cooldown. As soon as possible during the engine operation, gas is bled from the engine dome. There are two operating pressure requirements: main propellant tank (30 psia) and pneumatic actuators (220 psia). Because of these requirements, two different sets of storage tanks were established, one (LPPSS tanks) to blow down to 30 psia and the other (HPPSS tanks) to blow down to 250 psia.

The baseline system tank characteristics are as follows:

<u>Type</u>	<u>Total Volume (in.³)</u>	<u>Number of Tanks</u>	<u>Dia of Tank, in.</u>	<u>Design Pressure, psia</u>	<u>Material</u>
LPPSS	109,000	3	41	840	7039-T61 Aluminum Alloy
HPPSS	300,000	3	57.5	840	7039-T61 Aluminum Alloy

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The preliminary system weight summary is:

	<u>Weight, lb</u>
LPPSS Tank and Tank Structure	442
HPPSS Tank and Tank Structure	1220
Transfer Lines	19
Actuators, Regulators + Miscellaneous Valves	185
Total (Dry)	<u>1866</u>
Weight of Gas in LPPSS	48.0
Weight of Gas in HPPSS	17.4
Total (Including Gas)	<u>1931.4</u>

Alternatives to the baseline system are being studied. Flight safety requirements are being incorporated into the baseline system, since PSS is considered to be one of the most critical systems from a flight safety standpoint; therefore, a high degree of redundancy is desirable. To achieve this, one case is being studied that completely duplicates all components. Another case uses a third set of HPPSS tanks together with redundant lines, valves, etc.

Other alternative candidate systems are being studied that will reduce the weight. The pulse cooldown phase of operation is significant to PSS, and alternative cases to minimize the effect of cooldown operations on PSS will be investigated.

5. Pressure-Temperature Ramp and Throttleability Trade Studies

The purposes of the subject trade study have been defined as follows:

- a. To determine engine throttling requirements

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b. To determine criteria for high chamber temperature and low chamber pressure engine constraints

c. To determine criteria for startup and shutdown chamber temperature and pressure ramps

High-temperature - low-pressure engine limits that have been defined on the steady-state operating map are pump stall lines, single or dual TPA's, and the structural support unit (Figure 3).

The effect of throttling on overall mission average I_{sp} is being evaluated. At present, preliminary results are available for throttling up to 160 sec at full chamber temperature and chamber pressures of 350, 270, and 200 psia following a 20 minute run. Figure 4 shows the gain in performance over a base case that included no throttling.

At present a matrix of runs on the various identified NERVA missions is being compiled to analyze the effects of startup on mission performance. The analysis of Mission C-II is partially complete, and the results are shown on Figure 5.

6. Multi-Turbopump Study

The following multi-turbopump configurations have been considered:

- (a) Twin-Spool, Dual TPA
- (b) Single Spool, Three Parallel Pumps
- (c) Two Eight-Stage Parallel Pumps
- (d) Single Spool, Three Parallel Pumps with Backswept Impellers
- (e) Twin-Spool, Dual TPA with Backswept Impellers

Two methods of analyzing the NERVA engine system have been used with these TPA assemblies. The first was the existing D31201 Nuclear

Figure 3 - Preliminary Throttling Constraints

Figure 4 - Effect of Throttling on Engine Performance; Preliminary Results

- CASES
- ① 200 psia STARTUP
 - ② 270 psia STARTUP
 - ③ 350 psia STARTUP
 - ④ 450 psia STARTUP
 - ⑤ HIGH THRUST STARTUP

TEMPERATURE RAMPS: $150^{\circ}\text{R}/\text{sec}$
 ALL SHUTDOWNS: HI I_{SP} PER
 MISSION DATA BOOK

STARTUP	DURATION, sec	H ₂ EXP. IN STARTUP, lb	PAYLOAD AT INJECTION, lb	PAYLOAD, %	CHANGE IN PAYLOAD, lb
1	28	2188	60377	-0.84	-512
2	27	1153	60640	-0.53	-249
3	25	1431	60720	-0.28	-169
4	23	1565	60802	-0.14	- 87
5	23	1998	60889	0	0
NONE	0	0	61313	+0.69	+424

Figure 5 - Influence of Thrust Buildup on Payload, Mission C-II

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Engine Transient Analysis Program (NETAP) with the capability of handling a single TPA unit with either one or two spools. With this program, the input data were modified to account for the multi-TPA configurations under consideration. These results are acceptable for steady-state runs with all TPA units operating at design, but do not show the results of malfunctions or off-design operation of any one TPA.

The other method of analysis was to modify the existing program to handle multi-TPA operation. This modification was necessary to show engine operation with one TPA operating at off-design and to show the transient effects of this condition. The present major limitation of this method of analysis is that the program will handle a single-spool-design TPA. Further work is in progress to incorporate the twin-spool capability into the program.

Full-power steady-state points have been run for each of the TPA configurations. With the twin-spool, dual TPA with backswept impellers, additional computer runs have been made including 60% power, 30% power, startup transient, and shutdown transient. At the present time, calculations are underway to show operation with one TPA unit operating at the 3σ off-design condition and to show operation with one unit completely shut down.

Runs are being made with the twin-spool, dual TPA with backswept impellers to determine the maximum power that can be obtained with the present design operating with a single unit only, and to establish the flow design parameter necessary for full-power operation. Also, studies are continuing on the other four TPA configurations to demonstrate the complete engine operation with these designs.

7.. Availability Study - 75K NERVA Engine

The thermodynamic concept of the availability of a system pertains to the maximum amount of work that will have been done when the system undergoes a reversible process from an initial state to a state of

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equilibrium with the environment. The difference in availabilities between any two states of a system when referenced to a common equilibrium condition is defined as the reversible work of the process producing the change in state.

By considering the NERVA engine system to be a series of processes, a comparison was made between the reversible and the actual works produced across each of the major engine components. The thermodynamic efficiency of each component and the irreversibility of its process was established. The degree of influence of each component on the overall engine system performance was then determined in terms of an improvability factor, defined as:

$$\text{Improvability} = (100 - \% \text{ efficiency}) \frac{\text{Component Irreversibility}}{\text{Total System Irreversibility}} \quad 100$$

The availability study conducted for the 75K NERVA engine consisted of (1) establishing the relative influence of the various components on overall system performance, assuming nominal design operating conditions for each part; and (2) investigating the effects on engine system performance of changes in component performance.

The improvability values for the major engine components are shown in Figure 6, for nominal design operating conditions at full power. The improvability value of a component is an index of the effect that component has on the overall performance of the engine system; that is, a component with a large improvability factor decreases the overall efficiency of the system to a greater extent than a component with a smaller factor. A practical optimization program would require that the major technical effort be directed toward improving the design of components having large improvability numbers.

The effects of changes in a component's performance on system performance were determined in terms of specific impulse and thrust influence coefficients. The results of these sensitivity studies as they affect

Figure 6 - Engine Component Improvability Indices, 75K NERVA Engine with Gas-Cooled Skirt Extension

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component tolerances of the reference engine design are reported in the discussion of the Reference Design Engine at the beginning of this Project section.

8. Post-Shutdown Operations Trade Study

This study deals with cooldown and thrust nulling in the NERVA engine.

Technical work on Phase I of the study was completed. In Phase I, a broad range of concepts was examined, and their effect on mission performance was evaluated.

The selection of cooldown concepts was broadened to include those using tank pressure and those using pumps to drive the propellant. It was confirmed that vehicle attitude control during cooldown requires further study.

Twelve thrust-nulling concepts were evaluated, including those based on stem cooling in which the propellant is exhausted overboard to cancel thrust. These concepts included both tank pressure and pumps to drive the propellant. A stem-cooling approach was also studied in which a closed coolant loop transfers the afterheat to a radiator that radiates the heat into space. Additional concepts were examined in which the nozzle is modified to obtain a thrust reversal and cancellation effect.

The cooldown concepts selected for study in Phase II include both tank pressure and pump pressure techniques for driving propellant. Thrust-nulling schemes that use the same basic components are also included in Phase II. Use of a radiator will be an alternative thrust-nulling concept to be studied in Phase II. This approach is promising for long coast and cooldown periods.

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A report on Phase I is in preparation. Concurrently with this effort, the Phase II plan is being prepared to continue activity on the study.

9. Basic NERVA CAM Model Development

An evaluation was made of the adequacy of the existing representation of LH_2 properties over the complete operating range, using NETAP-generated data to define the variation of state points throughout the engine. It was found that the existing model represents a good compromise between accuracy and the limitation of NRO analog equipment in the map range. However, modifications were necessary for proper computation of the engine chilldown phase.

Checkout of the E-1 analog model was completed. Both static and dynamic checks were in good agreement with the corresponding TAF data.

Work was started on an initial version of E-1 CAM Revision 1, which would incorporate reactor revision plus several minor changes in the Aerojet equations. The TAF code developed for this model revealed, as subsequently confirmed by comparison with a similar TAF code at WANL, a 4 to 5 db peaking in all system parameters at a frequency of 0.016 rad/sec (6.5 minute period). It was determined that these low-frequency dynamics originate in the support system and are under further investigation.

10. Propellant Feed System Trade Studies

The initial PFS CAM study was made by adding a duplicate system in parallel with the existing TPCV and TPA. Although a successful design steady state was accomplished on TAF, the analog model was unstable in that only one pump (ganged TPCV control) could be operated at a time. This is consistent with the fact that the pumps are operating on the unstable portion

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(positive slope) of the pump-head-rise curve. The TAF model successfully determines a steady state with two pumps operating only because of the nature of its convergence routine.

Initial attempts to explore this instability on the analog by arbitrarily revising the pump characteristics were abandoned in favor of study of the first dual-spool TPA. The first TPA specifically designed for parallel usage to be modeled for this study was the dual-spool design utilizing separate high-speed and low-speed shafts. The main-stage pump was a single-stage, radial vane impeller, centrifugal type.

A TAF code was developed and used extensively to provide steady states and frequency responses for analog check purposes. It was also used to determine the effect of the slope of the head-rise curve on inherent open-loop stability. With both TPCV's in open loop (position control) operation, one TPCV was pulsed and then brought back to its original position. It was found that for positive slopes on the head rise vs Q/N characteristic, the pump flow rate on the pulsed side rises slightly and then goes to zero in 50 milliseconds. Low negative slopes gave oscillatory but stable response; greater negative slopes yielded overdamped behavior.

A second dual-spool feed system with a backswept impeller on the main-stage pump and a head rise slope that is negative throughout the operating range was the next TPA modeled. In addition to steady state and frequency response data, the TAF code for this design was used to obtain transient responses for various malfunctions.

The third system modeled incorporated three single-spool TPA's with backswept impellers. A TAF code for this system was debugged.

11. Sigma 5/CI5000 Hybrid Computer

The Sigma 5/CI5000 hybrid computer system has been delivered to Aerojet-Sacramento and is in the process of being set up and checked out. Digital programs run have included check programs for existing analog models and various FORTRAN and Symbol (assembly language) programs.

Digital programs have been written for checkout of XE-Prime, NERVA hot bleed, NERVA full-flow, and NERVA dual-TPA analog models on the IBM-1130 digital computer. In addition, the XE-Prime checkout program has been adapted for use on the SDS Sigma 5 computer; and the NERVA dual TPA program has been converted for use on the EAI 8400 computer in support of TPA trade studies.

A study has been started to design a hybrid TPA model for future CAM use. The NERVA CAM (N.E. REVO) single-spool TPA is being modeled first.

12. Computer Program Development

a. Nuclear Engine Transient Analysis Program

Development work has continued on the 31201 Nuclear Engine Transient Analysis program. This program calculates material and fluid temperatures and pressures throughout a modeled engine system, both as a function of time during transient operation and at steady-state operating points. A variety of modifications have been added to increase the utility of the program.

Significant engineering and programming effort was devoted to the development of new turbopump models and their incorporation into the program. A representation of a twin-spool turbopump had been developed previously but was not completely checked out. Several problem areas

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were discovered and corrected, and the routine has now performed satisfactorily after incorporation into the complete transient program.

A model was developed that can simulate operation of up to four turbopump assemblies operating in parallel. Satisfactory results have been obtained with this routine when the operating characteristics of the different turbopumps are similar, so that all of them are operating at nearly the same point. A more stable closure routine is being developed.

A preliminary analysis has been started to develop a model with multiple dual-spool turbopumps operating in parallel.

The full-flow engine cycle option of the program was checked out and several good runs were obtained using this program.

The program presently uses a routine to calculate hydrogen properties that was developed at LASL. A new routine was obtained from the National Bureau of Standards and has been incorporated into a version of the program and checked out.

The core size of the computer used with the 31201 program is such that program overlays are required. Studies are being conducted to minimize running time under different overlay configurations.

The neutronics equations used in the program were changed from an explicit to an implicit difference form to speed up the calculation procedure.

The controls equations have been modified so that the second-order terms in these differential equations are used for the pressure and temperature controllers. Previously only the first-order terms had been considered.

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The program output has been set up so that a plot tape can be produced that can be plotted using the data analysis plotting program together with test data to provide a graphical presentation of a comparison of predicted and actual data.

b. Simplified Steady-State Program

During this quarter the programming on a simplified engine balance steady-state program was completed and the program has been checked out. Each of the main engine components (nozzle, reflector core, etc.) is represented by an overall loss coefficient and an equivalent heat-generation rate. Desired chamber conditions are used for program input and the conditions throughout the rest of the system are calculated.

c. Flight Analysis Program

A number of modifications and improvements have been made in the flight analysis program. This program uses information about the reactor power during a mission and calculates the operating condition necessary to provide satisfactory cooldown to remove the nuclear after-heat from the engine.

A plotting option was added to the program to provide a graphical representation of any of the calculated variables. Several of the equations used in the program have undergone revision and improvement to increase the accuracy of the calculation procedure. The added feature to run stacked cases was added and a constant T_c cooldown option was built into the program. Preliminary study work was started on adding flight dynamic and trajectory equations to the program.

d. TAF Improvement

A number of changes were programmed in the TAF outer or executive code to improve the control and format of printed and plotted output and to simplify the input to reduce the chance of user and/or loader error. These changes have been checked out in a special deck but have not yet been put on production decks.

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Project 112 - Engine System Design and Integration

Suffix b - Technology

1. XE-Engine and Field Design Changes

The following significant changes have been made in the XE-engines:

a. Flexible Hose Replacement - The flexible hoses between the TBV and its pilot valves and the base supplying the TIL purge were replaced on XE-Prime with hoses that are more resistant to vibration. All flex hoses on the XE-Backup were changed to the new design due to accessibility of the engine and availability of the hoses. Ref: FCP's 704, 714, and 728.

b. Insulation samples were installed in the XE-Prime upper module to obtain radiation effects data for North American Rockwell. Ref: FCO 696.

2. XE-Engine Interface Control

The preamplifier for WANL neutron detector N845 on XE-Prime was replaced by installing a new pre-amp in the upper module. This required bypassing the 18 in. interface electrical connectors with the wiring. Ref: FCO's 720, 721, and 722.

3. XE-Engine Vibration Analysis Program

Vibration tests of XE components have been completed, except for the TPCV actuator. Qualification testing of the actuator should be completed next quarter.

Suffix f - NERVA

1. Engineering Data (Category A) for Design Evaluation

a. Reference Engine Design Effort

A design review meeting was conducted with SNPO-C, which included a review of the A Change 1134502 Flight Engine Layout Drawing. This reference engine concept included a single TPA hot-bleed cycle with a disc shield. One result of the design review was an agreement, documented in the minutes of the meeting, to change the reference engine design to a dual TPA configuration with a brim shield and to include a thrust-nulling concept. Work on the 1134502 layout and associated drawings for that configuration was terminated. These associated drawings included piping diagrams (1135152, 1134502, 1134505), flow schematics (1134503, 1134508) and instrumentation diagrams (1135201, 1135200). The work effort was redirected to a new reference layout, 1135222, and flight engine piping diagram, 1135223.

At the end of this report period, a pre-release copy of the reference engine layout was made available. It provides a baseline configuration for the system trade studies, system analyses, component conceptual design activities, and the maintainability and reliability efforts. The thrust structure from the gimbal point to the pressure vessel is currently a component conceptual design effort. Incorporation of the NSS and thrust structure concepts into the reference engine layout, release of the drawing for change control, and incorporation of a pneumatic subsystem concept are expected to be accomplished during the next quarter.

The dual TPA propellant feed system concept is shown schematically in Figure 7. The selected concept is the primary case being investigated in the Propellant Feed System Trade Study No. 012. Two separate

Figure 7 - NERVA Feed System Concept

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pump inlet systems from the tank are incorporated. The pump inlet line bellows in each system is located at the gimbal-plane centerline. The poppet-type PSOV's are shown on the engine layout mounted to the tank bottom. The engine-to-stage interface was relocated at the PSOV exit flange, 23-inches from the tank bottom. A 200-in. core centerline-to-tank bottom dimension is maintained on the engine layout as commensurate with the current criteria being used in the Shielding Trade Study, No. 003. With this criterion, the resulting engine length for the baseline configuration is 413.14 inches.

The valves for the initial PFS definition are essentially XE-type concepts. Although these are sufficient for describing an engine baseline configuration, the results of the system trade study (No. 13) on engine valves are required, as well as additional component design effort, before selecting design approaches for engine PDR.

The nozzle assembly, i.e., nozzle with bleed port, skirt and skirt extension, is that shown on the prior reference engine layout, except that a reverse bolt coolant concept is shown with the diluent extraction point at the bolt circle area. This is in accordance with the current Diluent and Bolt Coolant Flows Trade Study, No. 006. The 100% Rao contour nozzle assembly has an expansion ratio of 100:1. It has series flow pump discharge coolant for the nozzle and skirt with turbine exhaust gas coolant for the skirt extension. The design concept is from the component drawing 1136327 showing a throat ID of 11.136 inches and overall nozzle length of 208.84. The nozzle concept is based on Trade Study Report 7750:TR-0386; material selection on 7750:TR-0385; and coolant system on 7750:TR-0387. Additional design trade study work is in progress, particularly for the skirt extension design (Reference Trade-Study No. 014).

The pressure vessel is based on the component layout 1136330 and the brim shield concept is per drawing 1136176. Currently the pressure vessel OD is 54.10 in. and the brim shield OD is 80.36 in. The NSS design concept may cause minor variations in these diameters.

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A gimbaled engine concept is incorporated based on current component design efforts and on design studies reported in RN-TM-0356 and RN-TM-0436, conducted for the 250K engine design. The component design effort is continuing to further develop the TVC concept. This is closely related to the development of the thrust structure concept.

A thrust-nulling concept is shown on the preliminary reference engine layout on the basis of initial input from the systems trade study on Post-Shutdown Operations, No. 002. It is one of several approaches being considered. Further trade study work is required before a conceptual approach can be adequately defined. The system shown extracts coolant from the stage tank and introduces it through the stem coolant system, as well as through the nozzle and around the core periphery. The coolant is intercepted from flowing through the core by a valve in the pressure vessel dome that routes the coolant gas through radially-opposed exhaust lines forward of the dome.

The reference engine layout work effort will continue in the next report period to add the NSS, PSS and thrust structure concepts. Preliminary configurations of the wiring harness design will be incorporated. In addition, the system design will be upgraded in accordance with current trade studies and associated design study efforts.

A preliminary flight engine piping diagram, 1135223, was prepared for initial review. Work on the flight engine instrumentation drawing has been initiated. Associated drawings for the qualification engine configuration are following the lead of the reference engine and will be started during the next quarter.

2. Engineering Data (Category B) Interface Control

Consistent with the Reference Engine revision described in the preceding section, and the resulting preparation of new drawings, the

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preparation of interface control drawings 1134510, 1135153 and 1135182 was discontinued.

A new Data Item Form 9 sheet for Engineering Data (Category B) Interface Control, E-106 has been completed.

Preparation of Interface Control Drawing 1135243, 75K NERVA Nuclear and Non-Nuclear Subsystem ICD has been started.

The Engine Design Section was responsible for preparing the following NERVA Shielding Requirements Trade Study Engine Layout Drawings:

- 1135230 - 75K NERVA Flight Engine - Disc Shield, Concept A
- 1135231 - 75K NERVA Flight Engine - Disc Shield, Concept B
- 1135232 - 75K NERVA Flight Engine - Brim Shield, Concept A
- 1135233 - 75K NERVA Flight Engine - Brim Shield, Concept B

These drawings are included in Aerojet Report No RN-PA-0016, Status of NERVA Shielding Requirements Trade Study (Tasks 2 and 2A).

3. Data Item S-54, Design Trade Study Report

Work is being done on 11 trade studies to support a preliminary design review in August 1969.

4. Maintainability

Completion of the review and interpretation of the maintainability requirements in SNPO-NPRD-1 produced a definition of NERVA Maintainability Program Requirements and maintainability input to NERVA subsystem and component specifications.

Initial predictions of prelaunch failure rates of those components for which launch pad replacement capability is specified were made to

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enable initial allocation of quantitative maintainability mean-time-to-repair requirements for components. These predictions are presented in Table 11. The failure rate predictions will be revised as necessary after improved definition of component design details, failure mode and effects analysis, and prelaunch checkout and countdown procedures and requirements are available.

An initial prediction of the minimum launch window for the alternate missions selected for NERVA was made on the basis of data contained in Lockheed Missiles and Space Company Report LMSC-A830248. The prediction indicates that there is a 9-minute launch window; however, alternate launches are possible for four successive days at intervals of 24 to 27 hours. Obviously, any launch pad problems requiring NERVA engine maintenance would preclude launching during the first launch window, since a 15-minute period is required to transport maintenance men and equipment from the VAB to the launch pad. For this reason, allocation of component mean-time-to-repair requirements is being evaluated on the basis of meeting the second launch opportunity, 24 hours after the initial schedule.

Maintainability assistance has been provided in the FFD and RAS activities.

Engineering Change Proposals have been initiated for revision of the maintainability requirements in SNPO-NPRD-1 and Data Item C-002-CP90194-F1. An ECP is also being prepared for revision of Data Item R-102-SS-090205-F1, NERVA Maintainability Program Plan.

5. Full-Flow Engine Study

Studies to evaluate the feasibility of the full-flow NERVA engine culminated in an Aerojet presentation to SNPO on February 12, 1969, at Germantown, Maryland.

TABLE 11
 PHASE-3, NERVA-COMPONENT, PRELAUNCH FAILURE RATES

<u>Component</u>	<u>Failure Mode</u>	<u>Failure Rate, per 10⁶ hr</u>	<u>Failure Mode</u>	<u>Failure Rate, per 10⁶ Cycles</u>
PSOV	Leakage	25	Fail to cycle	144
DSOV	Leakage	2	Fail to cycle	144
TPCV	--	--	Fail to regulate	169
TBV	--	--	Fail to open	144
SSCV	---	--	Fail to regulate	144
EPIC	--	--	Fail to control	286
TVA	--	--	Fail to actuate	79
CDA	--	--	Fail to actuate	79
PSS Valves (Shutoff)	Leakage	14	Fail to open	65
PSS Pressure Regulators	--	--	Fail to regulate	219
PSS Relief Valves	Leakage	40	--	--
Check Valves	Leakage	14	Fail to close	5

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Engine assembly design studies were made of the full-flow engine and the hot-bleed engine to determine optimum configurations. Maintainability, reliability, development problems, weight, and envelope were included. For this presentation each engine with dual turbopumps, thrust nulling, brim shielding, and the 100:1 area ratio nozzle extension was studied. Layouts of the two engines indicated that the full-flow engine is advantageous relative to assembly packaging, performance, and reliability. The full-flow engine appeared to be about 800-lb lighter, fewer lines were adjacent to the reactor with less secondary radiation, lower operating temperatures permitted light alloy fluid lines and valve components, and the simplicity of the engine provided a significant increase in reliability.

Project 113 - Engine-System Test Engineering and Support
Suffix b - Technology

1. XECF

The XECF Final Test Report, RN-S-0496, dated February 1969, has been published.

2. XE

Support was provided for the three tests of the XE-Prime assembly during this quarter. Participation on the Test Review Board (TRB) has continued. SPEAR Team activity has been supported as required.

Numerous modifications of the XE Test Specification, RN-S-0400, as well as to the XE-1 (Backup) Test Specification, RN-S-0352, were processed. The review draft of the Phase III (post-test) sections of the XE Test Specification was prepared, and is ready for distribution for review.

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3. Documents

Aerojet review of various NTO documents was coordinated, and the comments were transmitted to NTO. The bulk of these documents were test operating procedures for XE-Prime tests at ETS-1. NTO Standard Operating Procedures and E-MAD "P" procedures were also processed.

4. Measurement Requirements List

The latest issue of 28 February 1969 XE-Prime MRL was transmitted during this quarter. MCR's XEP-A-009 through A-015, XEP-N-019 through N-027 and XEP-W-001 through W-005 were processed and approved for the above listing.

The XE-Backup listing has had no MCR's completed this quarter. Therefore, the listing XE-Backup dated 10 December 1968 is still in force.

5. Wire Termination Schedules

Termination Schedule Change Request (TSCR) No. A-032, 034, and 035 for XE-Backup, and TSCR-A-033 for XE-Prime were processed and approved this quarter. These changes were against Revision E of the Termination Schedule, Specification AGC 90166, dated October 1968 for XE-Prime and XE-Backup.

6. P&I Diagrams

There have been no revisions this quarter to the XE-Prime Piping and Instrumentation (P&I) Diagram, AGC Drawing 1135718, or to the XE-Backup P&I Diagram, AGC Drawing 1136085.

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Suffix f - NERVA

Engineering effort was continued in preparation of the Functional Flow Diagrams (FFD's) for the ground test engine program in support of the T-101 test plan. Preliminary data item descriptions (Form 9's) were prepared and published for the test plans T-101 and T-102.

Project 114 - Engine Integration Aids, Adapters, and Gauges

Suffix f - NERVA

Preliminary drawings were prepared for six basic structural TSA/EA concepts using current envelope conditions. These are currently undergoing stress review to determine the best approach for thrust-loading conditions in engine testing. The structural concept selected will form the basis for the planned TSA/EA layout design effort to be initiated in the next report period.

Project 115 - Engine Subsystem Testing and Evaluation

Suffix b - Technology

The vibration test program to test the flexible pneumatic supply line to the TBV was completed. The final test was to evaluate a 24-inch single ply versus a 28-inch double-ply flex line. Both lines were vibrated for 70 minutes in each of three axes (210 minutes total) at $1.0g^2$ /cps input. Both lines were tested in the radial axis during a 2-hour duration test. The 24-inch single-ply flex line failed during the last 30 minutes of this test.

The TBV supply lines and the TIL purge line were placed on XE-Prime with the improved line. All flex lines on the backup engine were replaced with the new design due to accessibility of the engine and availability of the lines.

Project 116

Project 116 - Engine System Engineering

Suffix f - NERVA

1. Trade Studies

The following new trade studies have been started. This project maintains cognizance of this activity, and the following is presented as a concise summary. Engineering on the studies is reported under the various projects responsible for the action item.

a. Engine System Studies

<u>Trade Study No.</u>	<u>Title</u>
001	Engine System Steady State Performance
002	Post-Shutdown Operations
003	Shielding
004	Engine Throttling
005	Start-up and Shut-Down Modes and Ramps
006	Diluent and Bolt Coolant Flows
007	Engine Systems Evaluation of Structural Support Coolant System
008	Engine Emergency Requirements
009	Engine Conditioning
010	Engine Weight
011	Engine Length
012	Propellant Feed System
013	Engine Valves
014	Skirt Extension
015	Engine System Evaluation for Alternate Source of Turbine Drive Gas

Project 116

b. NSS Studies

<u>Trade Study No.</u>	<u>Title</u>
701	Reactivity Control Concept
702	Nominal T_c for 4500°R Min
703	Reactor Cooldown Requirements
704	Thrust Nulling
705	NSS Shield
706	NSS Throttling
707	NSS Startup and Shutdown Study
708	Emergency Cooldown Requirements
709	Turbine Drive Gas from NSS
710	Allocation of Isp to NSS

c. Pneumatic Subsystem

<u>Trade Study No.</u>	<u>Title</u>
201	Pressurization and Actuator Gas Requirements

d. I&C Trade Study

<u>Trade Study No.</u>	<u>Title</u>
401	In-Flight Calibration
402	Startup Modes and Turbine Drive Control
403	Isp Tolerances
404	Temperature/Pressure Rates
405	Ground/Flight Crew Override
406	Power Requirements and Modes
407	Thrust Vector Requirements
408	Engine Preconditioning
409	Actuation Methods
410	Reactivity Control

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<u>Trade Study No.</u>	<u>Title</u>
411	Velocity Versus Thrust Setting
412	Reactivity Lock Versus Scram
413	I&C/Stage/Vehicle Interfaces
414	Cooldown Control
415	Rated Performance
416	Controllability
417	Pneumatic System(s)

2. Specifications

Efforts have been continued on the preparation of the sub-system and component specifications.

3. Planning Documents

Work was continued on the NERVA data and document management plan. The investigation of existing data management systems within the industry continued; documentation of operational data subsystems was initiated, and preliminary steps were taken to coordinate the efforts of all NRO activities engaged in data management.

4. Data Items

The initial issue of the Environmental Vibration and Acoustic Loading Report, Data Item S-38, has been prepared and is ready for internal distribution. The report provides the vibration and acoustic environment criteria for the C-2 specifications as well as supporting data for the Structural Analysis Report, Data Item S-36.

A preliminary document was prepared defining the natural terrestrial and spatial environments that are applicable to the design of the NERVA Engine and associated equipment. The preliminary document was submitted

Project 116

to SNPO-C for use in preparing the NERVA External Loads and Natural Environment, SNPO-C-6.

Data items required for Preliminary Design Review were identified in a series of meetings of SNPO-C, WANL, and Aerojet.

The engine system thermal and fluid flow analyses specified in Data Item S-31 were initiated. The objective is to determine the thermal environment throughout the system during all phases of operation.

5. Engine System Engineering

A Requirements Allocation Sheet (RAS) Column "C" check list was formulated to aid in establishing requirements to be covered in individual RAS's. Reviews and discussions were held with WANL and SNPO-C personnel to coordinate this check list.

A method is being sought for compiling and translating requirements outlined in the RAS's into the appropriate specifications.

Block 1.0 Systems Engineering Functional Flow Diagrams and Requirement Allocation Sheets were reviewed, revised, and expanded to the third level during a series of meetings with SNPO-C.

Analysis of engine component provisioning requirements under Blocks 5.0 and 6.0 of Requirement Allocation Sheets (RAS) was started.

A series of meetings were held to discuss System Engineering activities, interfaces, and control. Numerous action items resulted that have been documented in minutes of the meetings and in various directives pertaining to the items. Most of these have been completed and the remainder are being completed. A Systems Engineering Implementation Plan was prepared and submitted for review and discussion at the meetings.

Projects 117, 118

Project 117 - Nuclear Subsystem Test and Interface Control
Suffix f - NERVA

The first working Flight, Qualification, and Reactor Test Interface Coordination Meetings was held 28 January 1969 at WANL in Pittsburgh. Drawings required for preliminary interface control layout were requested from WANL. Coordination between NRO design departments and WANL has been continued. Preliminary copies of the NERVA Reference Nuclear Subsystem Drawing 939J685 were distributed on 13 March 1969 to all affected departments.

Coordination meetings for interface control activities related to interfaces between WANL and Aerojet hardware, which are identical on R-Test articles and NERVA Engine hardware, were conducted as reported under Suffix f of Project 112.

Project 118 - System Shielding Analysis
Suffix f - NERVA

The results of the NERVA Shielding Requirements Trade Study for Task 2 and Task 2A were presented to representatives of SNPO-C and SNPO-Washington at Washington, D.C., on 13 February.

A comparison was presented of a brim shield and uncooled disk shield configurations and their influence on total system weight with 60° and 75° propellant tanks (Figure 8). The study was based on the unmanned model shown in Figure 9, with the brim shield added as in Figure 10 and the disk shield in Figure 11. Details of the two disk shields considered are shown in Figure 12 for the 37-inch R model and in Figure 13 for the 50-inch R model. The reference model disk shield is shown in Figure 14.

The effects of separation distance between the core midplane and the tank bottom as well as total shield weights were studied. To provide a comparable basis, the initial comparisons were made of crew dose assuming no

Figure 8 - Comparison of Tank Shapes and Tangent Angles

Figure 9 - 75K NERVA Flight Engine - 1135234 (Unmanned Concept)

○ EXTERNAL BRIM SHIELD DIA	100"
○ DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER	200"

○ DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER 200"

Figure 10 - 75K NERVA Flight Engine - 1135232 (Brim Shield Concept, Straight Routed Lines)

○ EXTERNAL DISK SHIELD DIA	100"
○ MAXIMUM EXTERNAL DISK SHIELD THICKNESS	10"
○ DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER	200"

Figure 11 - 75K NERVA Flight Engine - 1135230 (Disk Shield Concept, Straight Routed Lines)

Figure 12 - Brim Shield Concept - 1136176

Figure 13 - Brim Shield Concept - 1135249

Figure 14 - Disk Shield - P/N 1136182

Project 118

attenuation in the payload (attenuation factor = 1.0), 3300-lb internal shield and 7500 lb of residual LH_2 at the end of the reactor firing. The crew doses for the ferry mission for the 60° tank with a 200-inch separation distance are shown in Figure 15 for a brim shield and in Figure 16 for the uncooled disk shield.

The crew doses for the same mission and propellant tank are given in Figure 17 for the brim shield and Figure 18 for the uncooled disk both for a 250-inch separation distance.

The crew doses for the same mission and propellant tank are given in Figure 19 for the brim shield and Figure 20 for the disk shield both for the 365-inch separation distance.

These curves show essentially equivalent weight vs dose rates for the disk and the brim shield, which is also shown in the summary envelope curves in Figure 21. Figure 22 illustrates how a maximum dose rate of 10 Rem at the crew quarters might be attained for payloads with effective attenuation factors ranging from 1.0 to 100 by combining brim or disk engine shielding with a 10-ft-diameter steel disk shield at the capsule. The use of crew capsule shielding to arrive at an optimum shielding weight is scheduled as part of the shielding trade study and only preliminary results were given in this presentation.

Preliminary results of the effects of the brim shield on system performance are presented in Tables 12, 13, and 14, where the influence on specific impulse can vary from +0.30 sec to -0.15 sec depending on whether the amount of helium required for preconditioning the brim shield is shown to be about 3000 lb.

The disk shield temperatures after 45 minutes of full power are given in Figure 23 for twice nominal heating rates and no heat transfer between

Figure 15 - Crew Dose vs Δ System Weight - Internal and Brim Shield - 200 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

Figure 16 - Crew Dose vs Δ System Weight - Uncooled Disk Shield - 200 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7700-lb Residual LH_2 at End of Firing)

Figure 17 - Crew Dose vs Δ System Weight - Internal and Brim Shield - 250 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

Figure 18 - Crew Dose vs Δ System Weight - Uncooled Disk Shield - 250 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

Figure 19 - Crew Dose vs Δ System Weight - Internal and Brim Shield - 356 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

Figure 20 - Crew Dose vs Δ System Weight - Uncooled Disk Shield - 200 in. S.D., 60° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

2

Figure 21 - Summary Envelope Curves - Brim and Disk Shields 60° Conical Tank.
Dose is Based on Drainage to 7500-lb of LH_2 Dose Point for Subsystem
Orbit Ferry Mission-Payload Attenuation Factor = 1.0

Figure 22 - System Weight Increment for 10 REM with Varying Payload Attenuation for Brim Shield and Uncooled Disk Shields

TABLE 12
EFFECTS OF BRIM SHIELD ON ENGINE SYSTEM

1. The brim shield will only be used on certain engines and will result in performance variations.
2. Evaluation of brim shield coolant extraction made at pump discharge and dome.
3. Dynamic effect has not been evaluated yet, including effect of brim shield mass on startup and having a variable volume and mass internal to engine.

TABLE 13
EFFECTS OF BRIM SHIELD ON ENGINE PERFORMANCE
(2.4 mw Heating Rate in Brim Shield)

PUMP DISCHARGE

Effect on specific impulse is +0.30 seconds (equivalent to decreasing chamber inlet temperature 3°R) and increasing turbine inlet temperature 56.2°R .

DOME

Effect on specific impulse is -0.15 seconds (equivalent to increasing chamber inlet temperature 1.5°R) and decreasing turbine inlet temperature 7.5°R .

TABLE 14
EFFECTS OF BRIM SHIELD ON PRECONDITIONING

WEIGHT

Stainless Steel	1101 lbm
Aluminum	302
Lithium Hydride	507
Lead	4099
Boral	<u>500</u>
Total	6509 lbm

HEAT-TO-BE-REMOVED DURING PRECONDITIONING CYCLE

316K Btu's

HYDROGEN REQUIRED

600 lbm

TIME (30 psi TANK PRESSURE)

5 minutes

RESULT OF PRECONDITIONING CYCLE (PRELIMINARY)

Adds ground chilldown system for brim shield

Helium requirements have been estimated to be 3000 lbm

Restart chill through engine

Figure 23 - Case 4 External Disk Shield - Lunar Mission Direct Landing (Heating Rate 180 Btu/sec. Schedule 2 Contact Conductances - Reference RN-PA-0015)

the shield material layers, and Figure 24 shows the temperatures for the nominal heating rates.

Based on the results to date of this shielding study, as well as on previous analyses, the Aerojet recommendation is as follows: To proceed with engine design based on single PVARA for all missions with internal shielding to meet unmanned requirements (Grand-Tour mission) and allow for incorporation of mission-dependent variable add-on uncooled disk shields as required for each manned mission.

The immediate result of the presentation was a directive for Aerojet to study a number of items. One item requested, the completion of the 75° tank studies, was accomplished. The results for a 75° tank with a 200-inch separation distance are given in Figure 25 for the brim shield, and in Figure 26 for the disk shield, with the envelope curves presented in Figure 27. As expected, the results are essentially the same as for the 60° tank; that is, the brim and disk shields produce comparable results relative to weight.

In response to the directive, Aerojet revised the Shielding Trade Study and initiated work consistent with the revised schedule.

A general geometry option is being added to DASH to allow radiation to be projected to a general surface as, for example, upward to a propellant tank bottom or radially outward to a cylindrical surface concentric about the DOT cylindrical model.

NOTES:

- a. DISK SHIELD IS 81 in. ABOVE CORE CENTER LINE
- b. ENGINE INCORPORATES A 3300-lb INTERNAL SHIELD
- c. INITIAL TEMPERATURE IS 70°F
- d. RUN DURATION IS 45 min

Figure 24 - Case 4 External Disk Shield - Lunar Mission-Direct Landing (Heating Rate 90 Btu/sec - Schedule 2 Contact Conductances - Reference RN-PA-0015)

Figure 25 - Crew Dose vs Δ System Weight - Internal and Brim Shield - 200 in. S.D., 75° Tank Ferry Mission Configuration, Payload Attenuation Factor = 1.0 (3300-lb Internal Shield, 7500-lb Residual LH_2 at End of Firing)

Figure 26 - Crew Dose vs Δ System Weight - Uncooled Disk Shield - 200 in. S.D., 75°
 Tank Ferry Mission Configuration, Payload Attenuation Factor =
 1.0 (3300-lb Internal Shield - 7500-lb Residual LH₂ at End of Firing)

Figure 27 - Envelope Curves - Brim and Disk Shields - 75° Tank with 200" S.D.,
Payload Attenuation Factor = 1.0 (7500-lb Residual LH₂ at End of Firing)

Project 121

Project 121 - Turbopump Assembly
Suffix f - NERVA

1. Design

a. Program Planning

An ROM Turbopump Development Plan through qualification was prepared and integrated with higher-level (propellant feed system and engine) plans.

b. Engine-Cycle Trade-Studies Support

The reliability of representative hot-bleed and full-flow engine turbopumps was analyzed in sufficient depth to define their relative failure potentials. Results are given in the failure-mode-analysis charts in Figures 28 and 29. These charts were prepared at the part level for the turbopump; there are 18 major parts in the hot-bleed turbopump and 15 in the full-flow turbopump. In the actual failure-mode analysis, breakdown was first made to the part level, then to the failure-mode level, and then to the failure-mechanism level. The failure-mode analysis was performed at this last level (the mechanism of failure for all possible modes of failure for all major components of the turbopump).

The charts have been simplified back to the part level for ease of presenting the results of the analysis. The hot-bleed turbopump is shown in Figure 28 in terms of failures per million vs the parts in the machine, starting at the forward end of the turbopump. Figure 29 gives similar information for the full-flow engine.

Figure 28 - Index of Criticality, Hot-Bleed Turbopump

Figure 29 - Index of Criticality, Full-Flow Turbopump

Project 121

The impeller in the full-flow turbopump is probably slightly less reliable than the equivalent part for the hot-bleed turbopump because, to retain a similar configuration, the impeller diameter must be greater for the increased pressure-rise requirement. The blade loading is also slightly higher, but the effect is offset by increasing the blade thickness slightly. The overall result is that failure rate for the full-flow impeller increases by about three parts per million to a rate of about 31 parts per million.

Because the two turbopumps have identical impeller attachment systems and the loads are quite similar, retainer reliability is unchanged.

For the thrust balancer, the required loads are slightly higher with the full-flow turbopump, but the source pressure providing the energy for the thrust balancer is higher by the ratio of the pump pressure rises; so reliability is about equal.

Pump-housing reliability is the same for the two engines. The pressure level required for the full-flow turbopump is slightly higher than for the hot-bleed turbopump, but minor changes in housing wall thickness reduce the stress level to about the same as that for the hot-bleed turbopump. Actually, as a result of maintaining standard stock material thicknesses, the stress is lower in the full-flow turbopump than in the hot-bleed turbopump.

The central housings in the turbopump (bearing support housings) and the turbine support housings are identical in configuration and similarly loaded; so reliability is unchanged.

The first-stage-turbine stator in the hot-bleed engine is subjected to an 1100°R temperature change, from ambient to about 1660°R (or gas temperature), requiring radial freedom for thermal expansion and

contraction of the nozzle in order to prevent excessive thermal stresses. In the full-flow engine, the stator is subjected to a temperature change of only about 200°R , from ambient down to about 300°R . It is thus possible to incorporate the stator in the turbine inlet manifold on the full-flow engine, thereby eliminating the part for the full-flow machine and causing some increase in failure rate for the turbine inlet manifold.

The large thermal transient to which the second-stage stator is exposed in the hot-bleed engine causes rather high thermal stresses and consequent high failure potential. In the full-flow engine, the thermal stresses are minimized because the thermal gradient is again about 200°R , and a rather significant reduction in failure rate results.

Stator No. 3 is eliminated from the full-flow engine because it is possible to design a two-stage turbine capable of meeting the bypass requirements (energy-availability requirements) as a result of the low-temperature gas and the low pressure ratio.

The first-stage-rotor failure rate is reduced in the full-flow engine for two reasons: (1) the absolute temperature level at which the rotor operates is considerably lower, 300 vs 1660°R , and (2) the radial thermal gradient in the rotor during steady-state operation is about 120°R per inch of radius for the full-flow engine, as compared with about 600°R per inch for the hot-bleed engine. The lower gradient results in a dramatic reduction in thermal stress for the part and a significant reduction in failure rate.

The second stage rotor shows a similar reduction in failure rate.

The third stage rotor, like the third stage nozzle, is nonexistent in the full-flow engine.

Project 121

Because the third turbine stage is eliminated in the full-flow engine and the lower operating temperature of the turbine rotors allows selection of one of the lighter alloys, a reduction of about 30 lb is possible in the weight of the turbine rotor assembly (in the comparison, titanium was used for turbine rotor material in the full-flow case, Inconel for the hot bleed). In addition, the amount by which the full-flow turbine rotor assembly overhangs the aft support bearing is reduced because of elimination of the third stage. The shaft-bending critical speed or first structural-mode critical speed is a function of the shaft diameter, rotor overhang, and the overhung mass. Since the mass and the amount by which it is overhung are both reduced, it is possible (with equal critical-speed margins for full-flow and hot-bleed engines) to select a smaller shaft for the full-flow engine than for the hot-bleed engine. This reduction is from about 90 mm down to about 70 mm and allows a similar reduction in bearing size at a fixed shaft speed, resulting in a reduced bearing speed. The reduction in bearing speed is from a DN of about 1-3/4 million for the hot-bleed engine to about 1-1/2 million for the full-flow engine. The mechanical reliability of the bearing (i.e., the amount of end wear, the amount of bearing-cage wear, the sensitivity to shaft fits, and thermal transients) is a strong function of this bearing speed. The reduction in bearing failure rate shown for these two bearings is mostly due to the reduction in mechanical failure rate.

The exhaust manifold in the hot-bleed engine is a rather complex part, requiring two outlets to maintain suitable exit Mach numbers and operating around 1200°R. In the full-flow engine, it is a rather simple, conical housing with a single exit flange. The pressure level is somewhat higher in the full-flow case, but all the effects combined result in an overall reduction in the failure rate of the exit manifold.

Project 121

c. Propellant-Feed-System Trade-Study Support

The propellant-feed-system (PFS) trade study was continued toward the following objectives:

- (1) Define the recommended conceptual configuration of the feed system, including turbomachinery, lines, valves, and related engine components, such as controls, cooldown system, and thrust structure.
- (2) Define specification extreme state points for CEI/ELL specifications for PFS components.
- (3) Predict system reliability and equivalent performance, including weight.
- (4) Identify critical assumptions requiring additional analysis or test evaluation.
- (5) Correlate with other trade studies, such as the throttleability and valve-requirement studies.

The full trade study will evaluate all promising feed systems, including two- and three-turbopump systems with various valve and line arrangements.

To expedite definition of the NERVA reference engine, one of the propellant-feed-system cases was selected as the reference-engine configuration. The candidate concept was selected (primarily on the basis of judgement of the outcome of the full PFS trade study) to result in the high reliability potential of a redundant pumping system. Assumed nominal and malfunction state points were used for component sizing. The system was designed to deliver rated (100%) thrust in both nominal and malfunction modes. Throttling was not imposed as a requirement; throttling capability will be a dependent parameter. Resulting engine I_{sp} will also be treated as a dependent parameter for the initial iteration. Reliability has been postulated as the major concept-selection criterion.

Project 121

(1) Overall PFS Concept

The overall PFS concept selected for the first-iteration reference engine (shown schematically in Figure 28) incorporates two turbopumps with individual turbopump power control.

A single turbine inlet line is used from the single bleed port (preferred nozzle concept) to a branch above the brim shield, where it splits into the two turbine inlet legs. Each leg incorporates a power-control valve and a block valve in series, with the block valve upstream to provide environmental protection to the control valve.

Twin exits from each turbine are joined into two turbine exit lines extending to the skirt-extension inlet torus. The turbine legs are cross-coupled to the two lines to provide gas cooling of both lines below the shield, even with one turbopump not operating. Two lines were selected on the basis of the preferred inlet torus concept (nozzle selection).

Two pump inlet lines are used with a propellant shutoff valve and gimbal bellows in each and with the valves direct-mounted to the tank bottom.

The individual pump discharge lines enter the brim shield; a single line connects the brim shield and nozzle inlet torus. Check valves are used in the individual pump discharge lines. The single lower line is consistent with the single nozzle inlet torus selected for the nozzle.

The specific control system and malfunction detection-switchover system will not be defined until the Case-I, intermediate-study, reference-engine PFS is completely defined.

Project 121

(2) Component Concepts

(a) Turbopump

The selected turbopumps are two dual twin-spool turbopumps incorporating centrifugal pumps and three-stage axial turbines. The pump inlet is 9 in. in diameter (axial), the pump discharge is 5 in. in diameter (tangential), the turbine inlet is 4 in. in diameter (tangential), and the two turbine exits are 6 in. in diameter (tangential).

The twin-spool configuration was selected because (1) it provides the best possibility of handling the severe pump-flow-rate change when switching from nominal operation (two pumps) to malfunction operation, (one-pump) and (2) in both operating modes, it provides for better performance at zero NPSP over that of a single-spool turbopump, because of improved main-pump-shaft speed.

Experience with the twin-spool turbopump recently tested confirms the feasibility, flow range, and performance capability of this concept.

(b) Turbine Inlet System - 4.0-in. Diameter

1 Turbine Power Control Valve (TPCV)

The configuration used (PN 1136285) is the XE butterfly-valve configuration. Because the TPCV trade study has not yet resulted in a valve-type selection, the technology valve is shown. A different type will probably be selected on the basis of flow characteristics and flow impedance.

Project 121

2 Turbine Block Valves

The configuration used (PN 1136286) is the XE butterfly-type configuration. The TBV trade study has not yet resulted in a type selection. A butterfly-type valve will probably be selected, but, because of closure-element inertia and the requirement for rapid closure, the actuator size may be increased because of pneumatic supply pressure being lower than for XE.

3 Turbine Inlet Line

The 4.0-in.-dia system incorporates three gimbaled bellows upstream of the valves plus a downstream bellows that is restrained with wire braid.

(c) Turbine Exhaust System - Dual, 6.0-in. Diameter

No valves are incorporated. The 6.0-in.-dia system uses a wire-braid-restrained bellows at each of the four turbine attachments.

(d) Pump Inlet System, 9.0-in. Diameter

1 Propellant Shutoff Valve (PSOV)

The tentative configuration for the PSOV (PN 1136282) is a tank-bottom-mounted, poppet-type, 9-in.-dia-outlet valve. This configuration was selected on the basis of 200K-engine trade studies relating primarily to leakage and flow impedance. The 200K-engine trade study is being reviewed and expanded to permit selection of a NERVA PSOV configuration.

Project 121

2 Pump Inlet Line

The line incorporates an unrestrained-bellows arrangement for gimbaling, misalignment, and thermal-dynamic compensation. The bellows is located between the valve outlet and pump inlet to provide for tank shutoff capability if the bellows should leak or rupture.

(e) Pump Discharge System, 5-in. Diameter

1 Discharge Check Valve (DSOV)

The reference drawing (No. 1136282) shows a straight-through two-way valve based on XE check-valve technology. The type used depends on whether an auxiliary emergency cooldown system will be required for ground test. The current configuration does not include the override shutoff feature required to eliminate a DSOV. Trade studies are currently in process on the DCKV.

2 Pump Discharge Line

The pump discharge lines incorporate three gimbaled bellows in each of the two segments above the brim shield and three in the single segment below the shield.

(f) Overall Line Configuration

Bellows are incorporated in all lines to provide for flexibility, because it cannot yet be shown, either analytically or experimentally, that a rigid line will not develop unacceptable flange loads.

An XE-type of gimbal-ring-restrained bellows unit for both the pump discharge and turbine inlet lines is shown but does not mean that this particular unit would be used.

Project 121

V-band clamps are shown at all joints because they incorporate the technology developed during past programs, but the type of seal is not yet stipulated.

Flange interfaces are depicted at numerous locations to provide for flexibility during component development testing and engine assembly. No attempt has been made to identify joints that will be studied for future elimination or replacement with a semipermanent connector.

Line routings are based on the engine using two identical turbopumps. It is assumed that pump, turbine-inlet, and turbine-exit flanges should not be oriented differently on the two turbopumps to optimize line or engine arrangement.

Line configuration is based on similar flow coefficients for the dual flow paths and separate but similar flange loadings for the two turbopumps. Separate loading means that neither line will transmit a significant dynamic load from one turbopump to the other and that the turbopump flanges are not to be manifolded together without interposing an isolation bellows.

It is assumed that the turbine inlet valves should be rigidly mounted to a fixed base and isolated from turbine and nozzle dynamic loading, and that some type of sway brace will be necessary for the turbine exhaust lines.

The turbopump cases being evaluated and showing the most promise include:

Project 121

- (1) Single-Turbopump System
 - Single-spool centrifugal,
- (2) Two-Turbopump Systems
 - Twin-spool centrifugal, radial-blade impeller
 - Single-spool axial
 - Twin-spool centrifugal, backswept-blade impeller for steeper pump characteristic curves
- (3) Three-Turbopump Systems
 - Single-spool centrifugal, radial-blade impeller
 - Single-spool centrifugal, backswept-blade impeller
- (4) Other
 - Remote-mounted, in-line boost pump with gas-turbine drive, applicable to two-turbopump systems.

Initial and second screenings of turbine-inlet, turbine-exit, pump-inlet, and pump-exit systems have been completed on the basis of mechanical considerations and preliminary reliability analyses. The surviving systems will undergo more detailed reliability predictions and performance and weight comparisons before the trade studies are completed.

Analysis of the first several cases of turbopump configurations has been initiated, and digital-program state points have been generated for some systems. Analog malfunction and transient-analysis results are pending satisfactory checkout of the models and computer setup. Preliminary digital evaluation of the two turbopump systems with radial-blade impellers (flat characteristic for pump pressure rise vs flow rate) indicates possible instability at normal-mode full-thrust (both pumps operating) flow rates. Confirmation is pending completion of analog steady-state, malfunction, and transient analyses.

Projects 121, 122

g. Bearing Tester-70- 90- and 105-mm

Design of 70-, 90-, and 105-mm-bearing adapter equipment for use on the 50-mm-bearing testers was completed, and detail fabrication drawings were prepared.

2. Development

Two PBI/graphite-fabric-composite roller-bearing retainers were successfully tested for durations of 6 and 7 hr, respectively. Prior to assembly into the test bearings, the retainers were lubricated with Molykote 321. Testing was conducted with a 2000-lb radial load applied to the test bearing. The liquid-hydrogen flow rate was approximately 25 gpm at a pressure of 205 psig.

Visual and nondestructive posttest inspection of the bearing and retainers revealed no evidence of degradation. The only measurable evidence of wear was the change in retainer weight, which was attributed to the normal loss of Molykote.

Project 122 - Propellant Shutoff Valve (PSOV)

Suffix f - NERVA

Housing contours for the reference NERVA PSOV design (Dwg 1135467) were refined during the report period.

The NERVA-valve trade study was initiated and includes trade-offs associated with the following valves:

Project 122

1. Propellant shutoff valve (PSOV)
2. Cooldown valve (CDV)
3. Discharge shutoff valve (DSOV)
4. Discharge check valve (DCKV)
5. Structural-support coolant valve (SSCV)
6. Turbine block valve (TBV)
7. Turbine power-control valve (TPCV)
8. Diluent control valve (DCV)
9. Thrust-Nulling Valves (TNVs)

Under the study plan the following process will be used in leading up to selection of a design concept to be used for engine system PDR:

1. Define system functional requirements related to valves.
2. Define preliminary performance criteria to meet functional requirements.
3. Define valve types capable of meeting performance requirements and decide on one or more types for conceptual investigation.
4. Define valve concepts (including preliminary performance characteristics) to meet performance requirements and select most promising concept for engine PDR.

The results of the valve trade study will be used to establish the basis for detail conceptual design leading to component PDR.

Valves 1 through 8 (above) are in Phase C of the Trade Study. Requirements for six different types of valves have been identified in the thrust-nulling valves, and these valves are currently in the initial functional definition phase.

The following conclusions have been reached as a result of Phase A of the Trade Study:

Projects 122, 123, 124, 125

1. The DSOV is not required in the engine system because its functions can be performed by other valves.
2. A separate valve for normal engine cooldown (CDV) is not required because its function can be performed by the PSOV.

An orifice specifically sized for a given set of engine components has been recommended for use in place of a DCV.

Project 123 - Discharge Shutoff Valve (DSOV)

Suffix f - NERVA

Preliminary design effort on the DSOV was terminated because of the trade-study decision to delete it from the engine system (see Project 122).

Project 124 - Turbine Block Valve (TBV)

Suffix f - NERVA

This project had no activity to report other than the trade-study effort discussed in Project 122.

Project 125 - Turbine Power Control Valve (TPCV)

Suffix b - Technology

Activities associated with the qualification testing program for the actuators were continued. Acceptance testing of TPCV Actuator SN 22 was initiated during the week of 17 January 1969. Abex servovalve SN 2 was installed in the actuator, and the actuator was taken to -160°F to set the gain. While at the low temperature, preliminary checks were made of the actuator performance, which was found to be satisfactory (gain, 0.214 a/v; threshold, 0.18° p-p ; saturation velocity, $490^{\circ}/\text{sec}$ closing, $540^{\circ}/\text{sec}$ opening; frequency response, -90° phase lag at 17 Hz). Abex servovalve SN 5 was installed in the actuator when tests proved SN 2 to be out of specification. SN 5 also was out of specification. Both servovalves were returned to the supplier for rework.

Project 125

Actuator SN 23 was being rebuilt concurrently with SN 22. Difficulties were incurred during attempts to run-in the transmission. The transmission was disassembled to isolate the cause of changes in torque and of backlash. Investigation revealed that a tapered input-shaft bearing bore in the output shaft was causing torque and backlash variation and was nullifying the effect of the bearing preloading spring that had been added during the transmission modification design. The assembly of the output-shaft bearing to the output shaft was also found to be out of alignment by approximately 0.002 to 0.003 in. because of a small metal chip discovered under one side of the bearing race. In addition, it was found that the input-shaft torque would increase as the shaft was turned slowly. This characteristic had been noted previously and was eliminated by selecting alternative bearings; however, the selective fit of bearings was not felt to be the appropriate solution because it did not identify the problem. A consultant recommended a small increase in preload on the bearings to keep the balls and ball retainers in proper relationship. This recommendation was followed, and the preload was increased an equivalent of 0.0005 in. The transmission was reassembled and successfully run-in. The acceptance testing of SN 23 was successfully completed on 2 February 1969. The actuator was then subjected to vibration testing at Aerojet-Sacramento Test Area G and was successfully completed on 17 February 1969. Life tests were initiated 20 February 1969, and an actuator bearing failed after approximately 30 hr of acceptance, vibration, and life testing. The bearing was disassembled and several areas of wear were noted, as well as running clearances that appeared to be inconsistent with drawing requirements. It was decided to incorporate Abex servovalve SN 1 in actuator SN 22 and use actuator SN 22 to continue with the qualification test program. The actuator successfully passed acceptance testing and was subjected to 20 hr of life testing. The original plan called for 20 hr of life testing, then actuator vibration testing, and then completion of the life testing. Vibration testing of the actuator has been held up pending a complete review of spare parts on hand to rebuild two new spare actuators by using the new refurbished bearings, as requested by the customer. Source control drawings for all seven types of bearings used in the actuator were completed to control critical dimensions on the bearings.

Projects 125-126

These drawings control dimensions of the ball pocket clearance, clearance between race and retainer, race groove depth, raceway curvature, and bearing materials. All spare bearings presently on order will be remanufactured to these standards. Quality Control requirements to be imposed on the bearing procurement were reviewed with SNPO-C through Aerojet Source control drawings. SNPO-C accepted the source inspection plan presented by Aerojet. Source inspection will be limited to a receiving-inspection check of the parts by Government Quality Control representatives at Aerojet. The fabrication order, inventory of spares, and reinspection, where required, have been initiated for the two spare actuators. Qualification testing has been suspended until this inventory is completed.

Suffix f - NERVA

An initial draft of actuator performance criteria was completed for concept-evaluation purposes as a part of the valve-study effort.

A conceptual design study was initiated in parallel with the valve trade study to investigate a variable-venturi TPCV concept. This concept will be included in the TPCV trade-study effort.

Project 126 - Turbine Inlet Line (TIL)*

Suffix f - NERVA

Design sketches and layouts have been prepared for various arrangements of the TIL, PDL, and TEL, culminating with the routing shown for the reference engine on Dwg 1135222. The supporting layouts are listed below.

*The first three paragraphs under this project include information on the pump discharge line (PDL) and the turbine exhaust line (TEL) to avoid repetitious reporting that would otherwise result because of the similarity of work performed in the three projects.

Project 126

TIL:

- SK 126-2 TIL for single-TPA engine with uncooled brim shield
- SK 126-4 TIL and diluent line based on diluent extraction from pressure-vessel closure
- SK 126-5 TIL for dual-TPA engine, manifold at brim shield, valves vertical, wire-braid bellows
- SK 126-6 TIL for dual-TPA engine, valves in horizontal leg on top of shield, gimbaled bellows
- SK 126-7 TIL for dual-TPA engine, valves vertical, gimbaled bellows
- SK 126-8 TIL for dual-TPA engine, valves attached to turbine, gimbaled bellows upstream

PDL:

- SK 127-4 PDL for single-TPA engine with uncooled brim shield, lower line has gimbaled bellows
- SK 127-5 PDL for single-TPA engine with uncooled brim shield, lower line is aluminum without bellows
- SK 127-6 PDL for single-TPA engine with cooled brim shield
- SK 127-7 PDL for nozzle tori at area ratios of 5:1, 24:1 and 30:1
- SK 127-8 PDL for single-TPA engine with emergency cool-down supply
- SK 127-9 PDL with discharge shutoff valve showing effect of three different candidate bellows lengths
- SK 127-10 PDL with five different manifolding options of SSCL
- SK 127-11 PDL for dual-TPA engine, two no-bellows routing options to dual brim-shield inlets
- SK 127-12 PDL for dual-TPA engine, identical lines with bellows, corresponds to reference engine
- SK 126-9 PDL for dual-TPA engine, two lines manifolding into single brim-shield inlet

TEL:

- SK 128-3 TEL for single-TPA engine with a non-hot-gas-cooled skirt extension, turbine nozzles at an uncooled shield

Project 126

SK 128-4	TEL for single-TPA engine with a non-hot-gas-cooled skirt extension, turbine nozzles at a cooled brim shield
SK 128-5	TEL for single-TPA engine, wire-braid bellows at turbine
SK 128-6	TEL for dual-TPA engine, no manifolding shown
SK 128-7	TEL for dual-TPA engine, options for manifold-ing turbine exhaust flanges.
SK 128-8	TEL for dual-TPA engine manifolding aft of brim shield

The weight distributions for TIL design SK 126-2; PDL designs SK 127-4, -5, and -6; and TEL designs SK 128-1, -2, and -5 were calculated and submitted for use in nuclear analysis of candidate shield systems.

Candidate TILs, PDLs, and TELs, all with bellows, were analyzed for the PFS trade study. These analyses defined the line weights and pressure drops as tabulated for the various diameters indicated below:

	<u>3-in.</u> <u>dia</u>	<u>4-in.</u> <u>dia</u>	<u>5-in.</u> <u>dia</u>	<u>6-in.</u> <u>dia</u>	<u>7-in.</u> <u>dia</u>	<u>8-in.</u> <u>dia</u>	<u>9-in.</u> <u>dia</u>
<u>TIL:</u>							
Pressure drop, psid	16.5	4.8	1.9	-	-	-	-
Line weight, lb	185	280	460	-	-	-	-
<u>PDL:</u>							
Pressure drop, psid	-	33	13	6	3.1	-	-
Line weight, lb	-	250	420	670	1020	-	-
<u>TEL:</u>							
Pressure drop, psid	-	-	4.5	2.0	1.0	0.5	0.3
Line weight, lb	-	-	270	330	400	470	540

Heating of the TIL-to-nozzle clamp was analyzed in support of the thrust-nulling study. This analysis showed no overheating during the postscram period.

Project 126

No further effort was expended on these analyses (which were based on NRX-A6 data extrapolated to 1600 Mw) because of impending availability of internal heat-generation rates for the NERVA system to be used subsequently in reanalyses of all affected components.

Sketches of candidate diluent lines were submitted to systems personnel for analysis in support of the bolt-coolant and diluent-flow trade study. The systems showed lines for a reverse bolt-coolant flow, a pressure-vessel-closure interface, and a reflector-inlet interface.

General activities were as follows:

a. A development plan was written that outlined the present options in designing NERVA lines. These options include the type of bellows, the elimination of bellows, the type of flange coupling, the type of flange seal, the use of semipermanent joints, and the diameter, material, and routing of lines on the engine. The development plan also outlined a test plan covering development through formal qualification.

b. As part of the post-engine-operations trade study, an investigation was conducted to define approaches to a liquid retainer for use during thrust nulling. Results of the study showed that the stage contractor could use a combination of liquid surface effects, multiple screens, and a low-gravity field to ensure a liquid interface with no input from the engine assembly.

Effort on the turbine inlet line included obtaining material from two heats each of Hastelloy C and C-276. These materials will be tested to determine their mechanical and structural properties. The samples from two heats of Hastelloy C were prepared and submitted for irradiation testing. The GTR, Facility at Fort Worth, Texas, is unavailable, so completion of the tests has been delayed.

Project 127

Project 127 - Pump Discharge Line (PDL)

Suffix f - NERVA

A conceptual layout of a combined discharge and emergency coolant (three-way) check valve was completed, and a conceptual layout of a two-way flapper-type check valve is in process. These concepts are being incorporated in the valve trade study (see Project 122).

Design sketches, weight distributions, and analyses performed to define line weights and pressure drops for various PDL designs are discussed in the first three paragraphs under Project 126.

Flexibility analyses were performed on various PDL configurations for the MEC-21 program. These analyses yield a readout of end-flange loads and line stresses caused by dimensional changes due to thermal effects. Maximum bellows rotation and line movement are also computed. The value of the analyses to date has been mainly in learning how to run and interpret the program. Some preliminary results are tabulated below:

	<u>Moment at Turbopump, lb-in.</u>	<u>Moment at Shield, lb-in.</u>	<u>Moment at Nozzle, lb-in.</u>	<u>Line Stress, psi</u>
Upper Pump Discharge Line:				
347 CRES, 2 bellows only	301,000	6,000	-	87,000
347 CRES, 3 bellows	4,000	5,000	-	2,000
Hastelloy C, 3 bellows	3,000	3,000	-	2,000
Lower Pump Discharge Line, Sketch 127-5:				
Hastelloy C, no bellows	-	58,000	218,000	186,000
Aluminum, no bellows	-	49,000	176,000	84,000

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	<u>Moment at</u> <u>Turbopump,</u> <u>lb-in.</u>	<u>Moment at</u> <u>Shield,</u> <u>lb-in.</u>	<u>Moment at</u> <u>Nozzle,</u> <u>lb-in.</u>	<u>Line</u> <u>Stress,</u> <u>psi</u>
Lower Pump Discharge Line, Sketch 127-6:				
347 CRES, 3 bellows	-	7,000	6,000	5,000
347 CRES, no bellows	-	101,000	274,000	79,000
Hastelloy C, no bellows	-	33,000	96,000	46,000
Aluminum, no bellows	-	35,000	98,000	31,000

A preliminary stress analysis of the sliding bellows (PN 1135262) was performed to assess the breakaway friction of the restraint bearing. This analysis showed that the breakaway torque for this concept would be approximately 63,000 lb-in. as compared with 7,000 lb-in. for the present 5-in. DK bellows (PN 1114084). This friction property is but one of many variables that will be studied in evaluating candidate bellows concepts.

Preparation of the four squashed elbows for flexibility and stress tests was continued. The following drawings of test hardware were made:

SK 127-13	Flange, Test Elbow
SK 127-14	Test Elbow, Short Radius
SK 127-15	Test Elbow, Long Radius
SK 127-16	Test Article, Squashed Elbow

A detail test plan is presently being written and is 40% complete. The supporting pipe required for the test was already available, and end flanges were ordered. Instrumentation locations for strain gages have been reviewed with structures and materials specialists.

The materials evaluation effort for the pump discharge line consisted of making welding samples of seven aluminum alloys: 5083, 5456, 5086, 5454, 6061, 2219, and 7039. The preparation and testing of the samples will determine the shape of the weld preparation, purging requirements, and power settings

Project 127-128

of the welding equipment. In addition, the mechanical properties of the materials in an as-welded condition will be determined. The information obtained will be used to write welding specifications.

A comparison of tensile properties for the above aluminum alloys plus CRES 347, Hastelloy C and X, Inconel 718, and Titanium 5Al-2.5 Sn was prepared for evaluation of candidate materials for the pump discharge line. This information will be used in selecting the material to be used for line fabrication.

Project 128 - Turbine Exhaust Line (TEL)
Suffix f - NERVA

Design sketches, weight distributions, and analyses performed to define line weights and pressure drops for various TEL designs are discussed in the first three paragraphs under Project 126.

The materials evaluation effort for turbine exhaust lines used the information and data generated for the other lines. The operating temperature of the TELs is lower than for the TIL, thereby allowing the use of materials data developed for the turbine inlet line.

After the studies initiated during the previous report period on possible shortening of the TEL with use of a non-hot-gas-cooled skirt, sketches SK 128-3 and -4 were prepared, which show a turbine-gas-overboard arrangement at the shield. Further study is necessary to define possible heat transfer to the pressure-vessel skin, or other side effects of this concept.

Project 129

Project 129 - Other PFS Components

Suffix b - Technology

Suffix c - Testing

1. Turbine Inlet Line (TIL)

Bellows flow testing to determine the nature of annular flow in the 4-in. gimbaled bellows was completed. Test results indicate the minimum annular velocity to be 10% of the mainstream velocity in the opposite direction of mainstream flow for bellows angulation of 4° as predicted during XE operation. With the use of test data and predicted bellows heating rates, a thermal analysis was conducted to determine the gimbal-mechanism metal temperatures during steady-state XE operation. The heating rates used have subsequently been verified by dosimeter data from the XE intermediate-power run (EP-1B)

The final stress analyses, utilizing the above thermal data, have been completed and indicate that positive margins of safety exist for all components of the bellows.

On the basis of the analytical and test results reported, the 4-in. gimbaled bellows is concluded to be structurally adequate for use at XE full-power steady-state operation.

2. 3/8-in. Pilot Valves

Narrative End-Item Report RN-TD-0032, Revision A, describing the results of acceptance testing of the last 14 XE pilot valves refurbished at the Marotta Valve Corporation was approved. This report concludes formal documentation required for the 3/8-in. pilot valves provided to NTO for use on the XE-engine.

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Six spare valves, SNs 117, 119, 114, 139, 140, and 141, have been shipped to the Marotta Valve Corporation for refurbishing. When these valves are acceptance-tested, all 3/8-in. three-way solenoid valves will have been reworked to the PN 806235-1, -3 configuration.

3. 8-In. Propellant Shutoff Valve (PSOV)

PSOV SN 880104 was assembled to the 1116000-29 configuration as a backup valve and was placed in storage after an ambient-temperature functional test.

Report RN-TD-0033, XE Eight-Inch Propellant Shutoff Valve Redesign, was completed.

4. 5-In. Check-Valve Assembly

Narrative End-Item Reports RN-TD-0034 and RN-TD-0035 for cooldown adapter spools, PN 1135829-9, SNs 880007 and 880009, were completed.

5. 3/8-In. Check Valves

No activity.

6. 5-In. Butterfly Valve

Valve SN 880007 was reassembled to the 1114342-59 configuration with new seals and bearings and was shipped, after ambient and LN₂ functional testing, to NTO as a replacement for the backup engine CVV (NEIR RN-TD-0023, Addendum 2). It was discovered at engine assembly that a -79 configuration was required (shorter purge control valve on the actuator spring cover housing). This change (installation of a 1118748-19 purge control valve) is being documented in NEIR RN-TD-0023, Addendum 3.

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The 5-in.-butterfly-valve (PDVV) random-vibration test was successfully completed, and results were reported in Report RN-TD-0050, dated 4 March 1969. On the basis of test results and conclusions, the PDVV is considered acceptable for use during 70 min of XE-engine operation with no problems expected.

Posttest disassembly and evaluation of the four 5-in. butterfly valves, SNs 5, 6, 7, and 8, used on XECF were completed. Valves SN 7 (CVV) and SN 8 (PDSV) exhibited greater-than-specification leak rates on the actuator piston seal, and valve SN 8 showed greater-than-allowed butterfly-seal leakage. The excessive piston-seal leak rates were due to scratched seals caused by corrosion deposits in the actuator piston bore. The excessive lip-seal leakage on SN 8 was caused by relaxation of seal-retention bolt torque due to creep of an aluminum spacer used in the seal-retention assembly. Functional operation of all four valves was acceptable. Detailed disassembly observations and corrective actions have been delineated.

The XE-prime CVV, SN 880011, was discovered to leak excessively past the butterfly-disk lip seal. The valve was returned to Aerojet-Sacramento, where the leakage was measured at 1800 scc/sec GHe at 50 psig. Investigation of the cause of the leakage showed that the leakage resulted from marginal seal deflection (interface stress) at assembly. Details of the investigation have been documented. An analysis was conducted to determine the possibility of leakage due to material stress relaxation during the two-year period that the valve had been in the closed (seated) position. The analysis showed that, since the hoop stress generated by the imposed lip-seal strain is approximately 60% of the material yield strength, reduction in initial seating load as a result of stress relaxation would be unlikely during storage under constant strain. It was calculated that the 63,000-psi imposed stress would decrease by less than 300 psi over the two-year period in question.

7. Turbine Block Valve (TBV)

Phase IV of the random-vibration test program of the XE-configuration TBV (PN 1117188-79, SN 880025) was successfully completed without significant damage to the components. The unit was subjected to predicted or greater-than-predicted engine-level vibration in each of three axes representing the engine radial, longitudinal, and tangential axes. Test durations in the three respective axes were 105.7, 83.7, and 93.5 min, respectively. Final results of the vibration test are documented in Report RN-TD-0047.

The XECF TBV (PN 1117188-39) was disassembled and inspected after successful conclusion of the XECF program. No significant damage was observed. Results of the inspection are documented in Report RN-TD-0052.

8. Turbine Power-Control Valve (TPCV)

Results of the XE TPCV demonstration test program were documented in a final report, RN-TP-0053. The dynamic torque characteristics of the valve with 1200°R hydrogen flowing were established over a valve operating-range position of from full open (90 degrees) to near closed (20 degrees) at constant valve inlet pressures of 100 to 600 psig in 100-psig increments. The valve operating torque characteristics at the respective inlet pressures are presented in Figures 30 through 35.

The XECF TPCV butterfly valve (PN 1116265-9) was disassembled and inspected after successful conclusion of the XECF program. No significant damage was observed. Results of the inspection are documented in Report RN-TD-0052.

Report RN-TD-0042, XE Turbine Power Control Valve and Turbine Block Valve Bearing Redesign, was completed.

Figure 30 - Torque vs Valve Position at Constant Inlet Pressure of 100 psia

Figure 31 - Torque vs Valve Position at Constant Inlet Pressure of 200 psia

Figure 32 - Torque vs Valve Position at Constant Inlet Pressure of 300 psia

Figure 33 - Torque vs Valve Position at Constant Inlet Pressure of 400 psia

Figure 34 - Torque vs Valve Position at Constant Inlet Pressure of 500 psia

Figure 35 - Torque vs Valve Position at Constant Inlet Pressure of 600 psia

9. General

All X-engine components made from aluminum-alloy 7075 were reviewed to evaluate these components for probability of failure due to stress-corrosion cracking. This investigation was made as a result of a stress-corrosion failure of the 5-in.-butterfly-valve actuator piston reported last period. Results of the investigation indicate that the probability of failure of the six suspect components is minimal because none of the components are loaded in a condition of sustained tensile surface stress in the short transverse direction; however, the actuator piston must be acknowledged to have a higher failure probability than the other on the basis of one known instance of failure. The failed piston is one of 18 parts of the same configuration fabricated from a single lot of bar forgings. All forgings were heat-treated to the T-6 condition and roll-straightened in the same manner. No additional instance of stress-corrosion cracking has been detected among the 17 remaining pistons machined from this lot of forgings.

Project 130 - Pneumatic Subsystem (PSS) |
Suffix f - NERVA

Support for the engine-stage pneumatic-gas-requirements trade study was initiated. The purpose of the study is to define the basic PSS operating characteristics that will meet the NERVA engine requirements and to determine the effects of various alternative designs on overall PSS weight, reliability, and performance.

A schematic of the PSS base-line design being used in the trade study is shown in Figure 36. There are two sources of GH_2 supply for the PSS system in accordance with Figure 36: (1) the ground supply used to fill the storage tanks prior to launch and (2) the engine dome supply. The gas that is bled off the engine dome at 640 psia and 300°R is used to recharge the storage tanks, furnish gas to make the pneumatic actuators function, and supply pressurant gas to the propellant-tank ullage space. Low-pressure (LP) and

Figure 36 - Schematic of Pneumatic Subsystem Baseline Design for Trade Study No. 8

high-pressure (HP) storage tanks are used to supply ullage pressurant at 30 psia (LP) and pneumatic-actuator gas at 230 psia (HP) during portions of the duty cycle when the dome pressure is insufficient to supply gas at the required pressures. Two separate storage tanks are used because the system weight is less when the pressure in the tank can be reduced to near the minimum required amount, thus resulting in less residual mass in the tank at the end of a duty cycle.

1. Transfer-Line and Pneumatic-Component Weight Determination

Transfer lines were sized so the greatest pressure drop between source and demand at conditions of greatest flow would be 20 psid. The weight of the lines was estimated by assuming aluminum tubing of the appropriate size and length. The total PSS transfer-line weight is 19 lb for the system of Figure 36.

Actuators, regulators, and miscellaneous valves and components were estimated to weigh 185 lb for the system of Figure 36.

2. Storage-Tank Weight Determination

The weight of the storage tank and structure was calculated by assuming a 7039-T61 aluminum alloy. The resulting scaling equation for three spherical tanks is:

$$W_{TS} = 81.1 \times 10^{-9} P_m D_t^3 + 13.5 \times 10^{-4} D_t^2 + 8,$$

where:

- W_{TS} = is the weight of tank and supporting structure,
- P_m = is the maximum use pressure, and
- D_t = is the tank inside diameter.

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A safety factor of 1.18 is incorporated in the above scaling equation. The relative location of the PSS system tankage is shown in Figure 37.

A computer program was written to determine the volumetric size requirement for the LPPSS and HPPSS storage tanks. The program determines the final tank pressure and temperature and the amount of gas used during four arbitrary duty cycles of an engine burn for an assumed tank size. The magnitude of end pressure determines the adequacy of the assumed tank size. The end pressure is determined to be adequate if the pressure efficiency is $0.85 + 0.05$, where the pressure efficiency is defined as the ratio of beginning tank pressure less tank pressure at the end of the fourth engine-burn duty cycle divided by the tank pressure less the minimum useful operating pressure (30 psia for ullage gas and 230 psia for pneumatic gas). The program is used to estimate flow requirement in terms of a reference temperature.

The amount of gas used by the actuators is a function of the type of actuator and the duration or extent of use. Table 15 outlines the actuators, the number used, and the mass flow rate required for a reference engine (see note 5, Table 15). Mission A-1, consisting of four engine runs, is shown in Figure 38 and is the reference mission used for this trade study. The valve action times for Mission A-1 are shown in Figure 39 for a typical engine-run duty cycle.

The ullage-gas demand was obtained from the results of calculations of venting and pressurization requirements. A computer program is presently being written that will yield the desired venting and pressurization requirements by using input from tabulated reactor profile and pulse-cooldown data. The program takes into account nuclear and solar radiation heating of the propellant.

The tankage size required for Mission A-1 to contain sufficient gas to furnish pneumatic and ullage loads, when pneumatic actuator exhaust is assumed to be vented to ambient pressure, is as follows:

Figure 37 - Pneumatic Subsystem - Synchronous Orbital Ferry Vehicle, Mission A-1

TABLE 15

ASSUMED ACTUATOR-DRIVE-GAS LOADS FOR MISSION A-I

Gas Mass and Flow Rates When Inlet Gas Temperature = 250°R

<u>Actuator</u>		<u>Mass Flow Rate</u>	<u>No. of Actuators</u>	<u>Notes</u>
(a)	Propellant shutoff valve, lb/cycle	0.03 max	2	1
(b)	Discharge shutoff valve, lb/cycle	0.011 max	0	1
(c)	Turbine block valve, lb/cycle/actuator	0.002 max	2	1
(d)	Turbine power control valve, lb/sec		2	1
	(1) Maximum actuator	0.02		
	(2) Null actuator	0.01		
	(3) Average flow/actuator	0.015		
(e)	Structural support coolant valve, lb/sec		2	2
	(1) Maximum actuator	0.02		est.
	(2) Null actuator	0.001		est.
	(3) Average flow/actuator	0.01		est.
(f)	Thrust vector subassembly, lb/sec		2	2
	(1) Maximum actuator	0.02		
	(2) Null actuator	0.01		
	(3) Average actuator	0.015		
(g)	Control drum drive assembly (NSS), lb/sec		6	
	(1) Maximum actuator	0.020		est.
	(2) Null actuator	0.001		est.
	(3) Average/actuator	0.01		2
(h)	Miscellaneous			
	(1) Average/cycle	0.01	3	est.
(i)	Null control valve			
	(1) Average flow/actuator	0.0055	1	5
(j)	Null valve actuators, lb/cycle	0.001	3	5

TABLE 15 (cont.)

		<u>Mass Flow Rate</u>	<u>No. of Actuators</u>	<u>Notes</u>
(k)	Leakage, (at 50 + 5 psia test pressure using helium at 540 + 20°R) (flow units are in SCC per second)	10		3
	(1) Flow rate/actuator	10		3
	(2) Flow rate/inch fitting (circumferential)	0.01		3
	(3) Flow rate/solenoid valve set	0.05		3, 4

- Notes: (6) Performance Design and Product Confirmation Requirements, CEI No. 90134, Pneumatic Subsystem for NERVA Propulsion System, Preliminary Proposal issue date: 12-5-68.
- (5) Based on "Reference Engine Design Definition," Memo 7840:M:0089, 2-11-69.
- (4) Estimated by L. D. Johnson, (Conference dated 2-4-69)
- (3) Estimated by L. D. Johnson, (Conference dated 2-3-69)
- (2) Telecon Bud Primm (WANL) to J. Alseimer (AGC), dated 1-31-69.
- (1) Aerojet Nuclear Division Specification No. CP-90134, dated 12-68.

Figure 38 - Mission A-1 Duty Cycles Consisting of Four Burns of Durations as Noted

Figure 39 - Mission A-1 Duty Cycles, Second-Burn Details

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LPPSS tank volume = 109,000 cu in.
LPPSS tank diameter (3 tanks assumed) = 41.0 in.
HPPSS tank volume = 500,000 cu in.
HPPSS tank diameter (3 tanks assumed) = 57.5 in.

3. Total PSS Weight (Actuators Exhaust to Ambient)

The weight breakdown is tabulated below for the PSS configuration shown schematically in Figure 36, in which the actuator exhaust is vented to ambient conditions.

<u>Description</u>	<u>Weight, lb</u>
HPPSS tank and tank structure	1220
LPPSS tank and tank structure	442
Transfer lines	19
Actuators and miscellaneous valves	<u>185</u>
Total Dry Weight:	1866
Weight of gas in HPPSS tank	48
Weight of gas in LPPSS tank	<u>17</u>

Total Weight with Gas: 1931

4. Total PSS Weight (Actuators Vent to Ullage Space)

This alternative requires that additional lines be incorporated to conduct the actuator exhaust gas to the ullage space and that the weight of the constant-displacement-type valve be increased because of the resultant decrease in ΔP when exhaust back pressure goes from near zero to approximately 35 psia; i.e., a change in usable ΔP from approximately 230 to approximately 195 psia, or a change of $(-35/230) \times 100 = -15\%$.

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The increased back pressure will cause a reduction in work of approximately 10 to 15% on the servo actuators. Therefore, a weight increase of 13% was assumed in those components exhausting to ullage space. An analysis of the mass schedule for the base-line design indicated that the minimum storage residual would occur at the end of coast phase during the third burn for Mission A-1. If the exhaust gas is assumed to be at a constant temperature of 368°R and at 33 psig (thermal equilibrium at the HPPSS tank), the required LPPSS tank capacity is 62,000 cu in., the diameter is 33.8 in., and the tank and structural-support weight is 260 lb. The added line weight and incremental weight increase of the valves will result in a net system weight of approximately 1750 lb, or a net decrease in system weight of approximately 10% from that of the ambient-vented system.

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Project 141 - Nozzle and Bleedport

Suffix f - NERVA

1. Hot-Bleed-Port Insert Design

Evaluation of the various candidate hot-gas-bleed port insert designs is continuing. The list of candidate designs has been expanded because of increasing problems with the nickel alloy candidates. A discussion of each of the design concepts follows.

A technology hot-gas bleed port insert design using CRES 347 for the liner and copper for the spacers is being evaluated. A parametric study, varying the number of spacers from 16 to 36 while holding state point conditions at nominal steady-state, has been made. Listed below are the maximum hot-gas-side liner temperatures for the various number of spacers.

<u>Number of Spacers</u>	<u>Temperature in Line with Spacers, °F</u>	<u>Temperature Between Spacers, °F</u>
16	1310	1592
20	1300	1565
24	1290	1543
30	1274	1507
36	1260	1474
16 (XE Operations)	1461	1263

The relatively high thermal conductivity of the copper spacers causes them to act as a heat sink conducting the heat away from the CRES 347. On the technology engine, it was desirable to reduce the number of spacers to reduce the number of hot spots. Because of the reduced diluent flow of the NERVA engine and the heat conduction capacity of the copper, it is desirable to increase the number of spacers. To maintain the same ρV (cooling effectiveness) product on the NERVA engine as on the technology engine, 36 spacers are required. It appears but has yet to be verified, that the

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diluent pressure loss in the 36-spacer NERVA bleed port insert will still be less than that of the technology engine as a result of reduced velocity in the mitre bend at the bleed port nose.

Work on the electroformed nickel bleed port liners has been terminated. The original advantage of the electroformed nickel was its high ultimate and yield tensile strength. These properties, which depend on the electroforming process, were three to four times higher than Nickel 201. However, at the projected 1200°F operating temperature of the nickel liner it is questionable whether electroformed nickel would match the properties of the wrought nickel. The high room temperature tensile properties are obtained at the detriment of elongation. Room temperature elongation values for electroformed nickel are 9% to 12%. While the unirradiated elongation of Nickel 201 increases from the nominal 50% at room temperature with increasing temperature, the electroformed nickel elongation remains nearly the same. At this point, the wrought nickel appeared to be superior to the electroformed nickel and all work on the latter material was suspended.

Continued effort was devoted to the Nickel 201 bleed port liner. Thermal analyses were run at nominal steady-state design point, while varying numbers of spacers were used, as was done with the copper spacer-CRES 347 insert. Listed below are the maximum hot-gas-side liner temperatures for the various number of spacers.

<u>Number of Spacers</u>	<u>Temperature in Line with Spacers, °F</u>	<u>Temperature Between Spacers, °F</u>
16	1016	1236
20	994	1201
24	974	1169
30	965	1120
36	918	1056

A program to determine the statistical design properties of Nickel 201 has been started. More than 100 specimens will be tested at

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temperatures ranging from -320°F to 1500°F . The properties to be determined include ultimate and yield tensile strength, elongation, reduction of area, and modulus of elasticity. It is also expected that shear strength data will be needed. Modulus of elasticity will be obtained by using the stress-strain diagram and the dynamic method. Some recent data indicate that high-purity nickel has a severe decrease in elongation at the projected operating temperature when the material is exposed to radiation levels only slightly higher than those to which the bleed port insert will be subjected. For this reason, testing of irradiated Nickel 201 is being given a high priority. Material for the test specimens will be available during the next quarter. In the meantime, a literature search is being made to obtain test data available for irradiated high-purity nickel.

An analysis to determine the required transpiration cooling flow rate through the rigimesh bleed port insert liner has been completed. The minimum flow rate to maintain a maximum wall temperature of 1600°F in CRES 347 is $0.0016 \text{ lb/sec-in.}^2$. The minimum flow rate to maintain a maximum wall temperature of 1200°F in Nickel 201 is $0.0024 \text{ lb/sec-in.}^2$. It is recommended that these flow rates be doubled to account for local flow variations in the rigimesh wall. If a hot spot develops, flow through the rigimesh becomes unstable, and the flow rate will be reduced as a result of locally decreased density. The converse is true if the liner operates below design temperature and increased flow goes through the pores. For this reason, the transpired flow values will be as indicated above only at the bleed port hot zone. All other areas will have increased transpiration flow. The analysis also provided a temperature profile through the rigimesh to be used for stress analysis. The equivalent air flow rate for determination of rigimesh permeability was also determined.

Work on the U-tube bleed port insert has been limited to improvement of conceptual sketches.

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Investigations of various forms of graphite indicate that this material probably would not withstand the chemical simulation test environment. However, the literature is being continuously searched for new forms of graphite or suitable coatings that could be applied to graphite. Tungsten-25% Rhenium alloy is also being investigated as a graphite coating that would withstand the chemical simulation testing.

Multi-port concepts are being considered. This involves tapping off the hot gas at many points around the nozzle between the tubes in roughly the same manner as the thermocouple pass-through is now fabricated. The turbine drive gas would be collected into a common manifold and then fed to the turbine inlet line.

Use of the reactor peripheral flow as the turbine drive fluid is also being investigated.

2. Coolant Channel End Cap Development

Flow test comparisons of the heat-transfer characteristics of pressure-drop-reducing end caps P/N 1135860-1 and 1136178-1 and of flat end cap P/N 1134995-2 were completed, and a final test report is being written.

Three phases of testing were performed. During Phase I testing, tube crowns in the end-cap area were coated with liquid crystal that changes color at 95°F temperature. Heaters were then turned off and tubes were cooled with cold GN_2 while monitoring color changes of liquid crystal on colored film by movie cameras and a 20 frame/sec sequence camera. Tests were made at flow rates of 0.2 lb/sec, 0.3 lb/sec and 0.4 lb/sec per tube by adjusting the pressure upstream of sonic orifices at the inlet to each tube.

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Phase II tests were similar to those of Phase I, except that tube crowns were heated with quartz lamps instead of using heated GN_2 .

Phase III tests were similar to those of Phase II, except that tube crowns were heated to a higher temperature (about 700°F) and tube crown temperatures were monitored by four thermocouples on each tube.

Test results are still being analyzed, but preliminary results indicate the pressure-drop-reducing end caps provide cooling of the tube crown ends as well as the flat end caps used on NERVA technology nozzles. Therefore, the expected reduction of pressure drop is being achieved with no adverse effects on cooling efficiency in this area.

3. Braze Development Program

Three 48-inch-long, low-aluminum content plates and tube assembly braze samples which were completed during the previous quarter have been tested. Braze material and processes used in each assembly under discussion are presented in Table 16. Braze sample 1 (Phoebus process) was used in the coolant channel end-cap development tests and has not been subjected to maximum pressure testing to date. (Low-pressure leak test revealed no leakage.) Leak tests of braze sample 2 (silver alloys) indicated 15 leaks in the braze joints and end caps. Attempts to repair these leaks with BT braze alloy with either an oxyacetylene micro torch or a plasma-arc process were unsuccessful. An oxyhydrogen flame generator (water welder) was rented and used to successfully repair the leaks with B-Ag-8 braze alloy. These first two braze samples will be pressure tested in the hydro lab.

Braze sample 3 (Palniro gold) was successfully leak and proof tested, and then subjected to a maximum pressure test with H_2O . The sample failed in the coolant channel parent material at 5800 psig. The failed area is shown in Figure 40.

TABLE 16

RESULTS OF PLATE-SPECIMEN BRAZE EVALUATION

Specimen Number	First Cycle Alloy and Temperature	Second Cycle Alloy and Temperature	Third Cycle Alloy and Temperature	End-Cap Configuration	Results			Remarks
					Leak	Proof	Burst	
1 See Report No. RN-S-0220	Nioro foil groove Preform () and Shim 0.008 Preform (V) and 0.020 Wire Braze Temp. 1825-1850	Palniro-7 Powder Filler Nioro Powder Alloy Braze Temp. 1800-1825	Nicoro-80 Powder Braze Temp. 1750-1775	Ind. Brazed Low ΔP 0.020 Dia. Palniro-1 Alloy	No leaks at 200 psig GN ₂	Scheduled completion date 3 April 1969	Scheduled completion date 3 April 1969	Special Heat Transfer Study.
2	Palniro-7 foil Groove perform () and 0.020 wire Shims Palsil-25 Powder Filler 1/2 specimen Braze Temp. 1930-1955	1/2 Specimen Palsil-25 at shim ends overlayed with Palsil 5 powder 1/2 Specimen Palsil-5 full length Braze Temp. 1870-1880	Palcusil 20 Braze Temp. 1745-1755	Ind. Brazed Flat 0.020 Dia. Palniro-1 Alloy	15 Leaks at 50 psig GN ₂	Scheduled completion date 3 April 1969	Scheduled completion date 3 April 1969	Leaks being repaired Evaluating oxy-hydrogen flame generator
3	Palniro-1 foil groove Preform () and 0.020 wire Shims Palniro-4 Powder Filler Braze Temp. 2050-2060	Palniro-7 Powder Braze Temp. 1960-1970	None	Welded end cap to tube. Furnace brazed to jacket.	No leaks at 200 psig GN ₂	No leaks at 1200 psig H ₂ O	5800 psig H ₂ O Tube material failure at tube crown.	Photo of failure taken. Sample will be reworked and used as sample No. 4.
4	Palniro-7 groove Preform () 0.020 wire Palniro-7 Braze Temp. 1930-1955 Palniro-1 powder as filler.	Nioro Powder Braze Temp. 1825-1850	For emergency use only. Nicoro-80 Braze Temp. 1725-1750	Brazed end caps using 0.020 dia. Palniro-1 wire. Furnace braze cap to jacket with Palniro-7				Parts ordered - Coolant channels and end caps complete. Plate being reworked.
5	Palniro-7 Powder Filler Nioro Foil Groove Preform () 0.015 Dia wire Nioro Braze Temp. 1825-1850	Nicoro-80 Powder Braze Temp. 1950-1775	None	Brazed end caps using 0.020 dia. Palniro-1 wire. Furnace braze end caps to jacket with Nioro powder.				Tentative process pending results of plate specimen No. 4.

Figure 40 - Failure of Braze Sample at 5800 psig

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The braze joints on samples 2 and 3 were inspected ultrasonically and radiographically. The results of these inspections indicate that valid interpretation of the X-ray and ultrasonic inspection requires sectioning of the test sample. Sectioning of these samples is not feasible at this time because they can be reworked and used for additional braze development work.

Sample 3 is being reworked to be used as a plate for braze sample 4. Samples 1 or 2 will also be reworked on completion of pressure testing to provide a plate for braze sample 5. Coolant channels, end caps, and braze alloy for the fourth and fifth samples have been obtained, and are awaiting completion of the reworked plates. Details of the braze procedure for samples 4 and 5 are described in Table 16. The process for sample 5 is tentative and depends on the results obtained with sample 4.

4. Hastelloy X vs CRES 347 Nozzle Material Study

Test results of the varying aluminum content Hastelloy X plates, which were received and tested last quarter, have been analyzed. The test report, which is being prepared, indicates there is a slight yield strength advantage with 27% aluminum content Hastelloy X. The increase in yield strength is not significant enough to influence the nozzle material selection, however.

The possibility of using CRES 347 as a nozzle jacket and tube material for the 75,000-lb-thrust NERVA engine is being reinvestigated. Previously it was decided that Hastelloy X would be the prime nozzle material candidate, because the strength limitation of CRES 347 steel would preclude its use on a 106,000-lb-thrust nozzle. Since the NPRD-1 has no requirement for possible upgrading of the engine to a 106,000-lb-thrust level, CRES 347 may be adequate.

A test plan for developing statistical material properties for CRES 347 has been written and is being transmitted to SNPO-C for review. A 0.014-inch-thick coolant channel is being designed. A layout of a CRES 347 jacket with current design information has been prepared and will be subjected to thermal analysis when NERVA nuclear heating rates are available. All analyses to date of the Hastelloy X and CRES 347 nozzles have been based on NRX-A6 heating rates, ratioed to 1600 Mw power and amplified by a 150% uncertainty factor.

5. Bolt Coolant/Diluent System Trade Study

The scope of this effort has been expanded to include consideration of a diluent control valve and to determine the location of the optimum diluent extraction point. With a detailed stress analysis, reliability analysis, and a study to determine the effect of adjacent components being part of the scope, compilation of technical material and publication of a formal trade study report is scheduled for July.

The nozzle-pressure-vessel flange thermal analysis, which was completed last quarter, will have to be revised to include steady-state points of 30%, 60% and 100% power levels with NERVA nuclear heating rates. Detailed thermal analyses and stress analyses depend on these heating rates, which have been delayed by shield analysis priorities. All information on the lines, diluent control valve, and nozzle flange necessary to perform steady-state and transient systems computer analyses has been provided to Systems Engineering. The systems analyses work, which is scheduled for completion in May, will determine the point where the diluent is to be extracted and will provide a basis for determining if a DCV is necessary.

6. Copper/Aluminum Coolant Channels

Thermal analyses that were made to determine the feasibility of using aluminum alloy 2219 or OFHC copper have been completed.

The result of the analyses indicate that it would be difficult to use aluminum as a coolant channel material. Run A8Y082 indicated that the coolant Mach number of 0.68 is needed to maintain an aluminum tube wall temperature of 700°F at area ratio 1.16 aft of the throat. The coolant pressure drop to this point was 400 psi.

It would be possible to use a copper coolant channel material; however, an increase in pressure drop of approximately 180 psi would be necessary to maintain a maximum tube wall temperature of 1030°F. This analysis was based on a 0.040-inch-thick coolant channel, and on the two-dimensional conduction effects that were used in the heat-transfer calculations.

7. Chemical Simulation Thrust Chamber Assembly

Initial computer runs have been made to determine the chamber pressure and mixture ratio required to simulate the nuclear engine test condition. Preliminary results based on skirt geometry A8AG001 and nozzle geometry A8AH12 using C_g values from Phoebus nozzle test 1.2-16-NNN-013 show the maximum nozzle tube wall temperature of 1605°F will be duplicated at a chamber pressure of 400 psia and a mixture ratio of 5.0. To simulate the maximum heat flux of 21.43 Btu/in.²-sec would require a chamber pressure of 500 psia at a MR of 5.0 with resulting maximum wall temperature of 1740°F. These chamber conditions appear to be low, and the analysis is being redone using C_g values derived from technology chemical simulation tests. Final P_c -MR graphs will be completed next quarter.

Interface dimension drawings showing a tentative bleed port nozzle test assembly have been prepared.

8. Hot-Bleed-Port Bypass Manifold

Fluid analysis of the Technology nozzle bleed-port manifold design was completed. The results of the analysis were within 2% of the hydrostatic test data and within 5 psi of the hot test data overall pressure drop.

The analytical model developed during the Technology analysis is being used for preliminary NERVA manifold sizing and pressure drop calculations.

Layouts of the NERVA manifold design are in process. The layouts will be used for nuclear heating analysis, stress analysis, and manufacturing technique evaluation. Significant problems in end-cap fabrication and installation have already become apparent during preparation of the bleed port layouts. Lack of geometrical similarity between the layouts leads to the many manufacturing problems that can occur.

9. Coolant Channel Design

A study was made of the nozzle/skirt assembly to determine how coolant bulk temperature, maximum gas side wall temperature and pressure drop vary with changes in flow rate over a range of +15 to -10 lb/sec using a nominal flow rate of 66.8 lb/sec. An identical study was made except the nominal flow rate was increased to 71.4 lb/sec. These studies were originally made to support the Structural Support System Trade Study, by defining the allowable weight flow swing through the nozzle. The analytical results were plotted and are presented in Figures 41 and 42.

A parametric study was also made to determine the changes in bulk temperature and pressure drop while varying coolant inlet temperature. The results of this analysis, which were used to evaluate the effects of a cooled brim shield on coolant channel design, are presented in Figure 43.

Figure 41 - Nozzle Skirt Assembly ΔT , Δp , and Maximum T_{wg} vs W , Fixed Geometry

Figure 42 - Nozzle Skirt Assembly ΔT , Δp , and Maximum Wall Temperature vs Flow Rate

Figure 43 - Nozzle Skirt Assembly ΔT and Δp , vs T_{in} , Fixed Twg Profile

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These studies were based on nozzle computer run A8AH001 of an unsmoothed tube. Layouts were made this quarter to smooth the leg height profile, which resulted in a pressure drop reduction of approximately 8 psi. This smoothed profile, which is computer run A8AH012, is considered to be preliminary, and subsequent changes to the coolant channel design could result in an increased pressure drop.

A 0.014-inch-thick CRES 347 coolant channel is being designed for minimum pressure drop. Initial computer runs indicated a 0.014-thick-channel would have approximately 40 psi more pressure drop than a 0.012-in.-thick tube. The ΔP difference could be reduced by decreasing the number of coolant channels in the nozzle and by flow area refinements. However, further studies in stress and reliability will show if this is feasible.

10. Bleed Port Boss Stress Analysis

Development of a finite element computer model, based on Technology test data, which may be used to predict NERVA bleed-port boss stresses, is being continued.

11. Preliminary Fabrication Drawings

Preliminary nozzle fabrication drawings are being prepared to provide a basis for more accurate and detailed cost estimates, and to define areas of needed design refinement. The job is approximately 90% complete.

12. Design Reliability Methodology

A preliminary nozzle mode of failure analysis was prepared this quarter to provide a basis for design reliability calculations, and for estimating nozzle reliability. The FMA was reviewed by SNPO-C representatives

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and Reliability Section personnel. The FMA will be revised to treat the modes and mechanisms of failure more precisely.

It is planned to initiate revision of computer programs next quarter to include a Monte Carlo technique for calculating variables data.

13. AFSCM/AFLCM 310-1 Nozzle Assembly Data Items

Work on the Preliminary Environmental Vibration and Noise Report (S-38) has been started.

14. Nozzle Performance Analysis

A nozzle performance map to define optimized Rao contour nozzle lengths as a function of area ratio for various specific impulses has been developed. The 75,000-lb-thrust NERVA engine parameters of 450 psia chamber pressure and 4500°R chamber temperature were used as input conditions. The AGC 10016 computer program was used to find the family of contours plotted in Figure 44. The range of initial divergence half angle considered is also included on the performance plot for information.

The study departed from the NERVA nozzle design in the assumption of an upstream radius (URAD). The NERVA nozzle design uses a URAD of $1.0 R_t$, whereas the Figure 44 plot is based on a URAD of $2.0 R_t$. Since there is no effect on performance caused by changing URAD from $1.0 R_t$ to $2.0 R_t$, rather than rewriting the program, the study was conducted with a URAD of $2.0 R_t$ (R_t = throat radius).

15. Nozzle Assembly Reference Engine Design

A design layout, showing all of the critical components of the nozzle assembly, has been generated. The layout includes interface

Figure 44 - Shifting Equilibrium Rao Nozzle Performance ($P_c = 450$, $T_c = 4500$)

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definition to the nuclear subassembly and to the other nonnuclear CEI's which interface with the nozzle. It is being used in the definition of the reference engine.

16. Nozzle Contour Studies

Contour optimizations as function of mission requirements and materials of construction have been expanded to Rao shapes other than the minimum length/maximum performance family. The objective of this expanded study is to establish parametrically the relationship between shielding requirements, nozzle area ratios, shapes, boundary losses and performance.

Project 142 - Nozzle Skirt

Suffix f - NERVA

Trade studies and concept studies for design analysis were continued. The most prominent activities were oriented to the following items:

- A. Mechanical Design - Support Band Analysis and Vibration Analysis
- B. R-Skirt - Contour Design, Scale Model Study, and Coolant Tube Geometry
- C. Braze Development Studies
- D. E-Skirt Tube Design - Coolant Tube Geometry: Full-Flow Cycle and Coolant Bulk Temperature Influence
- E. Nozzle Performance Study - Contour Modifications

1. Mechanical Design

Detailed stress analysis on the R-Skirt Tube Bundle was completed this quarter for the 50 psia leak check case. Based on this design requirement the minimum number of bands as a function of band cross-section area and spacing were specified. It was concluded that the addition of one extra band to the minimum required number reduces the tube stresses by

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factors ranging from 54% to 28%. Further analysis has been started to determine the reinforcement band size, shape, and placement when operating under start transient and steady-state nuclear conditions.

Detailed stress analysis of the nozzle/skirt interface was not accomplished this period since emphasis was placed on reinforcement band analysis for R-skirt and skirt extension.

Preliminary environmental vibration and noise analysis were begun using various combinations of the nozzle, skirt and skirt extension in order to determine their respective natural resonant frequencies.

2. R-Skirt

Based on the generated contour for the 100:1 optimized Rao nozzle, upper boundary characteristics and heat transfer information were obtained. This new contour has the same general shape as the previously design contour for the 70:1 base contour to insure retention of flow stability as proven by scale model tests. Figure 45 presents the gas-side pressure profile for nominal conditions ($P_c = 450$ psia, $T_c = 4500^\circ\text{R}$) for the 100:1 base R-skirt in comparison with the previous 70:1 base contour as predicted by the Method of Characteristics Program 10009. The gas-side profiles compare favorably with a difference of only 0.6 psi.

A report evaluating test results of the 1/8 scale model of the R-skirt contour based on a 70:1 optimized Rao contour with nozzle/skirt interface at $\epsilon = 5:1$ and terminated at $\epsilon = 12:1$ will be released next quarter.

An optimum tube geometry was obtained on the 100:1 optimized Rao contour for a nozzle-skirt interface at $\epsilon = 5:1$ and termination at $\epsilon = 11:1$. The skirt was shortened from an area ratio of 12:1 to insure full flow down to the 40% power level as determined by scale model test

Figure 45 - 75K R-Skirt Gas-Side Pressure as a Function of Area Ratio ($P_c = 450$ psia, $T_c = 4500^\circ\text{R}$)

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results reported last quarter. For nominal full-power conditions ($P_c = 450$ psia, $T_c = 4500^\circ\text{R}$) and a coolant weight flow of 66.8 lb/sec, a bulk temperature rise (ΔT_B) of 21.4°F , static pressure drop (ΔP_S) of 28.1 psi and maximum gas-side wall temperature (T_{wg}) of 1227°F were obtained for the series flow arrangement with the nozzle. This is a decrease of 6.1°F for ΔT_B and an increase of 7.6 psi for ΔP when compared to the E-skirt at the same conditions. The mismatch in ΔT_B was a consequence of improving the partial power characteristics. A nozzle analysis was conducted with this R-skirt design in series flow and compared favorably with the E-skirt combination.

	<u>R-Skirt</u>	<u>E-Skirt</u>
T_{out} of Noz ($^\circ\text{R}$)	192.1	200.2
P_T out of Noz (psia)	766.2	766.0
T_{wg} Max Noz $^\circ\text{F}$	1621	1605

3. Braze Development Program

The skirt braze development program has two parts: tube-to-tube braze specimen and tube-to-forward flange joint design and braze procedure. The first part has five phases. Phase I, Selection and Evaluation of Available Brazing Materials; and Phase II, Fabrication, Brazing, and Examination of Vertical Flow Specimens, were previously completed. Phase IV, Brazing and Examination of Simulated Full Skirt Section and Phase V, Specification and Report, depend on Phase III. In Phase III, Brazing and Examination of Full-Length Tube Sections Using Alloys and Temperatures from Phase II, the gold-base and silver-base braze alloy specimens were completed. However, due to the fluidity of the silver alloys, erratic alloy coverage was obtained when tube-to-tube preset clearances exceeded 0.003 in. The gold-base alloys provided consistent coverage for clearances up to and including 0.012 in. Since the candidate silver braze alloys investigated are not acceptable further search braze material investigation is required. Phase III will continue with investigation of copper-base alloys and an eventual trade study

comparing the gold base, silver base, copper base and Titan II manganese base alloys. Brazing of coolant tube samples to manifold assemblies (for simulating a portion of the skirt flange) will be accomplished on the basis of results of Phase III alloy selection.

4. E-Skirt Tube Design

A study was conducted to determine the influence of inlet bulk coolant temperature changes of $\pm 10^{\circ}\text{R}$ from nominal value of 53.4°R for the optimum tube geometry previously determined on a basis of a 100:1 optimized Rao contour for a nozzle-skirt interface at $\epsilon = 5:1$ and a skirt-skirt extension interface at $\epsilon = 24:1$. For this study the optimized coolant tube design was subjected to varying coolant flow rates (57 to 70 lb/sec) and varying bulk coolant inlet temperature ($53.4 \pm 10^{\circ}\text{R}$), while the bulk coolant inlet pressure was held at 903 psia. For these conditions ΔP and ΔT_B varied from 13.8 to 27.0 psi and 23.6 to 35.0°F , respectively, without any adverse effects on the optimum coolant tube design.

An optimum tube geometry was obtained for a full-flow cycle based on minimum length Rao contour for a nozzle-skirt interface at $\epsilon = 5:1$ and termination point at $\epsilon = 30:1$. Design was based on a coolant flow passage arrangement of 1-down 2-up in series with the nozzle, and the same number of coolant tubes (219) as the nozzle. For a coolant weight flow of 67.2 lb/sec (nominal conditions for 100% power), bulk coolant inlet temperatures of 52.0°R , bulk coolant inlet pressure of 1122 psia, and coolant tube wall thickness of 0.022 in., a bulk temperature rise of 50.0°F , pressure drop of 21.0 psi, and a maximum gas-side wall temperature of 1262°F were obtained without any adverse effects on the coolant tube design.

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5. Nozzle Performance Study

A study program has been started to evaluate the effect of various contour modifications on performance (thrust, specific impulse). A nozzle designed to an optimized 100:1 Rao contour was used as a basis to determine performance penalties resulting from blending a contour from interface points of $\epsilon = 4:1$, $5:1$, and $24:1$ to the exit planes of optimized 30:1 and 70:1 Rao-contour nozzles. The same procedure was used for 30:1 and 70:1 contours. A review of results obtained by initial analysis (constant gamma program) indicated the results were discrepant, and the analytical method was revised to obtain performance values using the Method of Characteristics Program (10009). The results obtained, shown in Table 17, indicate that performance is relatively insensitive to the location of the matching or transition point and that the performance values of the composite contours are very close (within approximately one second of I_{sp}) to those corresponding to Rao optimum nozzle. Effort is continuing to establish weight differences for each contour modification and resultant performance penalty.

6. Requirements Allocation Sheet

Preliminary requirements allocation sheets for the E-skirt were completed and submitted to systems-analysis personnel for the FFD block "Initiate and Direct Propellant Flow" phase for Mission C-2.

Project 143 - Skirt Extension

Suffix f - NERVA

Engineering activities have been devoted to evaluation of the following skirt extension design concepts: turbine-exhaust-gas cooled unit contained in the reference engine; radiation-cooled unit using fiber reinforced graphite composite structure; and cryogenically cooled unit under parallel flow with the nozzle/skirt combination.

TABLE 17

NOZZLE PERFORMANCE DATA

<u>Base of Initial Contour</u>	<u>Cutoff Point of Base Contour</u>	<u>Final Exit Area Ratio</u>	<u>Type</u>	<u>I_s (vac), sec</u>
	None	30	Rao	846.3
30	4	70	C	865.0
30	5	70	C	864.7
30	4	100	C	871.7
30	5	100	C	871.3
	None	70	Rao	865.5
70	4	30	C	845.9
70	5	30	C	845.9
70	4	100	C	872.0
70	5	100	C	872.0
70	24	100	C	872.0
	None	100	Rao	872.0
100	4	30	C	845.9
100	5	30	C	847.7
100	4	70	C	865.0
100	5	70	C	865.5
100	24	70	C	865.1
30	24	100	C	*
30	24	70	C	*
70	24	30	C	*
100	24	30	C	*

C Composite Contour

* Unreasonable Contour

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In the gas-cooled skirt extension study work the conceptual design of a 100:1 expansion ratio skirt extension for the reference engine was completed. Graphite skirt extension material development studies were continued. Test specimen materials that were ordered last quarter are being received and test specimens are being prepared. Under the cryogenically cooled skirt extension study, work was completed to establish coolant requirements for parallel flow operation with the nozzle/skirt combination.

The status and detailed results of the skirt extension studies are:

(1) Gas-Cooled Skirt Extension Study

During this quarter, the conceptual design of 100:1 turbine-gas-cooled skirt extension was completed. Using the conceptual design, a study was made to refine secondary gamma radiation effects and to establish comparative differences between the candidate materials (CRES 347 for the gas-cooled skirt extension; 7039T61 for the cryogenically cooled skirt extension and fiber-reinforced graphite for the radiation-cooled skirt extension).

A heat-transfer study was made to evaluate the effects of the turbine exhaust collector discharge state-point change. The new state points are $W = 4.10$ lb/sec; pressure = 27.6 psia total; and temperature = 1119°R (previous conditions were $W = 4.81$ lb/sec, pressure = 42.5 psia total and temperature = 1306°R). Study results indicated that the coolant tube hot-gas wall temperature $T_{wg} = 1600^{\circ}\text{F}$ at maximum Mach No. = 0.4 (previous $T_{wg} = 1500^{\circ}\text{F}$).

2. Graphite Fiber Composite Skirt Extension

The fiber-reinforced graphite composite studies have been continued to determine mechanical and physical properties of the material and to develop fabrication techniques for use in the conceptual skirt extension design. An industry search was completed on the carbon and graphite fibrous composites, and the results are contained in a report Fibrous Reinforced Graphite Composite Skirt Extension for the NERVA Engine. The report discusses commercially available types of fibrous reinforced graphite composites relative to: (1) current technology; (2) physical and mechanical properties; (3) thermal shock resistance characteristic exhaust gas compatibility, and nuclear radiation characteristics; and (4) fabricability and related experience in manufacture of rocket nozzle and thrust chamber assemblies.

Material test plans were initiated to evaluate the mechanical and physical properties and to determine erosion/corrosion rates of AGCarb-101 material in a hot hydrogen atmosphere. Test specimens are being prepared of the AGCarb-101 materials.

Two thermal analyses of the uncooled fibrous graphite composite skirt extension flange/cryogenically-cooled skirt flange concept (see CY 1968 summary report) are being made to establish temperature distribution in the joint concept. Using the temperature distribution data, a stress analysis study is being made to evaluate the joint concept. Further refinement of the thermal analysis program has been initiated to correct the computer model for contact resistances at graphite/steel and steel-to-steel interfaces.

3. Cryogenically Cooled Skirt Extension

Heat-transfer studies have been completed to establish coolant requirements for cryogenically cooled skirt extension using either

Projects 143 and 144

7039T61 or CRES 347 materials. The result of the studies to match bulk coolant outlet temperature of the skirt extension with the nozzle/skirt combination is presented in Figure 46 under parallel flow conditions. Because 7039T61 may be subject to stress corrosion, some other aluminum alloy may have to be considered.

Project 144 - Poison Wire Withdrawal Assembly

Suffix f - NERVA

1. General

During the second quarter of CY 1969 the poison wire withdrawal and reinsertion assembly effort concentrated on definition and determination of the withdrawal/insertion requirements and conceptual studies of devices capable of performing all or some of the SNPO-proposed requirements. This effort has been coordinated with WANL.

Aerojet has submitted recommendations for the poison wire requirements and completed 13 conceptual design layouts for mechanical devices capable of performing these tasks. The anti-criticality poison wire requirements have not been finalized.

2. Requirements

The proposed requirements are summarized as follows:

- (1) Remove all wires during checkout procedure at the assembly/checkout point.
- (2) Reinsert all wires for shipping to Kennedy Space Center.
- (3) Remove the peripheral wires in the vehicle assembly building.
- (4) Remove the central wires prior to launch on sub-orbital start missions.
- (5) Remove the central wires while in orbit in the event that manual removal cannot be assumed.

Figure 46 - Cryogenically Cooled Skirt Extension Parallel Flow

3. Conceptual Design and Layouts

Since the poison wire design requirements have not been fully established, Aerojet has decided to provide conceptual designs capable of fulfilling all the proposed anti-criticality requirements either independently (universal tool) or in concert with other concepts (conceived for specialized functions). The concepts and design layouts presented to WANL for their comments relative to the effect of these mechanisms on the NERVA reactor are as follows:

- a. Concept No. 1: a single lanyard powered by a motor drive that sequentially releases the retainer mechanism and pulls at the poison wire bundles simultaneously. This device can pull either the peripheral or central wires or both if required.
- b. Concept No. 2: a saginaw multi-extended ball bearing screw driven by an electric or pneumatic motor to release the wire retainers and pull the poison wires from the reactor. This device is limited to pulling all the core wires simultaneously. A protective boot is provided to shield the nozzle coolant tubes from damage.
- c. Concept No. 3: a cluster of plastic tubes, attached to the core retainers, that guides each of the poison wires into its specific core hole. This method will allow removal and reinsertion of any or all the poison wires at any stage of vehicle assembly.
- d. Concept No. 4: reinsertion or removal of only the central wires and must be utilized in conjunction with a device similar to Concept No. 1 or 2.
- e. Concept No. 5: a plastic-tube positioning device that can be attached to the core and guide the poison wires into specific core locations. This insertion technique is performed manually with the engine

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integrated in the stage. This concept modifies Concept No. 3, allowing removal and replacement of the plastic-tube positioners for test purposes.

f. Concept No. 6: modifications and supplemental hardware required to adapt Concept No. 4 for remote poison wire removal in a deep space environment.

g. Concept No. 7: A screwjack device and pneumatic motor to withdraw the central poison wires. A secondary compression spring is provided for redundant poison wire withdrawal as well as ejection of the entire mechanism.

h. Concept No. 8: a screwjack and pneumatic motor to withdraw central poison wires that have previously been reinserted into an engine with the nozzle and skirt attached. An unique expulsion spring seat is included in this design that could be utilized as the following:

- (1) A leak-check device
- (2) A throat plug
- (3) A centering guide tube
- (4) A check valve
- (5) A bumper

i. Concept No. 9 is attached directly to the WANL reactor core and does not require additional support from the skirt extension flange as in the previous designs. This concept considerably reduces the withdrawal device size. The primary compression spring retracts the poison wires into a storage cylinder while a secondary spring is provided for ejection of the entire device.

j. Concept No. 10: a pneumatic motor and spool capable of withdrawing all the poison wires (central and peripheral) simultaneously.

Project 144

k. Concept No. 11: a solid rocket motor and four lanyards each pulling a quadrant of poison wires simultaneously. This method provides a simple lightweight method for withdrawing all the poison wires while the engine is in orbit.

1. Concept No. 12: similar to Concept No. 9, with the addition of support struts for supporting the withdrawal assembly. The support struts are connected to the skirt extension. This device operates after detonation of a single explosive bolt frees a compression spring and withdraws the poison wires. When the explosive bolts that attach this assembly to the skirt extension are fired the primary compression spring ejects the entire mechanism.

m. Concept No. 13: a means for replacing the tube positioner and guide tubes as described in Concepts No. 3 and 5.

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4. EP-IA, EP-IB, and EP-IIA, SPEAR Controls Analysis

SPEAR analysis was performed for engine control systems after EP-IA, EP-IB, and EP-IIA.

Evaluation of the indicated drum position control static error was made after each of the EP's. During EP-IB, measurements of voltages at the control system amplifiers indicated that the actual static inaccuracy was 0.5° to 1.3° . Dynamic performance of the drum position controller was satisfactory. Bandwidth of the drum position control loop was found to be approximately 1 cps. Power control, as evaluated during EP-IA and EP-IIA, exhibited satisfactory static and dynamic performance.

The chamber temperature control responded in a stable manner during EP-IIA. Insufficient time at steady state during EP-IIA resulted in the inability to evaluate temperature control static accuracy.

TPCV position control and chamber pressure control performed in a satisfactory manner during EP-IIA. Based on checks made after EP-IIA, no significant change in TPCV actuator characteristics was found over EP-IB measurements.

Startup controls, evaluated during the three bootstrap runs of EP-IIA, were found to be satisfactory. The shutdown controller (pump tailoff control), evaluated during the third bootstrap run of EP-IIA, was found to be sluggish for shutdowns from low power. Further investigation of this controller was recommended.

Evaluation of the run tank (V5001) pressurization system during EP-IIA indicated that it operated satisfactorily.

The Safety System was evaluated during EP-IA and EP-IIA and found to be satisfactory except for two EP-IIA anomalies: (a) a program power Scram at 1.5 Kw when the setting was 1.0 Kw, and (b) no drum override when trip

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Project 151 - Electronic, Power, Instrumentation, and Control (EPIC)
Suffix b - Technology

Activities conducted in support of the technology program during this report period were as follows:

1. XE Control Systems Design and Analysis

The design and fabrication of modification kits for the XE Engine Control System (ECS) in support of the XE-Prime power tests continued during this report period. The status of the modification kits is as follows:

Modification Kits Completed and Provided to NTO

Removal of PDVV/TBV Interlock
Modifications to TPCV Pressure Compensation
Modification to TPCV Shutdown Compensation
Data and Control Room Analog/Event Channels

2. Engineering, Drafting, and NTO Support Documentation

Drawings were upgraded to reflect modification kit configurations, and configuration control was maintained for all NRO and WANL ECS drawings.

3. NTO Engineering Support

ECS control personnel assisted NTO personnel in the installation and checkout of the various modifications. All modifications were functionally checked out prior to EP-II. ECS personnel provided a review and upgrading of the NTO Standard Operating Procedures pertaining to the ECS equipments.

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conditions were encountered. Corrections were made and these two systems were considered ready for continued engine testing.

Temperature, pressure, log power, and position averages were evaluated during EP-IA, IB, and IIA and were considered satisfactory with only minor anomalies.

In order to check the implementation of the pressure controller in NETAP (Nuclear Engine Transient Analysis Program), comparisons of TPCV demand profiles were made in different ways. The XE pressure controller was simulated on the IBM 1130 computer with the Continuous System Modeling Program (CSMP). A chamber pressure error signal was obtained from the NETAP 360/65 digital model for a start transient and input to the pressure controller. The results showed the actual controller would cause the TPCV to respond to changes in error input more rapidly because of controller lead terms that are not incorporated in NETAP. This conclusion was confirmed by using a reverse model of the XE pressure controller with the CSMP to calculate the chamber pressure error required to give the TPCV position obtained from NETAP. The CSMP calculated pressure error during the response of the TPCV to the rise in chamber pressure was initially lower than the NETAP calculation, again reflecting the effect of the lead terms in the XE pressure controller.

An effort was started to study the effects of bandwidth and series compensation gain on two cross-coupled feedback systems. The system being considered is a simplified model of the XE engine, but the results will be applicable to NERVA engine controls.

A digital program was written for the Sigma 5 computer to calculate the time response of the above system to a step input. A series of runs is planned in which various system parameters are changed. The effects of these parametric changes will be shown in overlay transient-response plots. The program is in the process of being debugged on the Sigma 5 computer.

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An analysis was made of the effects of controller saturation (rate limiting) on the proposed measurements of power, temperature, and pressure loop transfer functions. With one exception, the transfer function input amplitudes specified in RN-S-0400 were found to cause negligible rate limiting within the frequency range of interest. A recommendation was made to reduce the input amplitude that caused significant rate-limiting effects.

Suffix f - NERVA

I&C system activities conducted in support of the NERVA program during this report period were as follows:

Review of NERVA engine requirements continued to establish I&C system and EPIC requirements. Examination and review of the potential impact on the I&C system concept that would result from system engineering verification of certain NPRD requirements were conducted.

I&C system input to the NERVA system engineering documentation was generated. Input was provided for the C mission sample package functional flow diagrams and requirements allocation sheets as well as for the B mission package of FFDs and RASs.

NERVA I&C system interfaces with nuclear stage/vehicle equipment were developed in conceptual block diagram form. Assumptions relative to these electrical/electronic interfaces were tabulated to form the ground rules for I&C system design efforts and to provide SNPO with information for stage/vehicle-engine interface discussions with other agencies.

A list of I&C system trade studies was developed. The trade study list included individual study priority and an indication of individual study relationships to the various engine level trade studies. Included on the list was a tabulation of work constraints affecting each study. These constraints include requirements for model availability, reference engine design, and mission timing, etc.

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Work continued on the NERVA I&C system reliability requirements. Additional literature was obtained relative to microcircuit reliability factors. Because of potential microcircuit mechanization of the EPIC subsystem, current technology relative to the integrated circuit (IC) and large-scale integrated circuit (LSI) technology is being documented, and plans are underway to develop a complete bibliography of microcircuit source data. In addition, trade studies have been started to determine the effect on I&C system reliability variations of the twin-turbopump, brim shield and thrust-nulling configuration of the reference engine.

A preliminary draft of test planning for EPIC has been completed. Categories I and II EPIC test logic was developed. This test planning will be eventually developed into Section 4 of the EPIC Contract End Item Specification.

Program planning efforts were conducted to revise I&C system element mileposts consistent with the overall program plan in effect during the report period.

An investigation of various chamber pressure controller designs that could be used with a dual TPA engine has been started. The initial possibilities being considered are as follows:

1. Single unit feedback controller with a common TPCV demand output to each TPCV actuator. A possible modification would be a controller gain change in the event of a pump failure.

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2. A dual-loop controller with an inner loop for each pump controlling pump discharge pressure. The single outer loop controller would generate a trim on pump discharge pressure based on chamber pressure error.
3. Open-loop programmed TPCV position with a trim based on chamber pressure error.

The design of a single series controller has been completed and is in the process of being evaluated on TAF. Design of the dual-loop controller is now in progress.

1. Full-Flow Studies

The E-1 CAM, incorporating the original reactor model, was modified to represent the full-flow engine by replacing the existing feed system with the full-flow TPA. The hydrogen properties representation used in the turbine area was modified to correspond to the lower temperature fluid for the full-flow engine.

The TAF code was developed for this model and was used to generate steady state at four points covering the entire operating map and to generate frequency responses at the design point.

The analog model was converted to the full-flow configuration and checked out statically and dynamically.

In order to demonstrate the feasibility of the full-flow configuration, a startup was run. The sequence was: a 25-second chilldown followed by bootstrap to 60 psia and a log power demand ramp to 1000°R. At 60 psi, a 10 psi/sec chamber pressure demand ramp was initiated to 450 psia. At 1000°R, a 175°R/sec chamber temperature demand ramp was initiated to 4500°R. During this ramp control drum excursions on the order of 25° in 5 seconds

occurred. It was necessary to use a 50% larger TPCV than with the hot-bleed configuration to bypass enough flow around the turbine to enable operation in the low-pressure regions of the operating map.

Several malfunctions were run. These included failure of TPCV to full-open; failure of TPCV closed; and failure of TPCV to 30°, 50°, all from 4500°R and 450 psia. Several ramps up and down the operating line were run. No insurmountable problems were encountered.

2. Reaction Control System

Consideration has been given to the use of a reaction control system to provide stage attitude control during engine pulse cooldown. The study to determine reaction control requirements and weight penalties was in conjunction with evaluation of thrust utilization/nulling concepts.

RCS systems with the following thrust characteristics were evaluated:

- a. Continuous with variable level.
- b. Continuous with limited variability.
- c. Pulse-frequency modulated.
- d. Pulse-width modulated.

RCS propellant requirements and system weights were obtained using the data on the cooldown pulse positions and durations for the first burn of Mission B (case B.2a). For the assumed condition of no continuous external disturbances, the mode of control consisted of pulse-frequency modulated RCS thrusts activated by a position switch whenever the preset attitude error limit is exceeded. The calculation did not include the effects of time delayed signals. Based on a preliminary analysis, the propellant combination of N_2O_4 /AeroZINE 50 with a mixture ratio of 2.0 and 275 sec I_{sp} , was used for determining RCS propellant requirements.

Project 152 and 153

Project 152 - Wiring Harness

Suffix f - NERVA

Activities conducted in support of the NERVA program were as follows:

1. Trade studies were started for the interface electrical connectors, for the electrical harnesses, and for the electrical connectors to be used on rods, valves, and other equipment that will require remote removal and replacement.

A specification file was completed of all referenced and applicable specifications listed in the CEI Detail Specification (CP-90194).

2. A trade study was started to establish the configuration of the electrical harness for the reference NERVA engine. This study included a layout of the harness using the reference engine layout as a guide and resulted in data concerning tiedown areas, tiedown methods, cable bundling, and gimbaling provisions.

3. Additional studies were started to establish electrical cable/harness bundling, and attachment requirements. This study includes subassembly grouping, shielding, attachment methods, vibration effects, cooling requirements, and gimbaling provisions. Areas in which the remote connectors will be installed were reviewed for unit remote replacement requirements.

Project 153 - Nonnuclear Diagnostic and Control Instrumentation

Suffix b - Technology

Activities conducted in support of the Technology program during this report period were as follows:

1. XE-Prime

Several channels were discrepant during electrical checks at E-MAD after the removal of the engine from the test stand following EP-I. TE712, a tie rod temperature, and HT803, a TIL accelerometer, were deleted. TE971, a TIL bellows thermocouple and HT205, a pressure vessel accelerometer were repaired. The UTS gamma detectors, N840, N841, and N842 were defective and were replaced with new units. Insulation resistance readings were taken on 54 additional channels that used integral sheathed cable. Of these, only four were below the specification value but were accepted for use. Channels below specification were HT201, a nozzle flange accelerometer, and three UTS strain measurements, MG801, MG803, and MG805. The electrical checks at E-MAD were completed on 10 January 1969. A check of all appropriate channels was completed on 17 January 1969 after reinstallation of the engine in the test stand. The final check disclosed 14 anomalies, 10 of which were low-insulation-resistance values; the remaining four anomalies were not significant and the channels were accepted for EP-II.

2. XE-Backup

The P-4 Assembly Procedure review was completed on 17 January 1969. Comments on this procedure, together with upgrading FCOs, were forwarded to NTO. The LMA Instrumentation Kit drawing was updated and released to include all changes on 14 February 1969. The electrical checkouts of the UTS and LMA were completed, and disclosed a number of discrepant channels that were repaired, deleted, or accepted. A total of 28 channels were accepted with a lower-than-specification insulation-resistance value. TE841, a pump bearing thermocouple, was deleted due to a bad pin in the pump connector; HT110, a pump discharge line accelerometer, was damaged during relocation of the accelerometer and was deleted.

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Flame spray and LMA electrical standoff waterproofing operations were completed without incident.

The upper and lower modules were mated on 28 March 1969, and engine integrity electrical checks were started.

3. Test Support

Support was given to SPEAR both at NRDS and Sacramento relative to instrumentation and data processing for XE-P EP-IA, EP-IB, EP-II, and EP-IIA.

4. Facility Support

a. Piezoelectric Sensor Measurement System

Engineering time was spent troubleshooting the interaction of the piezoelectric sensor measurement system with the rest of the data acquisition system. Changes were made in the facility grounding system and cable termination techniques, while filters were added at the output of the charge amplifiers so that system noise will be reduced and useful data could be collected.

b. Data System Checkout Test

Results of the Data System Checkout Test have been evaluated and reported by a SPEAR team type of effort.

Projects 153 and 160

Suffix f - NERVA

Activities conducted in support of the NERVA program during this report period were as follows:

1. Studies have been started to establish requirements for the diagnostic and control instrumentation for use on NERVA. Emphasis was placed on establishing flight instrumentation requirements, since ground requirements cannot be determined until the test program has been more completely defined.

2. Thrust Chamber Gas Thermocouple - Design studies of several candidate sensor systems to measure mixed mean chamber temperature have been resumed.

Project 160 - Thrust Structure Assembly

Suffix f - NERVA

Thrust structure design effort was provided to support the reference engine layout. Reconsideration of previous concepts is necessary because of the spacing of the dual turbopumps and associated lines. Design details and a more refined concept definition are expected to result from a thrust structure component design trade study.

Design effort also provided conceptual mechanical shield designs in support of the NERVA shield trade study. Based on shielding material requirements generated by nuclear analysis, mechanical shield designs for a 50-in.-dia disk shield, 37-in.-dia brim shield and 50-in.-dia brim shield were evolved. Cooling for the brim shield concepts was provided with full-flow hydrogen from the pump discharge line. No cooling was provided for the disk shield concept. The mechanical designs were presented at a shield status meeting⁽¹⁾ at SNPO-W on 13 February 1969, and are shown as Figures 12, 13 and 14. Analyses are being made to initiate a second iteration of the brim/disk shield comparison.

(1) RN-PA-0016, Status of NERVA Shielding Requirements Trade Study (Tasks 2 and 2A), dated 13 February 1969.

Projects 181 and 182

Effort was devoted to a computer program to calculate crossed flexure pivot characteristics under transverse loading while carrying an axial thrust load. The crossed-flexure pivots are being studied as a candidate for engine gimbaling.

Project 181 - Radiation Effects Integration, Analyses and Documentation
Suffix a - Support

Shutdown of the Ground Test Reactor at General Dynamics, Fort Worth has delayed completion of GTR-20 and subsequent tests.

A series of Radiation Effects Coordination Meetings was held with WANL, AGC, and GD/FW to review program plans, test requirements, and define radiation effects initiated data items required for the NERVA program.

The Radiation Effects Program Plan (Data Item S-104) was issued.

Guidelines for application of materials trend data to the NERVA design and reliability effort were developed. Material-property information in the data bank was updated.

Project 182 - Radiation Effects Instruments and Components
Suffix f - NERVA

1. TPA Bearing Cages

A polybenzimidazole, glass-cloth-reinforced bearing cage, irradiated in GTR-21 to a gamma dose of 7×10^{10} ergs/gm (C), was operated successfully in the bearing tester at Aerojet-Sacramento, at design conditions for 6 hours (Test 37R107).

Bearing cages irradiated at General Dynamics/Fort Worth in GTR-20A were shipped to Aerojet for evaluation in Test 37R011.

Projects 182 and 183

2. Pressure Transducer Test 23R512A

Evaluation of results and the preparation of the final report on Pressure Transducer Test 23R512A were completed. Figure 47 shows transducer zero shift as a function of nuclear heating rate. Regression analysis shows that the shifts are well correlated by temperature coefficients of resistance and heating rate.

3. REIR's

Radiation Effects Information Requests were initiated for the TPA bearings and elements of pneumatic subsystem.

Project 183 - Radiation Effects Materials

Suffix f - NERVA

1. REIR's

Radiation Effects Information Requests were initiated for the following problem areas: organic insulation for electrical and electronic components; nickel for hot-bleed port; turbopump; graphite; beryllium thermal conductivity; and aluminum 7039-T63 fracture toughness.

2. GTR-20A

Polymide actuator seals (Test 37R013) and bearing cage materials (Test 37R010), irradiated at General Dynamics, Fort Worth, were shipped to Aerojet-Sacramento for testing.

Figure 47 - Zero-Shift Individual Pressure Transducers, 23R512

Projects 186 and 187

3. GTR-21

The test report on high-temperature structural materials (37R017) and cryogenic structural materials (37R018) is being reviewed by Aerojet and SNPO-C.

The draft of thermal conductivity report, FZK351-3, was reviewed and final recommendations for data presentation were made to SNPO-C. Figures 48 and 49 show graphite and beryllium thermal conductivities as functions of neutron fluence.

Project 187 - Non-Fuel Development

Suffix a - Support

1. Statistical Properties

The guidelines for computing statistical mechanical property data were revised. Data have been recalculated with direct calculations rather than the reduced ratio calculations. The minimum number of specimens acceptable for inclusion as statistical design data in the Materials Property Data Book has been established at 15. Statistical mechanical properties for the Materials Property Data Book now available are shown in Table 18.

A review of thermal expansion, α , and Young's modulus, E, indicates that heat-to-heat variations are very small (order of 2%). It appears that the 99/95% confidence limits for these two properties can be based on the experimental errors inherent in standard test methods. It is expected the preceding can be verified for several NERVA materials that have been measured by NBS. A request was made for NBS to establish the 99/95% limits for α and E of the alloys previously measured, to determine the general applicability of these limits to many alloy types.

Figure 48 - Thermal Conductivity vs Temperature for Graphite Before and After Irradiation

WANL Beryllium

Figure 49 - Thermal Conductivity vs Temperature for Beryllium Before and After Irradiation and After Test-Irradiation Anneal

TABLE 18

STATUS OF AEROJET-AVAILABLE STATISTICAL MECHANICAL PROPERTIES
OF ENGINE ALLOYS FOR THE MATERIAL PROPERTIES DATA BOOK, AGC 2275

(Based on Three Lots and a Minimum of 15 Measurements)

<u>Material</u>	<u>Form</u>	<u>Condition</u>	<u>Temperature, °F</u>
Ti5Al-2.5Sn	Bar and Forgings	Annealed	-423
Ti5Al-2.5Sn	Bar and Forgings	Annealed	-320
Ti5Al-2.5Sn	Bar and Forgings	Annealed	70
AISI 347	Bar and Forgings	Annealed	70
Hastelloy X	Forging Longitudinal	Triple Brazed	-320
Hastelloy X	Forging Longitudinal	Triple Brazed	70
Hastelloy X	Sheet	Annealed	70
Inconel 718	Bar and Forgings	Heat-Treat Condition	
		A	70
		B	70
		B	-423
Inconel 718	Sheet and Plate	A	70
Inconel 718	Sheet and Plate	B	70

2. Wear and Friction

A PBI bonded fiberglass ball retainer, irradiated in liquid nitrogen to a total gamma dose of 5.9×10^{10} ergs/gm(C), was tested for 6 hours in the liquid hydrogen bearing tester. No degradation of performance was noted during the test, and posttest visual inspection detected no evidence of significant wear. These results substantiate previous mechanical property tests which indicate that this material is highly radiation resistant, and the material properties have good resistance to wear in liquid hydrogen.

An unirradiated PBI/graphite roller bearing retainer was tested in liquid hydrogen for 7 hours without degradation of performance. Previously, an identical retainer successfully withstood a 6-hour test. These results provided additional evidence to qualify this second material for this component.

3. Titanium-Hydrogen Reactions

Although it has been well established that titanium alloys do not interact with hydrogen of commercial purity at temperatures below about 500°F, recent studies have shown that high-purity hydrogen (e.g., vapor from liquid hydrogen) can produce a surface hydride formation at temperatures as low as 100°F under special conditions. If the surface is abraded or annealed in vacuum, this low-temperature hydride formation can occur. Aerojet investigations to determine the threshold temperature for the reaction of pure hydrogen with a clean surface, although incomplete, indicate that this threshold temperature is about 200°F at 23-psia H₂ pressure for times of about 8 hr.

4. Contamination Control

A study has been made to determine if particulate contamination levels allowed by specification in the propellant systems are compatible with engine design. Since the NERVA design is not yet available, XE design was

Project 187

compared with NERVA specification CP 90194. This specification allows approximately 400 cc of greater than 150-micron-size particles before an acceptable maximum of 10% of the screen is blinded. The study shows: (1) that the NERVA engine must be designed to tolerate ingestion of larger particles than those allowed for the XE; (2) engine specifications should be modified to be consistent with XE experience; or (3) a suitable compromise between these alternatives.

5. Effect of Gaseous Hydrogen on Mechanical Properties

Degradation of notch strength, ductility, notched fatigue strength, and fracture toughness has been observed in Inconel 718, 302 stainless steel, and several alloys tested in high-purity hydrogen at pressures between 1000 and 10,000 psi. Quantitative data are lacking relative to the pressure and temperature dependence in the ranges of interest for TPA materials. The turbine and hot lines will be subjected to hydrogen pressures up to 500 psi with temperatures ranging from cryogenic to 1200°F. Further study will be required to determine if property degradation occurs at the pressure, temperature, and time of the environments of NERVA components such as the TPA turbine and housing.

6. Fracture Toughness of 440C SS

Cryogenic (-320°F) K_{Ic} fracture toughness of Rc 57 440C stainless steel was shown to be 25% less than at room temperature. Calculated critical crack size of 0.008-in. minimum was established for the material in the 250,000 psi condition at -320°F.

7. Corrosion Resistance of 7039 Al Alloy

Laboratory accelerated testing of high and low alloy chemistry heats of aluminum alloy 7039-T63 showed no significant difference in stress corrosion susceptibility. Oblique (45°) exposed grain material was not susceptible to stress corrosion cracking.

8. Alloy Selection for Lines

Secondary gamma emission, strength, and fabrication-property studies indicate that aluminum alloy 7039 should be used for cryogenic lines and Hastelloy C or X for hot lines.

9. Valve Piston Investigation

Cracking of the 7075-T73 actuator piston for the XE-5-in.-butterfly-valve was caused by stress corrosion that occurred while the material was in the T6 condition; the problem was reduced by straightening and rough-machining the piston prior to anodize coating.

10. Nozzle Brazing

A 40-in.-long flat braze section sample fabricated with low-residual-aluminum Hastelloy X from commercial heats exhibited no leakage after a Phoebus 60-hour simulated braze cycle.

Project 201

C. GROUND SUPPORT EQUIPMENT AND FACILITY SUPPORT-ENGINE SYSTEM

Project 201 - Engine Assembly and Disassembly, Tools and Fixtures (NRDS)

Suffix b - Technology

Activity during this report period centered on preventative maintenance and preparation of Ground Support Equipment for a hot-engine recovery from ETS-1 as follows:

1. The MCC/EIV and Prime Mover were used to remotely reinstall XE-Prime into ETS-1.
2. The off-spring limit switch operating cam on the EIV has been lengthened to prevent switch damage that has occurred in the past.
3. The EIV hot-air system has been disassembled, inspected, and reassembled with individual flow control valves to each of six pads. These valves will be used to adjust the float level under load conditions.
4. The torque limiter in the OPS positioning head was modified to increase the torque capacity of the unit. This will insure positive actuation of the locking dogs.
5. GSE procedures were reviewed to insure proper procedure and usage of the equipment.

Suffix f - NERVA

Support was provided to Project 116 in the area of GSE capabilities.

Projects 211 and 212

Project 211 - Engine Checkout and Test (NRDS)

Suffix b - Technology

The necessary support engineering required for the checkout and assembly of XE backup engine was provided.

Project 212 - Engine System Electrical GSE - Test Stand Control System (NRDS)

Suffix b - Technology

1. Design Modifications

The design and fabrication of modifications to the XE Test Stand Control System (TSCS) and Test Simulation System (TSS) in support of the XE-P power tests have been continued.

Modification kits completed and provided to NTO include: He inerting control, steam generator pressure detector system, cooldown modifications, and data and control room analog/event channels.

Modification kits were cancelled for programmed power scram and scram indicator reset.

2. Engineering, Drafting, and NTO Support Documentation

TSCS/TSS drawings were upgraded as a result of modification kits, and configuration control was maintained for all NRO and WANL TSCS/ECS drawings.

3. NTO Engineering Support

TSCS personnel provided a review and upgrading of the NTO Standard Operating Procedures pertaining to the TSCS equipments.

Projects 220, 221 222 and 223

Assistance was provided to NTO for the incorporation and checkout of the various modifications required for XE-P power tests. TSCS personnel also assisted in the SPEAR team effort for EP-IA, EP-IB, EP-II, and EP-IIA tests.

Project 221 - Module/Engine Test Stand

Suffix b - Technology

Engine test requirements and test operational requirements were informally provided to SNPO-N/FEO for preparation of the E/STS-2 (MSTS-2) design criteria. Assistance was given in the development of the criteria, including reviews for consistency with the NERVA program.

Projects 222 and 223 - E-MAD and ETS-1 General

Suffix b - Technology

1. Design Modifications

Engineering assistance and support to NTO were continued for the development of requirements and design criteria and for the accomplishment of specific design modifications. The design modifications that consumed the major portion of the engineering, coordination, and liaison efforts are presented below.

a. Seismic Event Modifications

The removal of temporary modifications was essentially completed. Work-completion documents that had not previously been prepared for permanent modifications were completed. Documentation to summarize this effort is being prepared and will be issued during the next quarter.

Projects 222 and 223

Specific items of work to be performed in support of the evaluation of ETS-1 for future seismic events were identified in Change Order No. 69-5, dated 24 January 1969. SNPO-C supplied ground-motion criteria for this effort.

At NRDS on 28 and 29 January 1969, SNPO-C/N, J. A. Blume & Associates, and AGC personnel discussed modifications, schedules, and areas of design responsibility for accomplishing permanent reinforcements for future seismic events. It was indicated that it would be desirable to have conceptual designs of modifications completed in time to support an AEC-NASA meeting tentatively scheduled for 4 February 1969, which would present a difficult schedule. It was considered at that time, however, that the final designs for modifications on the test-stand side of the shadow wall would be completed in time to permit their installation prior to EP-III.

A major effort by J. A. Blume, AGC, and SNPO-C/N was initiated to prepare the required designs for the AEC-NASA meeting (later scheduled for 14 February 1969). This conceptual design effort was essentially complete for use at the meeting. Preliminary information indicated that the engine could be left in the stand during an event. However, means of reinforcing the top facility shield with the engine in the stand have not been resolved.

Change Order No. 69-9, dated 11 March 1969, redirected and amplified the efforts directed by Change Order No. 69-5 and provided ground-motion criteria and a schedule for completion of design and analysis.

As part of the seismic-event effort, a comprehensive dynamic model and response analysis of ETS-1 has been under preparation by both AGC and Blume. Efforts to complete the model and obtain a valid analysis have been unsuccessful to date. A more simplified model is now under preparation.

Projects 222 and 223

b. Steam Line

The new steam line was installed and partially tested during the first quarter of the contract year. Final testing was delayed by the seismic-event effort at ETS-1. After initial testing and use during early XE-P low-power testing, the steam line was found to be slightly lower in the cold condition after use. The line was easily returned to the original elevation. It was concluded that breakaway torque of a gimbal was restraining the return of the line to its original position; so the line was left in the lower position and a test was conducted. The line returned to this lower original position in the cold condition. In effect, the gimbal is introducing cold spring in the strain line, which is considered acceptable.

The steam-line testing was successfully completed on 27 February 1969.

c. Steam-Line Plenum

During the steam-line effort, it was noted that the steam-generator plenum welds did not appear to be of the highest quality; and a program was initiated by NTO to radiograph both the installed plenum and the spare. The spare was found to contain several welds of poor quality. NTO and NRO prepared repair, inspection, and test procedures for NTO to use in repair of the unit to provide an acceptable spare.

Inspection of the installed unit indicated that it was adequate for continued operation.

d. Acoustic Modifications

A number of analyses, tests, and modifications to modify ETS-1 to withstand the acoustic effects of the NES exhaust duct has been underway

for several months. The modifications were completed during the first quarter of CY '69. Documentation of certain analyses and tests is continuing. Documentation of other analyses has been delayed by higher-priority work, including:

- (1) An acoustic study of the noise field of the jet from the ETS-1 scale-model NES duct.
- (2) ETS-1 acoustic modification - stress analysis.
- (3) ETS-1 acoustic modification - evaluation of damping coefficient and vibration test results.
- (4) ETS-1 acoustic modification - detonation test evaluation.

The inerting tests of the pipe chase and duct vault, finished in February 1969, completed the final acceptance testing of the acoustic modifications.

2. General Support

Activities related to ETS-1 modifications have been reviewed on a continuous basis, and design assistance has been provided as required. General support has been provided during the installation and checkout of such major modifications as the acoustic and steam-line modifications. This support included analysis of test data and SPEAR-team participation.

SPEAR-team support for XE-P testing has also been provided as required.

Spare steam-generator differential-pressure switches were provided and installed. During early XE-P testing, steam-generator shutdowns were experienced. Review of the performance of pressure switches and specifications for the switches showed that the switches were operating within

Project 223

specification requirements. It was also found, however, that pressure transients occurred during steam-generator operation that caused the differential-pressure switches to operate. Lowering of the low-pressure tap of the pressure switch corrected the problem.

A steam-generator-system igniter and two injectors were damaged during testing in late CY '68. These units were received in Sacramento in December 1968. Repairs were completed during the current reporting period, and the units were returned to NTO. An additional injector has since been received from NTO and is being repaired.

Support was provided for refurbishing miscellaneous valves for ETS-1.

3. XE Support

Dosimetry packets containing gamma-sensitive thermoluminescent dosimeters (TLDs) were located at the three bellows on the turbine inlet line (TIL), along the lower thrust structure (LTS), and along a radial traverse (RT) for both the XE low-power and intermediate-power tests. The data obtained are used as a check on calculations of gamma heating of these bellows and on the lower thrust structure. These data update earlier data presented in the last quarterly report that were based on measurements from the XE low-power run. Table 19 compares measured gamma dose rates in the turbine-inlet line (TIL) bellows with those predicted for full-power operation of XE. The measured data are scaled up from the low- and intermediate-power dosimetry runs to full power for comparison with the point-kernel (QAD) calculation. Figure 50 compares measured and QAD- and faster-calculated gamma dose rates along a radial traverse. There is enough spread in the data so that the uncertainty factor of 35% or greater in the QAD calculations that has been used in heating calculations of these components should be retained.

TABLE 19
COMPARISON OF MEASURED AND CALCULATED GAMMA
DOSE RATES AT TURBINE-INLET-LINE BELLOWS

<u>Location</u>	<u>Full-Power Gamma Dose Rate in Rad(C)/hr</u>				
	QAD Calculated	Measured*			
		XE Low Power		XE Intermediate Power	
		CaF ₂	Li ⁷ F	CaF ₂	Li ⁷ F
Middle Bellows (TIL-16)	6.17x10 ⁸	9.34x10 ⁸	1.14x10 ⁹	3.6x10 ⁸	2.84x10 ⁸
Upper Bellows (TIL-15)	3.00x10 ⁸	4.26x10 ⁸	8.82x10 ⁸	2.14x10 ⁸	1.96x10 ⁸
Lower Bellows (TIL-17)	3.70x10 ⁸	5.03x10 ⁸	6.64x10 ⁸	3.15x10 ⁸	2.73x10 ⁸

*The intermediate-power measurements are considered far more reliable than the low-power measurements.

Figure 50 - Calculated and Measured Gamma Dose Rates During Full-Power Operations Along Radial Mid-Plane Traverse

Projects 223 and 224

Figure 51 compares the calculated and measured gamma dose rates along the LTS. This comparison shows that the gamma heating rate in the LTS at full power would be about double the calculated heating rate.

Support was provided in maintaining configuration control of the NRDS facilities through coordination and liaison activities concerned with generating, monitoring, and processing of various change proposals and authorizing program directives.

Project 224 - Nuclear Altitude Simulation System

Suffix f - NERVA

1. General

The preliminary design of the wet duct was initiated during this quarter, together with the associated analyses and documentation. A study of the duct collar requirements was started with emphasis on deleting the collar or using an uncooled collar. A materials survey was initiated to determine a suitable material for the fabrication of the plenum-ejector portions of the duct. Stainless steels were found to meet all of the criteria specified in the duct design requirements document.

Eight biweekly SNPO-NRO design review meetings were held during this quarter to review the status of the duct design and supporting documentation.

Scale-model testing was continued, and the NASS duct scale model-diffuser aerothermodynamic evaluation testing was completed the week of 7 February. The scale-model system evaluation program was started to determine the overall system response and performance.

Figure 51 - Calculated and Measured Gamma Dose Rates During Full-Power Operation Along Lower Thrust Structure

2. Documentation

The following is a summary of the NASS documentation activity for the second quarter.

- a. RN-S-0499, NERVA Altitude Simulation System (NASS) Management Plan, January 1969

This document establishes the interface of the NASS with Engine Test Stand No. 1 (ETS-1) defines the organization which will be responsible for designing the NASS and installing it in ETS-1, and describes the program that will accomplish the NASS design and installation. The document was submitted to SNPO-C for approval on 16 January 1969. Approval, with a request for minor changes, was received on 6 February 1969. The requested revisions were completed and provided to SNPO-C on 26 February 1969.

- b. RN-DR-0150, Supplement 1, NASS Trade Studies, January 1969

This document presents the data resulting from a trade-off study that was made to establish the relationship of the original NERVA Program Requirements with modified, but less costly, program requirements. The basic purpose of the study was to evaluate cost and reliability of a wet and dry configuration as functions of performance. The document was submitted to the SNPO-C on 29 January 1969.

- c. RN-S-0500, NASS Modification Plan, April 1969

This plan, originally entitled "Program Plan," was submitted to SNPO-C for approval on 16 January 1969. NRO was requested to revise this document by deleting all technical requirements. In addition, SNPO-C redefined the NASS to include only the duct and steam generator system. The ancillary systems therefore were deleted from the revised document. These changes were made and the document resubmitted for approval on 3 April 1969.

Project 224

- d. S057-DS090221-F1, NASS Exhaust Duct Design Sheet, S-57, 1 April 1969

The initial document defined the performance and design requirements and verification requirements of the total NASS as installed in ETS-1. The definition of the initial NASS S-57 data item included the duct, steam generator system (SGDS) and ancillary systems. Following an S-57 review meeting in Las Vegas on 18-19 February 1969, NRO was directed to revise the S-57 format by deleting all reference to ancillary systems and to prepare only two design requirements sheets, one for the duct and one for the SGDS. The revised NASS Exhaust Duct Segment S-57 was initiated.

- e. Engineering Change Proposal (ECP) No. 0002, which requested that the engine test compartment back pressure requirement of 2 psi be deleted from the NPRD was returned to NRO for resubmittal. The configuration control board requested that the ECP be resubmitted with appropriate justification for the steam requirements.

- f. ECP-004, which requested clarification of the NPRD on the limitation of the existing ETS-1 facility with respect to the NERVA engine gimbal angle and area ratio and a maximum run time of 15 minutes for a full duration test, was resubmitted in February and is still pending resolution.

- g. The tentative NASS guidelines submitted by NRO in December 1968 were considered technically acceptable by SNPO-C on 9 January 1969.

3. Duct Design

a. Collar

Early in this quarter NRO was directed to delete the engine-to-facility misalignment requirement of ± 2 inches since it was felt that the duct center line could be held to $\pm 1/4$ inch. This tightening of the misalignment enabled the use of a one-piece collar and a 5-inch separation of the nozzle exit-to-duct inlet while still containing the exhaust plume. An investigation to eliminate the collar revealed that the engine installation and removal required a 9-inch nozzle exit-to-duct inlet separation. With this data available, a twofold duct collar study was started; first, to investigate the possibility of designing the one-piece collar; and second, to investigate the possibility of eliminating the requirement for a collar.

Since the NERVA engine configuration has not been completely established, final engine-to-duct clearances cannot be established and consequently, the decision to eliminate the collar could not be made. A one-piece collar design study is continuing.

The first part of the collar design program compared the radiation cooled (uncooled) concept with the water cooled (cooled) concept. Cost, ease of handling, and minor perturbations to the facility indicate acceptability of the uncooled collar concept. A one-piece collar can be made of a graphite fiber composition having properties and machinability that make it a promising candidate material. Thermal, nuclear and stress analyses have been started, and a scale-model test is in the planning stages to examine the erosive effects of high-temperature, high-velocity, low-pressure hydrogen gas on graphite. AGCarb-101 appears to have satisfactory properties for the duct collar.

Project 224

b. Materials

An evaluation of the materials that could have application in the fabrication of the duct plenum and ejector was also started. Thirteen different materials were evaluated, including stainless steels, low-alloy steels, and low-carbon steels. Several of the materials were rejected because elevated-temperature yield strength allowables in Section III of the ASME Boiler Code are lacking. Other materials could not meet a 200°R minimum operating temperature requirement for the duct. (This latter requirement has since been deleted.) Of all the materials considered, it appeared that the stainless steels adequately meet the duct requirements. AISI Type 347 stainless steel would be preferred based on higher elevated temperature weld-strength allowables, excellent corrosion resistance, good weldability, and excellent low-temperature properties.

c. Drafting

Drafting activity during this quarter included layouts of duct water injection nozzle configurations, steam line routing, diffuser coolant passage sizing, duct deflector plate configurations and plenum trunnion supports. Sketches showing conceptual requirements of the Module Engine Test Stand (METS) were made to support the SNPO criteria rework. Drafting support was also provided for the documentation which was released during this quarter.

d. Stress

Preliminary thermal and stress analyses of the primary diffuser coolant passages indicated that the gas sidewall thickness would be on the order of 0.070 to 0.080 in. (based on the 5000°R hydrogen gas

temperature and a 100 pps H_2 flow rate). The coolant passage configuration will be similar to that used on the ETS-1 NES duct. A preliminary loads analysis was conducted together with preliminary weights calculations.

4. Scale Model Testing

A 1/8 scale NASS duct was assembled and prepared for testing during this period. The environmental cell, the diffuser, and a scaled NERVA nozzle that had been tested during the previous quarter were attached to a plenum containing a circular arc flow deflector. Three water-flow manifolds were installed around the diffuser exit supplying 24 nozzles directed into the core of the hot gas entering the plenum. A secondary ejector nozzle was installed in the plenum and directed through a converging-diverging ejector attached to the outside of the plenum. Following the repair of a GN_2 feed line, which failed during the initial testing, a series of scale model-NASS correlation tests was successfully completed.

Subscale NASS duct tests were conducted to successfully simulate primary GH_2 flow temperatures and pressures for two points on the NERVA engine startup ramp. This series of tests using a water injection system demonstrated the cooling effectiveness and the operating characteristics of the wet-elbow system in the NASS duct start region. These data indicated that the secondary ejector was not operating as efficiently as predicted. Also, hot spots occurred on the plenum wall around the periphery of the diffuser. A second hot zone occurred near the top of the deflector. Inadequate distribution of gas and water, which is attributable to the geometry of the water system, appears to permit the gas to expand in radial zones between water jets and to bypass the water sprays. Overpenetration or blockage was found to worsen this situation. Changes in the diffuser plenum spray system geometry were initiated to correct this condition.

A series of tests was conducted on the scale model NASS to evaluate the effectiveness of the water spray cooling system in penetrating

Projects 224 and 225

the high-velocity GH_2 core. With sufficient water only to saturate the hot-gas stream, it was found that penetration occurred when the deflector plates were cooled below the saturation temperature. A steam supply line leading to the test facility was installed and flow checked. It was determined that the capability of the system to supply the required steam flow is marginal for the 1/8 scale NASS and that evaluation tests of the secondary system will have to be on a smaller scale.

Preliminary data from the scale-model tests showed a higher than predicted plenum pressure. It was determined that the injection water was not being evaporated, so a test was conducted without water injection to see if the plenum pressure was reduced. Results of this test verified that plenum pressure is a strong function of the unevaporated water.

NRO made a formal presentation on the Water Droplet Size Determination Plan at a meeting in Cleveland on 23 January 1969. This plan was for the testing to be completed in the Lewis Research Center 6' x 9' wind tunnel. The program was approved and scheduled for the first availability of the wind tunnel after 1 April 1969. The test plan has been completed, and material has been ordered for the droplet probe. Testing is scheduled to start in June. A plastic model is being fabricated by Aerojet-Sacramento for test demonstration.

Project 225 - ETS-1 Modifications

Suffix f - NERVA

Development of ETS-1 Data Item F-7, Facility Design Requirements, was participated in with SNPO-N/FEO. This work included generation of preliminary drafts of Sections 1 and 2 and the chapter covering the NASS. Work is continuing on development and finalization of the total document.

The NASS trade study, Supplement 1 to RN-DR-0150, was prepared and as a step in updating this basic document. Supplement 2, the facility shielding trade study, was identified as the next step to update RN-DR-0150.

The nuclear analysis for this study is in progress and is being conducted in conjunction with related engine-shielding studies.

The FESTF (Flexible Engine Shielding Test Facility) study defines an experimental program and associated facility for the NERVA program to provide a means to: (1) obtain radiation data for design of facility and flight-engine shielding; and (2) verify and perform qualification testing of these shields. There is an interrelationship and commonality between the two shielding design problems that indicate the advisability of providing radiation data in a common experimental facility.

The facility would ultimately include a propellant tank bottom, as shown in Figure 52. Initially, however, it would only be the lower half of the facility, with the tank bottom to be added later. The facility would be located adjacent to Test Cell A, with the control console located in the test-cell building behind the shadow wall (the engine axis is roughly 100 ft from the shadow-wall front face).

Other potential facilities and technical approaches have been investigated. Results of these investigations indicate that the total required experimental data can be obtained only in the facilities described here.

The basic objectives of the FESTF program are to provide much-needed experimental inputs to (1) support the design of adequate facility shielding to allow for the testing of the NERVA engine (including module) in ETS-1; (2) support the design of engine- or module-associated biological shielding (or both) to meet the requirements imposed by manned missions; and (3) allow for qualification testing of NERVA engine shielding.

The facility must be capable of allowing an experimental evaluation of the effect of hydrogen on the source strengths and gamma spectra. The presence of hydrogen in the nozzle tori, tube bundles, and reflector inlet

Figure 52 - Flexible Engine Shielding Test Facility at NRDS

plenum has a marked effect on these sources, based on discrete-ordinate (S_N) analyses. Hydrogen must be located in these regions to properly mockup the sources in question.

An essential part of the development and qualification testing of the NERVA propulsion system is simulation of the in-flight radiation environment during ground testing with the concomitant qualification of the engine radiation shields. Another essential part is simulation of the vacuum conditions of space in an evacuated engine test compartment. However, the interactions of the engine and the facility are so great that a separate shielding test facility is required to attempt radiation simulation with a minimum of ground-test effects. Such a facility could also allow for experimental measurements to aid in design of facility intermediate shielding, which is intended to protect engine components during tests in an evacuated test compartment.

A suggested schedule for construction of such a facility, which would provide experimental data in time for use in NERVA design, is shown in Figure 53.

Figure 53 - Schedule for Construction of FESTF and Use of XE-Backup Engine

Projects 231, 232 and 233

D. PROGRAM MANAGEMENT

Project 231 - Program Planning and Control

Suffix a - Support

Effort continued on the development of PERT networks leading to PDR. The networks developed during the last quarter were held in abeyance from reporting pending completion of incorporation of revised systems engineering activity and clarification of requirements for the effort preceding DRB and PDR. During the period program planning and PERT logic were developed for the 11 major trade studies. Extensive efforts were conducted to develop the interface procedures and actual events and descriptions. This effort involved coordination among the trade study managers and their counterparts at WANL. PERT reporting was started on the trade studies. These trade studies are expected to be reported the next period with PERT report input from WANL. Following discussions with SNPO regarding the systems engineering process, work was started on revising the engine system network to show the agreed upon process for developing FFD's and RAS's for the various missions. In addition, the logic relationship for the upgrading of the reference engine design, specifications, and data items was incorporated. Work was initiated in coordinating the interfaces between the engine system network and the nuclear subsystem network.

Based on the progress during the quarter on networking and estimating the amount of planning and coordination remaining, it is expected that the PERT to PDR networks will be reported the next quarter.

Projects 232 and 233 - Fiscal Control and Material Inventory

Suffix a - Support

All work statement items were completed as required.

Project 234

Project 234 - Technical Reports

Suffix a - Support

The following technical reports and documents were published during the report period.

<u>Report No.</u>	<u>Title</u>	<u>Classi- fication</u>	<u>Publication Date</u>
RN-S-0418	XE-P Test Prediction Section 8 Phase II Low Power Flow Tests Revision Book I	U	3-7-69
RN-S-0418	XE-P Test Prediction Book II	C/RD	3-7-69
RN-S-0418	XE-P Test Prediction Book 1 Section 5 Steady State Maps	U	3-69
RN-S-0418	XE-P Test Prediction Section 8 Phase II Low Power Flow Tests	U	3-7-69
RN-S-0418	XE-P Test Prediction Section 9 Phase III Intermediate & Rated Power Tests and Temp. Autostart Tests	U	3-7-69
RN-S-0418	XE-P Test Predictions Supplement to Section 9	U	3-7-69
RN-S-0418	XE-P Test Predictions Book II Section 5	C/RD	3-7-69
RN-S-0450	Revision 1A, Handbook of Operation and Main- tenance for XE-1 Engine Control System	U	2-17-69
RN-S-0450	Part II, Revision 1, Handbook of Operation and Maintenance for XE-1 Engine Control System	U	2-17-69
RN-S-0450	Part III, Revision 1, Handbook of Operation and Maintenance for XE-1 Engine Control System	U	3-12-69
RN-S-0450	Section V, Revision 1, Handbook of Operation and Maintenance for XE-1 Engine Control System	U	3-12-69
RN-S-0450	Revision 1, Part IV, Handbook of Operation and Maintenance for XE-1 Engine Control System	U	3-13-69
RN-S-0493	XE-P Malfunction Analysis	C/RD	1-30-69

Project 234

<u>Report No.</u>	<u>Title</u>	<u>Classi- fication</u>	<u>Publication Date</u>
RN-S-0496	XECF Final Report	U	2-12-69
RN-S-0498	High Temp. Water Penetration Test Results	U	1-29-69
RN-S-0499	NERVA Altitude Simulation System (NASS) Management Plan	U	2-3-69 and 1-14-69
RN-S-0500	NERVA Altitude Simulation System (NASS) Program Plan	U	3-24-69
RN-S-0502	NERVA Pressure Vessel Material Program Plan	U	3-5-69
RN-S-0506	NERVA Mission Data Book	U	2-27-69
RN-TM-0575	ETS-1 Acoustic Mod. Damping Coefficient and Vibration Test Evaluation	U	2-3-69
RN-TM-0579	An Acoustical Study of Noise Field of Jet from ETS-1 Scale Model NES Duct	U	1-27-69
R&QA-48A	Reliability and Quality Assurance Informal Progress Letter No. 48A	U	1-27-69
RN-Q-0048	Quarterly Progress Report No. 48 for 1st Quarter, October, November and December	U	2-6-69

Project 235

Project 235 - Central Data System

Suffix a - Support

Central Data Control continued to update the engineering drawing release functions associated with the NERVA program. All work statement items were complied with and reports were submitted on schedule. Documents microfilming and updating of the Technical Document Index are now back on schedule and are current with the NERVA Program. The Technical Document Index program furnished completed reports each month during the quarter. Work has begun to purge the stop-word index to provide better indexing searches. The program was also modified to eliminate special characters and numerals from the sorting routines.

Procedures for the documentation of Field Change Notices (FCN) and Field Change Orders (FCO) have been established and implemented. A 35-mm microfilm file is maintained of the changes with indices showing the project engineer disposition and the required approval signatures.

An IBM 1130 FORTRAN program has been written for the Materials Control Section. The program can retrieve data by words input to the system via punched cards in increments of from 1 to 99 words. The system retrieves on two control factors; by single words or by a combination of up to 99 factors that must be met before retrieval is achieved. All information pertaining to the control words is then listed for the inquirer.

The incremental plotter acquired last quarter, operating in conjunction with the IBM 1130 computer, has been used on an average of two jobs per day. As a result the cost savings and increased engineering productive time exceeded the original estimate. A generalized curve plotting capability has been used and is currently being expanded to include log and other scales.

Test data plots were processed in support of XE-P EP-IA, EP-IB and EP-II and were supplied to the SPEAR team, SNPO-C and WANL as appropriate.

Project 235 and 236

Over 1200 CRT plots, 200 narrow band Cal comp plots, and 700 wide band, time history, and transfer function plots in addition to calibration analysis data were processed and distributed.

The SPEAR Team Data Availability Listing index showing plots and recorders for all XE-P channels has been updated periodically to reflect data availability prior to each EP.

The Central Data System is actively involved in the support of the Data and Document Management Plan. The design, development, implementation procedures and utilization of a computerized data bank concept for data traceability and retrieval are being investigated.

Project 236 - New Technology Reporting Suffix a - Support

New Technology Reporting efforts during the second quarter included: Transmittal of Reportable Items, including Disclosures of Invention; submittal of backup data in support of Reportable Items; contributions of computer programs with eventual COSMIC listing at the University of Georgia under contract to NASA; continuation of the NASA-sponsored Technology Utilization/ Patents Awards Program for contractor employees; Aerojet T. U. Award-of-the-Month program; and related special items.

NRO transmitted 11 reportable items to SNPO-C which included three Disclosures of Invention.

As a result of evaluation and approval for subsequent publication of NRO reportable items as AEC-NASA Tech Briefs or compilations, 20 backup packages of drawings, reports, photographs, illustrations, procedures, and specifications were compiled and transmitted in support of the NRO-generated reports.

Project 236 and 238

The NRO T.U. Award-of-the-Month for January 1969 was presented during March for contribution NUC-10372, "Inexpensive Inert-Atmosphere Furnace Provides Temperature of 4500°R," submitted by R. G. Hoff, Instrumentation and Controls Section and C. M. Gracey, Aerophysics Department.

The NASA Technology Utilization Awards System conferred awards for three published AEC-NASA Tech Briefs originally transmitted by Aerojet.

<u>Number</u>	<u>Title</u>	<u>Innovator</u>
68-10024	Locating and Sealing Air Leaks in Multiroomed Buildings	J. M. Britton
68-10023	Hastelloy X Properties, Data, and Metallurgical Characteristics	L. F. Glasier, Jr.
68-10006	Computer Program Performs Frequency Analysis of Non-uniform Turbine Disk Subjected to Temperature Gradients	Paul P. Soo

Project 238 - Project Management
Suffix a - Support

NERVA Program direction and surveillance were provided as required.

Revision of the NERVA Program Management Plan (M-1) dated April 1968 to reflect SNPO-C guidelines was continued. This plan is expected to be completed during the 3rd quarter of CY '69. Supervision was provided for the Data Item Description, Form 9's, preparation. These describe the content and application of all NERVA data items required at the Design Requirement Baseline and Preliminary Design Review.

A NERVA ROM Qualification Study was completed and transmitted to SNPO-C. This study outlined in basic form the general steps that are required to qualify the NERVA Engine by 1977. In addition it supplied ROM cost estimates of the funding required to support that schedule at the end of the quarter. Guidelines for the agency budget study were received from SNPO-C, and work was initiated for that activity.

Project 238

The Aerojet Configuration Management Plan, C018-SS090205-F1, has been informally reviewed with SNPO-C personnel.

Project 241

E. SAFETY, QA, AND RELIABILITY

Project 241 - Ground Operational Safety

Suffix f - NERVA

Supplement 1 to the XE-1 Safety Evaluation Report, Phase II (NJD-11), was prepared jointly with WANL Safety personnel to support XE Phases II and III test operations. The supplement, which contains complete revisions of Chapter 6 - Test Operations; Chapter 7 - Safety Evaluation; and Appendix A - XE-1 Malfunction Analyses of the original XE-1 SER Phase II, was formally issued in February.

Addendum 1 to Supplement 1 of the XE-1 Safety Evaluation Report, Phase II (NJD-11), was prepared jointly with WANL safety personnel. This addendum was issued in February in support of a request to permit the bypass of the drum position override when T_c is less than 1600°R in the event the override interferes with actual engine startup operations or if analysis indicated the probability of interference was extremely high. The addendum also indicated that when the drum position override is bypassed during engine startup operations, the period and maximum drum positions scram inputs should be active to provide safety protection.

The safety aspects of XE-Prime EP-II Test Operations were reviewed by the NRO Safety Staff. Approval for these operations was requested and was received from SNPO-C.

A scheduled safety audit of NTO facilities at NRDS, Jackass Flats, Nevada was conducted on 16 and 17 January 1969. The audit was directed toward the Radiological Safety Program and the Emergency Planning and Procedures as implemented at the various NTO facilities.

The design and use of WANL shipping containers for the transport of radioactive and fissile materials were reviewed by the NRO Safety Staff. Approval to submit the application for the containers to the U.S. Department of Transportation was requested and was granted by SNPO-C.

Project 242

Project 242 - Ground Operational Safety - NRDS

Suffix b - Technology

1. Training

The training course on the use of self-contained breathing apparatus (SCBA) was continued.

Safety training was provided to candidates for A-FOSS assignments during off-shift hours.

2. Industrial Hygiene

Medical evaluations and physicals were provided as required.

3. Audits and Inspections

Special safety inspections of the ETS-1 operating area were performed immediately prior to XE-Prime EP-1A, EP-1B and EP-2 tests. Emphasis was placed on the adequacy and operational readiness of emergency equipment and procedures.

4. Radiation Protection and Criticality Safety

An estimate of expected radiation dose rates for various locations at ETS-1 after the next seven EP's was prepared. These data will be used for seismic planning.

A proposed design for shipping containers for the transport of semi-processed NERVA fuel was prepared.

Project 242

Requirements for Rad-Safe support during EP's I, IB, and II were revised and submitted to Pan Am. Pan Am support during EP's was monitored.

R-MAD shielding effectiveness as it relates to proposed ASTR and GTR reactor operations in the facility was evaluated.

5. Operations

Hazard control support was provided during operations and re-entries for EP-IA, EP-IB and EP-II (XE-Prime).

6. Accidents and Incidents

There were no lost-time accidents during this period. Three property-loss accidents occurred. The E-MAD 10-ton auxiliary hook block was damaged when it fell from its top position. Electric motor control center No. 11 at the E-MAD was damaged due to electrical shorting.

7. S.S. Material Accountability

Approximately 1.6 Kg of uranium in the form of Pewee fuel elements and element pieces were received by NTO from LASL.

Approximately 250 grams of unirradiated NERVA fuel were received by NTO from the WANL, Pittsburgh facility, in the form of powder.

Dosimetry foils containing neptunium, plutonium and uranium were returned to EG&G after the XE dosimetry test series was completed.

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Project 251 Flight Malfunction Studies Suffix f - NERVA

The emergency mission was incorporated into the flight safety effort. The objective of this mission is to provide for conditions which require a departure from or abort at any point along the flight path of the normal NPRD missions. Base data were transmitted to Lockheed for use in mission and trajectory studies to establish engine performance requirements for the emergency mission. These studies will be parametric based on the following engine data:

<u>Thrust, lb</u>	<u>Isp, sec</u>	<u>Power, Mev</u>
27,400	500	360
20,000	500	280
13,700	420	170

Preliminary functional flow diagrams (Block 9, Safety) were prepared for the emergency mission to the third (engine) level for Mission B. Requirement Allocation Sheets (RAS's), identifying engine requirements and/or trade studies to determine requirements were started.

The NERVA Flight Safety Analysis was divided into two phases as discussed in the previous report. The first phase used a qualitative Hazards Analysis procedure. The objective was to identify design safety requirements to define areas where trade studies are required to support optimum safety design, and to identify undesired events that require more intensive safety analysis. The second phase uses Fault Tree Analysis (FTA) procedures that are adaptable to both qualitative and quantitative evaluations.

1. Hazards Analysis

The Hazards Analysis for the post-launch phases of NERVA Mission B has been completed. The primary flight safety considerations in Mission B are to prevent failures that would result in inadvertent loss of thrust during the African overflight and in the orbital phase of the first

thrust period. Loss of thrust during the African overflight could result in impact of the nuclear stage on land. Loss of thrust during the orbital phase of the first thrust period would result in an unsafe lifetime orbit with subsequent random re-entry of radioactive debris into the earth's atmosphere.

The non-nuclear portion of the NERVA engine analyzed in the Hazards Analysis was the reference engine as described in the NERVA Engine CEI Specification 90194 dated November 1968. The propellant feed system (PFS) of the reference engine is a single flow path through a PSOV, TPA, and DSOV. The gas required for turbine drive is removed at a hot-bleed port in the nozzle and is metered to the turbine by parallel TPCV-TBV circuits. GH_2 from the reactor dome recharges the PSS during engine operation.

Single component failures in the non-nuclear portion of the NERVA engine identified in the Hazards Analysis, which could result in advertent loss of thrust, are the PSOV, TPA, DSOV, nozzle and lines. Subsystem failures that could result in loss of thrust by their malfunction effect on other components of the system are the EPIC and PSS. Component and subsystem failures that could necessitate or result in reduced thrust operation, although not critical in Mission B provided the thrust can be sustained for a sufficient duration of time, are the TPA, TPCV, TBV, SSCV, nozzle, hot-bleed port, nozzle skirt extension, pressure vessel and closure, EPIC and the PSS.

As a result of the Hazards Analysis, specific safety recommendations were made concerning the reference engine design and the scope of the currently defined trade studies.

In reviewing efforts in both Hazards Analysis and FTA activities, it was concluded that the major benefits of Hazards Analysis have been realized with the Mission B completion. It was further concluded that FTA is a more effective tool for safety evaluation and should be implemented as soon as possible. No further efforts are planned for Hazards Analysis and all available effort has been directed to FTA.

2. Fault Tree Analysis

Primary efforts in FTA were directed at establishing the undesired events at the top level of the tree relative to the six assigned NERVA missions and working the branches of the tree down to the nuclear subsystem interface, so that WANL can contribute to the FTA activities. These efforts have been completed with the publication of the top level fault tree and with the reviewing of the fault tree down to the nuclear subsystem with WANL. WANL is supporting NRO in the fault tree analysis of the nuclear subsystem. Qualitative fault trees are planned for completion in support of engine PDR.

The six top-level undesired events that form the basis of all subsequent fault tree branches are as follows:

- a. Uncorrected thrust vector misalignment during first steady-state burns of Missions AI, B, CI, CII; second, third, or fourth steady-state burns of Missions AI, AII; and return leg of Mission D.
- b. Loss of nuclear engine thrust to $F < 30,000$ lb, $I_{sp} < 500$ sec during second or third steady-state burns of Missions AI, AII, and return leg of Mission D; and first steady-state burn of Missions AI, B, CI and CII.
- c. Failure to attain full steady-state thrust $F = 75,000$ lb, $I_{sp} = 825$ sec on initial startup for return leg of Mission D.
- d. Reduction of nuclear engine thrust to $30,000 < F < 75,000$ lb, $500 < I_{sp} < 825$ sec during steady-state operation on return leg of Mission D.
- e. Unsuccessful nuclear engine shutdown/cooldown after second steady-state burn, which precludes restart of Missions AI and AII.
- f. Unsuccessful startup to attain thrust $F > 30,000$ lb and specific impulse $I_{sp} > 500$ sec after second burns of Mission AI and AII.

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A copy of the Phillips Petroleum, NRTS computer program for FTA (FATE) was obtained. FATE uses importance sampling to identify the minimal cut sets assuming no repair. Although some modifications and improvements in the code are desirable, it appears the code can be used in its present form for the initial evaluation of NERVA fault trees.

3. Additional Safety Analysis

Additional safety effort has been expended in support of current trade studies, design studies, and preparation of Requirement Allocation Sheets.

a. Thrust-Nulling Concepts

Twelve different design concepts to satisfy thrust-nulling requirements were evaluated for their effect on system safety. Four of the concepts were tank-pressure feed systems. One of these concepts, the Quench system, does not represent true thrust nulling because it uses only a lengthened period of time between thrust pulses gained by subcooling the reactor. It is assumed this could be used to obtain a sufficient zero-thrust-time window for docking or undocking maneuvers. Three of the concepts are pump fed systems, either by an auxiliary pump or by the main TPA. Two concepts are radiator systems with no flow exhausted from the system. The last three concepts are reactor full-flow systems. Theoretically these full-flow systems have an efficiency advantage in that all stem and reflector coolant flow is passed through the reactor core for added cooling, then split in axially opposed directions to gain zero thrust.

The majority of the concepts specify a liquid retainer in the propellant tank to assure the availability of liquid hydrogen during zero thrust pulse cooling. The type of liquid retainer component or system operational mode to maintain liquid hydrogen at the tank outlet is not known at this time. Several concepts, however, are under consideration: diaphragms, baffles, low forward acceleration, and spinning of the nuclear stage.

In the safety evaluation only two concepts, Quench and the Counter-Balanced Stems with Tank Pressure appear to have no single failure possibilities in the components added for thrust nulling that could cause a total loss of thrust. This is true in the Quench system because no components have been added for thrust nulling. In the Counter-Balanced Stems with Tank Pressure, the stem flow only is brought out of the dome and is used to axially oppose the reflector flow, which continues its normal path through the reactor and out the nozzle. A failure of the stem flow line out of the dome or a failure of the valve would, at the worst, cause a reduction and not a complete loss of thrust capability. Since the NPRD states that "maximum effort should be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the completion of the mission, the flight crew, the launch crew or the general public," it was recommended that this feature, inherent in the above two concepts, be given considerable weight in the final selection of the thrust-nulling design concept

b. Pneumatic Supply Subsystem

Design features necessary to comply with the safety objectives of the NPRD were recommended for inclusion in the PSS trade study. These were presented as alternative system designs to the baseline PSS being developed for evaluation. The alternative designs for tradeoff with the baseline PSS include a completely redundant PSS and two other systems that feature lower degrees of redundancy but provide protection against hazards from single failure events that would endanger human life.

c. Hazards Comparison Between Full-Flow and Hot-Bleed NERVA Engine Designs

A preliminary gross hazards comparison of the full-flow and hot-bleed NERVA designs was completed.

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The differences between the full-flow and hot-bleed systems are briefly summarized as follows:

(1) In the full-flow system, the TPA is driven by a large mass of relatively low-energy propellant, which is diverted from the main propellant stream through the TPA before the recombined propellant flow enters the reactor.

(2) In the hot-bleed design, the TPA is driven by a small quantity of high-energy gas, which is bled from the nozzle chamber and mixed with propellant diluent obtained from the reflector inlet plenum.

The principal safety requirement from the NPRD for proposed NERVA missions and the main considerations during the hazards analysis is that the design shall eliminate the occurrence of a potential single failure or potential combination of errors or failures, which as an end result, would prevent safe return of the crew or would endanger the earth's population.

The hazards analysis showed that the single TPA full-flow and hot-bleed systems are comparable relative to safety. The full-flow system, when backup modes of operation are present to counteract single failures, has a slightly lower hazard risk because it does not have the added failure modes that effect safety contributed by the long hot-gas line between the nozzle and the turbine.

Project 261 - Quality Assurance - Contractor's Plant

Suffix f - NERVA

1. XE-Prime Engine

The Data Book and End Item Report for the XE-Prime Upper Module was made current. All open items at the previous review in October 1968 have been closed, except for completion of the qualification tests on the TPCV

Actuator. A supplementary narrative was written to describe the actions resolving the open items and includes discussion of the incorporation of additional FCOs initiated as the result of necessary changes.

The related End Item Report Supplement was approved and issued.

2. Valves

All of the Marotta valves from the XE engines have been modified and tested. Data books and End Item Reports were approved, and the valves were shipped to NTO for the XE-Prime engine and XE-Backup engine.

3. TPCV Actuator

Demonstration testing of the TPCV Actuator SN 019 was completed. Quality Engineering reviewed all assembly and testing history and prepared a summary Inspection Report (IR) listing all discrepancies and nonconformances to drawings, assembly procedures, and test plans. A data book was prepared and reviewed with engineering. Engineering has prepared a qualification test report substantiating satisfactory qualification of the actuator for the XE engine use.

4. Lines

Fabrication and acceptance of lines required for the XE-Prime engine and the XE-Backup engine modifications were completed.

An extensive revision of NTO Product Assurance activities has been instituted to support the XE test series and is defined by revision to NTO-A-0030, Section 022. This procedure was changed to define the Product Assurance activities that are routinely performed with specific functions to determine readiness for each EP.

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The NRO Product Assurance Program Plan for the NERVA engine system, (Data Item P017-SS090205-F1) has been revised to include the review comments received from SNPO-C. The operational quality plan was reviewed with SNPO-C, and is now included in Data Item P017. This plan provides a more detailed and specific working guide for personnel within the NRO Quality Assurance organization regarding the quality tasks required to be performed to meet the milestones and objectives of the NERVA engine program.

The NRO Product Assurance data and documentation system is continually being upgraded and improved to provide effective support of the NERVA engine program, control of configuration, and implementation of the trend data information system.

The WANL Product Assurance Program Plan (Data Item R-101) is currently scheduled by WANL for release by approximately 15 June. The WANL quality methods and procedures (QMPs) have been released for review. The WANL reliability methods and procedures are approximately 90% completed. Final revisions of the WNCO quality methods and procedures manual are nearly complete.

NRO Quality Engineering effort was mainly in support of the technology engine. This included turbine inlet line modifications and related demonstration testing, valve modification and demonstration testing, turbine power control valve actuator modifications and demonstration testing, and coordination with NTO related to engine documentation, quality problems, and QRDR review and analyses.

NERVA Program effort consisted primarily of supporting the Systems Department in definition of the reference engine design; providing quality engineering reviews and comments related to concept and approach; materials and design development programs for the Engineering Department; and providing

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requested qualitative R_Q evaluations for reliability. Some limited formulative work was done in preparation for quality engineering and NDT engineering work plans.

Quality Engineering is participating in a task force organized to coordinate efforts necessary for defining the engine operating requirements and general arrangement of components within the dimensional limits of the test facility.

1. EPIC

Quality Engineering is working with the EPIC engineers on a quality assurance plan for microelectronics. It will be necessary to establish quality assurance requirements and acceptance criteria for discrete electronic components and associated circuitry.

2. Pressure Vessel

A drawing of the pressure vessel forward flange, PN 1136274, was reviewed and approved. The flange will be used as a test specimen in the study of a stress-strain relationship.

3. Nozzle Skirt

The material development program for the NERVA nozzle skirt is in progress. Fiber-reinforced graphite materials are being developed. The effort includes technical instructions for fabrication and for process controls; raw material supplies for proprietary specifications; fabrication controls, temperatures and time cycles for curing, carbonization, and graphitization; X-ray examinations and criteria for reporting; penetrant inspection and criteria for reporting; density requirements for finished materials; and test specimens for each lot.

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Development of the NERVA Engine Master Nondestructive Test Plan is continuing. This plan will provide coverage for the engine system, engine end items, engineering critical components, and materials as the designs are developed.

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Project 262 - Quality Assurance - NRDS

Suffix b - Technology

1. E-MAD Product Assurance

NTO E-MAD Product Assurance provided inspection support for ETS-1 activities associated with the preparations for the seismic event and the return of the XE-Prime engine to E-MAD for interim storage. All engine modifications and checkouts per approved procedures were monitored at E-MAD, and inspection coverage was provided for engine checkouts and facility modifications at ETS-1 subsequent to the return of the engine.

All Field Change Orders, Secondary Work Requests, Purchase Requisitions, and "P" procedures related to XE-Backup engine were reviewed. All QRDR's related to this work were processed and input to the compilation of the Engine Log Book was provided.

Inspection support for work related to the preparation of the hot-bay equipment for the disassembly of the XE-Prime engine was provided.

2. ETS-1 Product Assurance

An extensive revision of NTO Product Assurance activities has been instituted to support the XE test series and is defined by revision to NTO-A-0030, Section 0.022.

The QRDR procedure was revised and issued for ETS-1. With the issuance of this procedure, the reporting of all nonconformities by NTO is now on the QRDR.

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Project 263 - Reliability

Suffix a - Support

1. Reliability Training Program

For the past six months a formal reliability training program has been underway to train all NRO personnel who will be involved in the design of the NERVA engine in the basic concepts and methodology of the "Design for Reliability" approach. The training program has taken two forms: the use of outside authorities in the field as consultants, and conducting training programs by NRO Reliability personnel.

The outside consultants have included Dr. D. Kececioglu of Arizona State University, and D. Haasl of the Institute of Systems Sciences. Dr. Kececioglu presented a series of lectures to NRO Design/Development supervisory personnel to introduce the general methodology utilized in "Designing for Reliability." In addition, specific problems pertinent to design were discussed with individual design groups. This included lectures at WANL. Future efforts by Dr. Kececioglu at NRO are expected to consist of consulting (as required) on specific problems. It is planned that Mr. Haasl will continue to be consulted relative to specific Reliability and Safety methods. These will include determination of the optimum methods for performing failure modes and effects analyses, the development of mathematical reliability models, and assistance in performing the system safety fault tree analysis.

In addition to the use of consultants, training in reliability methods is being provided by the NRO Reliability staff. A course has been developed to meet the specific needs of design/development engineers. This included a presentation of the preliminary procedures and methods to be used in performing failure mode analyses, a general review of statistical concepts pertinent to reliability, and the use of computer Monte-Carlo methods to solve engineering stress/strength probability problems.

2. Reliability Management Program Plan

The Reliability Plan, R-101, which was presented in a preliminary form in the third quarter of 1968, has been reviewed by SNPO-C and comments have been received indicating areas in which improvement is required. Subsequent to receipt of these instructions, work has been initiated revising this plan. The general philosophy of the revised plan is to present a comprehensive plan that will integrate all NERVA reliability efforts, and will reflect the NERVA Management Plan as well as the NERVA Program Requirements Document.

3. Failure Mode and Effects Analysis

A complete set of preliminary failure mode analyses was prepared for the full-flow engine study. These were useful for comparing the full-flow concept with the hot-bleed concept, but more comprehensive analyses are necessary to develop data for further reliability studies. Therefore, a comprehensive FMA revision has been started as a joint venture between design and reliability engineering with subsequent support analysis and review to be performed by all technical disciplines within the program.

To initiate these studies a preliminary procedure was written (Table 20).

4. Reliability Studies

a. Reliability Comparison of Thrust Nulling Concepts

Functional schematics of 11 thrust-nulling concepts, Figures 54, 55, and 56, were studied. A rough reliability ranking of 10 of these concepts is shown in Table 21 (concepts 11 and 12 are not included because meaningful failure rates could not be derived for the core plug and balanced thrust end-plate concepts). The total capability of each concept was considered to depend on the capability to perform one thrusting and one nulling cycle. In addition to the overall ranking, pressure-fed and pump-fed concepts are ranked separately. The failure rate ratios for each concept were used as relative weights in trade-offs with other considerations: the higher failure ratios being less desirable from the reliability standpoint.

Figure 54 - Thrust Nulling Pressure-Fed Concepts

Figure 55 - Thrust Nulling Pump-Fed Concepts

Figure 56 - Thrust Nulling Balanced-Thrust Concepts

Generic failure rates were assigned to each required component function of a thrusting and nulling cycle. Those components shown in the functional schematics and listed in Table 22 were assigned failure rates. Other essential functions of the engine system were assumed to be unaffected by nulling concept. System failure rates for thrust nulling and total capability were derived by summing the failure probabilities of the component functions required in each concept.

Concept 1 is the single TPA engine without modification for thrust nulling. The failure rate ratios in Table 21 represent the increase in failure rate of each concept over the failure rate of System 1.

Table 23 documents the data sources and methods used in establishing failure rates for each component function. Assumptions relative to redundancy and effect on system reliability due to location of valves are also presented.

b. Reliability Apportionment of Revised Reference Engine Concept

A reliability reapportionment of the preliminary twin TPA engine concept (Figure 57) reference engine was completed and is presented in Table 24. The non-nuclear subsystem (NNSS) was separated into the same four subsystems as in Table 1 in R202-CP090194-F1. The R-202 predicted reliability for the thrust subsystem, pneumatic subsystem, and EPIC were considered unchanged, since no design details were available that reflect the required changes to effect a twin TPA concept.

A new propellant feed system predicted reliability was derived using a mathematical model representing the functional relationship of the components and substituting the R-202 component reliabilities. Three new components are introduced in this design: The thrust-nulling valve (TNV), the diluent control orifice (DCO), and the discharge check valve (DCKV). The

- 1 RELIABILITY OF TPA PATH = $P = \text{PSOV} \cdot \text{TPA} \cdot \text{TBV} \cdot \text{TPCV}$
- 2 RELIABILITY OF TPA NETWORK = $\text{TNET} = P^2 + 2(1-P)P \cdot \text{DCKV}$
- 3 RELIABILITY OF PROPELLANT FEED SYSTEM = $\text{PFS} = \text{TNET} \cdot \text{SSCV} \cdot \text{DCO} \cdot \text{TNV}$
- 4 RELIABILITY OF NONNUCLEAR SUBSYSTEM = $\text{PFS} \cdot \text{THRUST SUBSYSTEM} \cdot \text{PNEUMATIC SUBSYSTEM} \cdot \text{EPIC}$

Figure 57 - Twin TPA Functional Schematic and Reliability Mathematical Models

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reliability of the TNV was assumed to be the same as the TBV, the DCO reliability the same as the PV, and the DCKV reliability was derived from Apollo test history.

The component-apportioned reliabilities in Table 24 were derived by multiplying the ratio of each component predicted failure rate to the total system failure rate times the engine goal failure rate of 0.002. Due to the parallel redundant pump paths the apportioned values of components in each pump network had to be derived by the technique described in Table 25.

These apportioned goals will be revised as soon as additional details of the thrust-nulling concept and the pneumatic supply system are available.

c. Materials Properties Requirements

As agreed upon with SNPO-C a minimum sample of 15 will be used on all materials tests to expedite data for design decisions. From the reliability standpoint, additional information will be obtained on the distribution of data and material use. It was recommended that plots of test data be made on probability paper for inclusion in the Data Book. This information will be used in subsequent reliability analyses of stress/strength.

A sample of 15 specimens is an adequate test level for initial evaluation of materials when no information is available relative to the criticality or the fabrication variables. However, considerable design information is available for many materials that will be used in NERVA. It was recommended that a master test plan be developed for each material relating the material characteristics and variables to the intended use and environments. This planning will help identify the criticality and the number of specimens to be tested for each characteristic.

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The materials test plan will tie in with critical areas identified in the modes of failure analysis for each component and eventually should form a part of the integrated test plan for the components and the engine.

Reliability will assist in preparing the master test plans and relating them to modes of failure characteristics, and assuring that the results fit into the integrated test plan.

d. Materials Test Plans

(1) SS347 Nozzle Material

The test plans presented in Tables 26 and 27 represent a start point in materials property evaluation of 347SS as a candidate for the NERVA nozzle shell forging. These plans establish allowable property values to the "A" basis criteria of MIL Handbook 5 (a value exceeded by 99% of all values at 95% confidence).

Earlier strength data obtained from SN 27 nozzle were used as guides in developing these plans. In addition, statistical testing gave an estimate of the expected influence of the various factors affecting strength levels and their variability and is reflected in the test plan. Existing data will be combined with the data obtained from this test plan, thereby reducing the testing that would otherwise have been required.

Testing to date on 347SS specimens is outlined in Table 26. All tests to date have been conducted on specimens from one heat (SN 27 nozzle), designated as Heat A. To satisfy the general requirements of MIL Handbook 5, the following guidelines have been developed during prior testing:

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(1) A minimum of 35 specimens will be tested at room temperature to establish a reference point on the curves.

(2) A minimum of 10 specimens will be tested at other temperature levels.

(3) The results of several heats will be included in the testing, so that the allowable values obtained will reflect heat-to-heat variability.

Based on these guidelines, the test program presented in Table 27 was developed. The values shown in the table indicate the number of tests required at various temperatures from each of three heats and for the two specimen orientations. Test requirements presented in Table 27 include the tests conducted to date, as presented in Table 26 as a result the 410 total tests specified in Table 27 indicate that 364 additional tests are required to meet the 99/95 requirement.

The proposed test plan has the following attributes:

(1) Sufficient test samples will be available for establishing reference points for both axial and circumferential specimens at room temperatures.

(2) Three heats are sampled, and as a result an estimate of heat-to-heat variability can be statistically derived.

(3) Sufficient testing is provided in each heat to enable estimation of the variations within a heat as a function of temperature. If the heat-to-heat variability is not significant, the results of the three heats can be statistically combined. This will result in a larger sample size for the determination of the allowable strength at each temperature.

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The following general comments apply to this test plan.

(1) If upon completion of testing, more information is required, the test plan can be expanded to provide additional information.

(2) Contingency tests may be added as to the proposed test plan to provide for unforeseen developments in the course of testing.

(3) All of the specimens indicated in Table 26 were taken from the high-stress region of the nozzle shell. As additional specimens are required, sufficient material may not be available in the high stress region, and some of these specimens would be taken from the throat or aft-end regions. Since the material strength can be expected to vary from region to region, the test plan will be statistically designed to enable an evaluation of these variations. Therefore, the number of specimens to be selected, from each region, must be defined prior to the start of testing.

(4) The test plan will provide adequate numbers of test specimens to permit the computation of MIL Handbook-type derived values at other temperatures if desired.

5. Full-Flow Engine Study

A study was completed estimating the reliability differences that might be expected between the hot-bleed and full-flow engines.

a. Method of Analysis

A four step approach was used to compare the reliability of the full-flow and hot-bleed engines.

- (1) Investigate system-related parameters that could affect reliability.
- (2) Prepare reliability block diagrams of the two engines.
- (3) Conduct failure mode analysis of each block in the reliability diagram and using the empirical technique described in the section dealing with failure mode and effect analysis compare reliabilities for major components.
- (4) Combine all reliabilities and compare performance - reliability trades for the system.

b. System Related Parameters

The candidate engines were reviewed for their basic operability through chilldown, startup, steady-state operation, shutdown and cooldown to assure system adequacy for performing all functional requirements.

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Computer studies verified the thermodynamics of startup and steady-state operation, and the adequacy of the engine dynamics. From these studies no major operating problems were identified that would adversely affect the reliability of either engine system.

c. Reliability Block Diagrams

Reliability block diagrams for the two engines are shown in Figure 58. Two significant points were presented in these block diagrams. The first is that out of 17 functional blocks in the engines 14 are common to both engines. Therefore, reliability differences would only result from differences in environment on these common items. The three unique blocks are the turbine block valve and the hot-bleed port in the hot-bleed engine and the turbine shutoff valve in the full-flow engine. The blocking valve is a design feature that could be made common between the two engines, but the bleed port and shutoff valves are unique design requirements to the individual engines.

The second significant point in the reliability diagrams is that all functional blocks except the turbine power control valve and the turbine block valve are in series relative to reliability. In other words, the failure of any series component will result in system failure.

d. Failure Mode Analysis

Qualitative failure mode analyses were prepared for most of the components in the reliability block diagram. The objective of these analyses was to determine (down to the lowest mechanism of failure that could be visualized on a design concept) if there are expected differences in environments or requirements that could effect reliability. The failure mode analyses were conducted using parts of the procedure already described.

Figure 58 - Reliability Block Diagram Full-Flow and Hot-Bleed Engines

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The failure ratings were prepared by design and quality engineers to give a preliminary estimate of the potential reliability of a component. The purpose of the rating is to reflect the qualitative experience, judgment, and opinions of the designers and quality engineers in a semi-quantitative number that can be added to other numbers for reliability comparisons. The resulting numbers are most valuable in comparing candidate designs, but absolute use of the numbers should be avoided.

The ratings are derived in the following manner. First, the designer gives ratings of A, B, C, or D in accordance with the following schedule.

<u>Rating</u>	<u>Description</u>
A	Low probability of occurrence
B	Medium low probability of occurrence
C	Medium high probability of occurrence
D	High probability of occurrence

For example, in considering the mechanism of failure whereby undersize wall thickness results in a pipe burst, a designer should have good confidence in his ability to properly size the pipe because he has experience with and confidence in the design tools he is using and an "A" rating would be expected. Conversely, relative to the thermal stress in a rotating TPA blade in a rapidly changing environment, there are numerous uncertainties associated with designing a part to prevent thermal failure. It is likely a designer might consider this a "B" or "C" item on initial review.

A significant point is that the ratings are probabilities, not absolute conclusions, and a low rating means the mechanism is more likely to cause a problem, not that it absolutely will.

The failure rating is then rated by the quality engineer in accordance with the following schedule.

<u>Rating</u>	<u>Description</u>
1	High probability of detection
2	Medium high probability of detection
3	Medium low probability of detection
4	Low probability of detection

Table 30 shows the reliability comparison for all non-nuclear subsystem components. As shown in the second column, in all but four cases, a detailed failure mode analysis was conducted to arrive at the reliability comparison. For these four components engineering judgment indicates little or no reliability difference between the full-flow and hot-bleed concepts. The third column is the estimated percentage change in failure rate for individual components. The last column is the net non-nuclear subsystem reliability effect of the changes indicated.

The major contributor to system failure rate is the turbopump assembly. A 53% reduction in TPA failure rate is predicted for the full flow over the hot bleed engine.

In both the pump discharge line and the pressure vessel there is only a slight rise in pressure; therefore, a negligible reliability difference is predicted. The diluent line and the hot-gas bleed port are unique to the hot-bleed engine; therefore, the overall effect of eliminating these components from the full-flow engine is an estimated 1% reduction in failure rate. The reason the overall effect is small is that the hot-gas bleed port and the diluent line are assessed to be high reliability components.

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This assessment is predicted upon experience with operating designs developed in the technology program, the capability to subject the components to extensive hot-firing qualifications tests, and the fact that these designs have no moving parts.

The turbine inlet line is expected to have a reduction in failure rate from hot-bleed to full-flow cycle mainly because of a drop in operating temperature from 1660°F to about 300°F. However, designing a turbine inlet line even at 1660° is not expected to be a difficult design job, and the designer's reliability assessment does not identify any problem areas. Therefore, it is a very high reliability component and despite the marked change in its reliability, the net effect on the non-nuclear subsystem is not great, only a 1% reduction in failure rate. The turbine shutoff valve is unique to the full-flow engine. The effect on the full-flow cycle non-nuclear subsystem is to increase the failure potential by 3%. A safety analysis indicates failure of the turbine shutoff valve to be a single failure point, which could result in a catastrophic engine failure. Consequently, the final design most likely would include redundancy in this valve and the effect on the reliability of the full-flow engine would be less than is indicated on Table 30.

The turbine power control valve and the turbine block valve indicate a significant change in reliability from the hot bleed to the full-flow engine because of a reduction in operating temperatures. However, because of planned redundancy, the net system reliability effect is negligible. The thrust vector assembly and the stem coolant valve are also predicted to have negligible changes in reliability. The nozzle will undergo an expected 4% reduction in component failures from the hot-bleed to the full-flow engine. The reason for this is elimination of the hot-bleed port in the full flow engine. The nozzle and nozzle skirt remain the same regardless of engine concept, and therefore are not significant to this trade study.

Considering all component failure modes the principal change in failure rate is the 53% reduction expected for the turbopump assembly. Because the turbopump is the highest failure rate component, the direct system effect for the NNSS of the full flow over the hot-bleed engine is an expected decrease in failure rate of 34%. Consideration of the effect of dual turbopumps on both concepts indicates an overall reliability advantage for the full-flow engine of only 6% as compared with the 34% improvement for the single TPA trade off.

e. Performance - Reliability Trades

Systems analyses indicate significant reductions in operating (chamber) temperature as a result of changing from the hot-bleed to the full-flow engine. A marked reduction in the required operating temperature is noted for the full-flow engine with either single or dual TPA's. The single TPA hot-bleed engine requires operating temperatures ranging from 4450°R to 4650°R, while for the full-flow engine, the required temperatures range is only 4305°R to 4410°R in order to meet the 825 sec I_{sp} requirements. This reduction in operating temperature does not affect the reliability of the non-nuclear subsystem components, but there is a marked effect on the nuclear subsystem.

The nominal reliability requirement for the NERVA engine is 0.995 at a specific impulse of 825 seconds with a chamber temperature of 4500°R. This basic reliability requirement is apportioned to the nuclear subsystem and the non-nuclear subsystem as 0.997 and 0.998, respectively.

The nuclear subsystem reliability relationship with core exit temperature has not been precisely defined. There are, however, a number of things known about the nuclear subsystem that permit a qualitative assessment of this relationship. Specifically, there are three known factors. The first is that the nuclear subsystem reliability requirement is 0.997 at

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4500°R. The second is that within the temperature range 4700 to 5000°R, a practical limit is reached where the core cannot operate for the required time and at this point reliability will approach zero. The third point is that for temperatures below 3700°R the nuclear subsystem reliability is relatively constant at about 0.997+. Assuming that corrosion ultimately limits reliability, a relatively smooth relationship between reliability and temperature would be expected.

A summary of this expected relation between reliability and core exit temperature is shown in Figure 59. Also shown are the required nuclear subsystem reliabilities to give an engine system reliability of 0.995. These data are based on the assumption that the hot-bleed, single-TPA system meets its reliability goal of 0.998. The corresponding required nuclear subsystem reliability is 0.997, giving an engine reliability of 0.995.

The non-nuclear subsystem reliability was changed (from the basic) engine to other engines using the ratios computed from Table 30 and the required NNSS reliability computed to give an engine system of 0.995.

The significant conclusion from Figure 59 is not the numbers, since these are based on assumptions, but the spatial relationship of the full-flow and hot-bleed reliability requirements. The full-flow engine can be operated at either a significantly improved reliability at constant specific impulse or at a higher specific impulse at the same reliability. This relation will hold whether the base operating temperature which meets the reliability goal is higher or lower than 4500°R.

In summary, the non-nuclear subsystem with single TPA will experience a 34% reduction in failure rate for the full-flow engine cycle compared with the hot-bleed cycle due primarily to improved turbo-pump reliability. With dual TPA's this relative advantage drops to 6%. In the nuclear subsystem, there is an additional advantage for the full-flow

Figure 59 - Required Reliability for 0.995 Engine Reliability

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concept due to operating temperatures. From the engine system standpoint there is a much greater potential of meeting the overall engine requirement of 0.995 at 825 I_{sp} with the full-flow engine concept.

TABLE 20

DESCRIPTION OF FAILURE-MODE-ANALYSIS INPUT

Column 1 - Engine Failure Mode (Table 29)

The purpose of this column is to relate the component mechanisms of failure to its effect on the engine.

The following define the five columns:

- (1) Failure to start
- (2) Performance out of specification
- (3) Sudden and irretrievable loss of LH₂
- (4) Failure to shutdown
- (5) Failure to cooldown

Column 2 - Component Mode of Failure

The component mode of failure should describe the condition of the component after it has failed. This column will generally be prepared by the component designer and others if additional modes are identified.

Column 3 - Component Failure Mechanism (Part Level)

Identification No. - This is a code number that increases numerically as additional mechanisms are identified. The purpose is to key the various pages of the FMA together. Some analyses on an individual mechanism of failure will be on succeeding pages and a common tie-in is necessary.

Description - These are the mechanisms that result in the mode of failure described in the previous column. These will be filled in initially by the designers and added to by the subsequent analysts if additional mechanisms are identified. Component mechanisms will be identified primarily on the

TABLE 20 (cont.)

basis of past experience refined to indicate (a) conceptual configuration, (b) comparative environments and (c) NERVA duty cycle requirements. Each mechanism will be analyzed in detail by all personnel participating in the failure mode analysis.

Column 4 - Mechanism Sensitivity

This column designates conditions to which the mechanism of failure is most sensitive. The appropriate column is checked for each mechanism as applicable.

Column 5 - Ratings

The ratings are prepared by design and quality engineers to give a preliminary estimate of the potential reliability of a component. These are converted into a failure rate estimate via the matrix shown on Table 28. The purpose of the rating is to reflect the qualitative experience, judgment, and opinions of the designers and quality engineers in a quantitative number, which can be added to other numbers for reliability comparisons. The resulting numbers are valuable in comparing candidate designs and absolute use of the numbers should be avoided.

As a design progresses these qualitative judgments can be eliminated and replaced with detailed calculations, or more preferably, with statistically analyzed test data.

R_D

This is the column filled in by the designer. The following describes the input:

TABLE 20 (cont.)

<u>Rating</u>	<u>Description</u>
A	Low probability of occurrence
B	Medium low probability of occurrence
C	Medium high probability of occurrence
D	High probability of occurrence

TABLE 20 (cont.)

This column is filled in by the quality engineer using the following guide:

<u>RATING</u>	<u>DESCRIPTION</u>
1	High probability of detection
2	Medium high probability of detection
3	Medium low probability of detection
4	Low probability of detection

The prime concern of the quality engineer is, does he have the tools to detect a mechanism of failure before it results in an engine failure. This includes all normal Q.C. tools including inspection procedures, process control, acceptance testing, and performance monitoring.

The procedure used in conjunction with Table 28 requires that each mode of failure have one failure rate. This column provides a weighting factor that identifies the relative importance of each mechanism of failure to the mode of failure. This adjustment is agreed to jointly by the design and reliability engineers with review by all analysts.

Column 6 - Design Analysis

In this column the designer gives the analyses that resulted in the preliminary rating, the more comprehensive and detailed this analysis is, the more valuable the FMA becomes. As the design progresses the FMA will be upgraded and the design analysis will change.

TABLE 20 (cont.)

Column 7 - Quality Analysis

In this column the quality engineer provides the analyses that lead to his rating. He should provide detailed descriptions of the inspection techniques or controls he intends to use and provide estimates on probability of detection. If additional refinements are needed, these should be so indicated to show the need for a development effort in quality technology. As the design progresses and experience is obtained, the upgraded versions of the FMA should reflect this increase in knowledge.

Column 1 - Page, Table 29, Failure Mech. Identification No.

This column corresponds to the identification number in Column 3, Page 1, and is used to key the analyses together.

Columns 2 - 6, Page 2, Table 29

Detailed analyses by the various program talents are required in these columns. The objective is to identify or emphasize problems associated with each mechanism and to define the studies being done in the specialty areas, which have a bearing on each mechanism of failure. By rigorous analysis of each mechanism of failure, the program is assured that no critical analyses or test programs will be overlooked. In early issues of the FMA, the specialty analysts can refer to prior studies which support their conclusions, indicate studies which are planned to support their conclusions, or development efforts that are required to obtain the analytical techniques or data to assure there is no reliability problem. As the development effort proceeds, the analysis will be changed to reflect the additional supporting data which have been acquired.

TABLE 20 (cont.)

Column 7 - Page 2, Table 29 Reliability Analysis

Reliability will be responsible for scheduling the overall FMA effort, training the various talents in FMA procedures, coordinating analyses, providing input where needed, and summarizing all analyses.

Reliability will also coordinate the component FMA effort into the system studies to assure that all component failure modes and the interaction of failures are properly assessed in system studies.

Reliability will assure that sufficient studies are made to enable comprehensive predictions and assessments of engine system reliability and the means by which the FMA's are to be integrated into the system reliability predictions will be shown. Reliability will coordinate with safety to integrate the component analyses into the system fault tree effort.

TABLE 21

RELIABILITY RANKING OF THRUST-NULLING CONCEPTS

Rank	<u>Total Capability</u> ⁽⁴⁾		<u>Thrusting Capability</u>		<u>Nulling Capability</u>	
	Concept No.	Failure-Rate Ratio (1)	Concept No.	Failure-Rate Ratio	Concept No.	Failure-Rate Ratio
1	1(press) ⁽²⁾	--	1	--	1(press)	--
2	3	2.7	6	0.36	3	15.2
3	2	8.1	8&9	0.45	2	57.3
4	8&9(3)	18.2	2	0.58	1(pump)	66.1
5	5	18.9	3	0.81	4	111.1
6	7	19.2	7	0.81	8&9	134.5
7	1(pump)	22.0	5	1.65	5	139.8
8	4	26.4	10	8.2	7	139.8
9	6	43.6	4	13.4	6	326.3
10	10	48.2			10	310.2

Ranking of Nulling Concepts Using Pressurized Flow Only

Rank	<u>Total Capability</u>	<u>Thrusting Capability</u>	<u>Nulling Capability</u>
	Concept No.	Concept. No.	Concept. No.
1	1	1	3
2	3	2	1
3	2	3	2
4	4	4	4

Ranking of Nulling Concepts Using Pump Assisted Flow

Rank	<u>Total Capability</u>	<u>Thrusting Capability</u>	<u>Nulling Capability</u>
	Concept. No.	Concept.No.	Concept No.
1	8&9	6	8&9
2	5	8&9	5
3	7	7	7
4	1	5	1
5	6	10	10
6	10		6

(1) Failure Rate Ratio is % increase in failure rate over Concept No. 1 failure rate.

(2) Concept 1 considered as pressure-fed and a pump-fed system.

(3) No measurable difference between nominal and optimistic concept.

(4) Total capability depends on the capability to perform a single thrusting cycle and a single nulling cycle.

TABLE 22
THRUST-NULLING-CONCEPT TOTAL FAILURE RATES

Component			Generic Failure Rate f/10 ⁶ cycles	System No. Description Thrust/ Null	Pressure-Fed Systems								Pump-Fed Systems								10				11				12					
					1		2		3		4		5		6		7		8 & 9															
					Quench		Counter Bal. Stems		Nominal Stems		Advanced Stems		Nominal Stems		Advanced Stems		Axially Exhausted		Radiator		Split Flow		Throat Choke		Balanced Thrust									
No.	Name	Function			T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N				
Thrusting Components	1	Liquid Retainer - PSOV	Oper. Full Press.	300							300																							
			Oper. Null Press.	100							100																							
	2	PSOV	Cycle Leak	184 25	184 25	184 25	0	184 25	0	184 25	184 25	184 25	0	184 25	0	184 25	0	184 25	184 25		184 25	184 25	184 25	0	184 25	184 25								
	3	Main Pump	Oper. Full Oper. Low	1706 568	1706 568	1706		1706		1706	1706	1706	1706	1706	1706	568	1706	1706		1706	568	1706	568	1706	568									
	4	SSCV	Control	144	144	144		144		144	144	144	144	144	144	144	144	144		144	144	144	144	144	144									
	5	Disch. Throt. Valve (DTV)	Control	144							144					144																		
	6	TNV (1) (2)	Cycle Cycle	144 144			144		144		144		144		144 144		144		144					144										
	7	TPC Network	Control	8	8	8		8		8				8	8	8		8			8	8	8	8	8	8	8	8	8	8	8			
	8	Check Valve	Reverse Leak	5										10		5		10		10														
	9	Pressure Vessel-Chamber	Contain Full Press.	170	170		170		170		170		170		170		170		170		170		212		170									
Nulling Components			Contain Tank Press.	6		6		6		6																								
			Contain AP Press.	57									57		57		57		57				57		65		5							
	10	Liquid Retainer - NSOV	Oper. Null Press.	100			100		100				100		100		100				100		100		100									
	11	NSOV	Cycle Leak	144 8		144 8		144 8		144		8	144 8	144 8	144 8	144 8	144 8				8	144 8	144 8	144 8	144 8									
	12	AP-AT	Operate	213									213				213																	
	13	DTV-AP	Control	144		144							144				144		144															
	14	TPCV-AP	Control	8										8				8																
	15	Check Valves	Reverse Leak	5		5		10					10				10		10															
	16	Compressor - Turbine	Oper. Null Level	213															213	Ducts	80	27	2287	1173										
	17	Radiator	Contain Turb. Press.	50															50	Valves	120	171	+	+	Unknown									
Total Failure Rates			Thrust	2237	2250	2255	2537	2274	2245	2255	2247	2420																						
			Null - Press.	342	538	394	722													1403														
			Null - Pump	910								820	1458	820	802																			
			Combined	2579	2788	2649	3259	3067	3703	3075	3049	3823	3460+	3050+																				

TABLE 23

COMPONENT FAILURE RATES

Item	Component	Failure Rate	Remarks
1.	Liquid Retainer	100 300	A number of design concepts are being considered. An arbitrary failure rate of 100 was assigned to the secondary nulling flow liquid retainer and three times that rate was assigned when using in the main propellant feed system - 300.
2.	PSOV	184	Reference (1) using Apollo test history derives a failure to open, slow open, and internal leakage of 184. Operating at lower flow rates has no effect on the mechanical failure probability.
3.	Main Pump Turbine	1706	Reference (1) using Titan test history derives a fail to start, low performance, and premature shutdown of 1706.
4.	SSCV	144	Reference (1) using Apollo test history derives a valve timing and slow-opening failure rate of 144.
5.	DTV	144	Discharge throttle valve was assumed to have the same failure probability as the SSCV.
6.	TNV	144	Thrust-nulling valve was assumed to be a normally closed valve and the failure to open was derived from Apollo test history as 144. Failure to close of a normally closed valve is considered negligible.
7.	TPCV Network	8	Reference (2) assuming two parallel redundant paths each containing a TPCV and a TBV derived a network failure rate of 8.
8.	Check-Valves	5	Reference (2) derives a probability of reverse leakage of 5. Failure to open or close is considered negligible.

- REFERENCES: (1) Derivation of Predicted Component Reliability Values Presented in Reliability Assessment and Analysis Report dated September 1968.
 (2) Reliability Assessment and Analysis Report - September 1968 - R202-CP090194-F1.

TABLE 23 (cont.)

<u>Item</u>	<u>Component</u>	<u>Failure Rate</u>	<u>Remarks</u>
9.	Pressure Vessel and Chamber	170	Reference (1) using Titan test history derives a nozzle and skirt failure rate of 170. The pressure vessel is assumed to be 1. Operating at tank pressures lowers the failure rate by the ratio of operating pressures. Approximately 1/30 reduces the rate to 5.7 from 170. Operating with auxiliary pump pressures the failure rate is 1/3 the full thrust or 57.
10.	Liquid Retainer - NSOV	100	See Item 1.
11.	NSOV	184	Mechanical probability is assumed to be the same as the PSOV. Internal leakage potential is one third of the PSOV primarily due to the smaller size.
12.	AP-AT	213	Auxiliary pump and turbine is estimated to have 1/8 the failure probability of the main turbine pump assembly.
13.	DTV-AP	144	Discharge throttle valve-auxiliary pump was assumed to have the same failure probability as the SSCV.
14.	TPCV-AP	8	Turbine power control network for the auxiliary pump was assumed to have the same network failure probability as the main pump network.
15.	Check Valves	5	Since the valves are exposed to the same back pressures as the main propellant feed system the failure rate is the same - 5.
16.	Compressor - Turbine	213	The compressor and turbine for the radiator were assumed to have the same failure rate as the auxiliary turbine - pump assembly.
17.	Radiator	50	The radiator was assumed to have one third the failure rate of the chamber and nozzle.

TABLE 23 (cont.)

<u>Item</u>	<u>Component</u>	<u>Failure Rate</u>	<u>Remarks</u>
18.	Core Plunger and Shutoff Valve	-	Inadequate details to derive a meaningful failure rate.
19.	Balanced Thrust End Plates	-	Inadequate details to derive a meaningful failure rate.
20.	Split Flow	80	Current estimate of hot-bleed-port failure rate is 40. Two ducts equal 80. One third the failure probability during nulling due to lower pressures = 27.
		27	
		120	Valves assumed to have five times the leakage probability of the PSOV due to high temperature environment.
		171	Valves assumed to have a 25% increased mechanical failure probability due to high-temperature environment.
21.	For two valves in series the probability of both leaking simultaneously was considered negligible.		
22.	Valves in critical locations that can shut off all coolant to the reactor are assumed to be designed to fail in the coolant flow position. If this is not possible parallel valves may be used that will essentially double the valve nulling function failure rate but makes the probability of loss of coolant flow negligible.		

TABLE 24

NONNUCLEAR SUBSYSTEM (NNSS)
PREDICTED AND APPORTIONED RELIABILITY
FOR TWIN-TPA CONCEPT

	<u>Predicted Reliability</u>	<u>Goal</u>
Nonnuclear Subsystem	0.982285	0.998000
		<u>Apportioned Reliability</u>
1. Propellant Feed System (PFS)	0.996878	0.999611
a. Pump Network	0.999516	0.999940
1. PSOV	0.998161	0.999356
2. TPA	0.983173	0.994109
3. TBV	0.998860	0.999601
4. TPCV	0.998310	0.999408
5. DCKV (Discharge Check Valve)	0.999600	0.999950
b. SSCV	0.998500	0.999813
c. DCO (Diluent Control Orifice)	0.999999	0.999999
d. TNV (Thrust Nulling)	0.998860	0.999858
2. Thrust Subsystem	0.997511	0.999690
a. Nozzle and Skirt	0.998300	0.999788
b. Pressure Vessel (PV)	0.999999	0.999999
c. Thrust Structure	0.999999	0.999999
d. Thrust Vector System	0.999210	0.999902
3. Pneumatic Subsystem (PSS)	0.990551	0.998823
4. Electrical-Electronic Subsystem (EPIC)	0.999000	0.999876

TABLE 25

RELIABILITY APPORTIONMENT OF PUMP-NETWORK COMPONENTS

Referring to Table

(2) $TNET = P^2 + 2(1-P)P \cdot DCKV$

(1) $P = PSOV \cdot TPA \cdot TBV \cdot TPCV$

Using Enclosure (1) predicted reliability for TPA path components in equation (1)

$$P = 0.978589$$

and $DCKV = 0.999600$ from Apollo test history.

Assuming that the ratio of apportioned unreliabilities will remain in the same ratio as the predicted ratios.

$$\frac{1-P}{1-DCKV} = K = 53.5275$$

(3) Then $DCKV = 1 - \frac{1-P}{K}$

Substituting (3) in (2) for DCKV:

(4) $TNET = P^2 + 2(1-P)P \left[1 - \frac{1-P}{K} \right]$

Enclosure (1) provides an apportioned reliability for TNET of 0.999941
Substituting in (4) the values for TNET and K the apportioned value of P solved by trial and error is:

(5) $P = 0.9924695$

Substituting this value into (3) an apportioned value for DCKV may be derived.

$$DCKV = 0.9998593$$

The apportioned failure rates for the TPA path components are derived from equation (1) using the ratio of predicted component failure rate to predicted TPA path failure rate times the apportioned path failure rate.

TABLE 26

AVAILABLE STRENGTH DATA; NOZZLE SN 27, 347 STAINLESS STEEL

<u>Heat Orientation</u>		<u>Number of Specimens</u>						<u>Totals</u>
		<u>-320°F</u>	<u>RT(70°F)</u>	<u>600°F</u>	<u>1200°F</u>	<u>1400°F</u>	<u>1600°F</u>	
A	Circumferential	5	15	5	5	5	5	40
	Axial		6					
B	Circumferential							
	Axial							
C	Circumferential							
	Axial							
Totals:		5	21	5	5	5	5	46

TABLE 27
 PRIMARY TEST PLAN FOR ALLOWABLE YIELD STRENGTH*;
 347 STAINLESS STEEL FOR NOZZLE FORGINGS

<u>Heat</u>	<u>Orientation</u>	<u>Number of Specimens</u>						<u>Totals</u>
		<u>-320°F</u>	<u>RT (70°F)</u>	<u>600°F</u>	<u>1200°F</u>	<u>1400°F</u>	<u>1600°F</u>	
A	Circumferential	10	35	10	10	10	10	85
	Axial	10	35	10	10	10	10	85
B	Circumferential	10	10	10	10	10	10	60
	Axial	10	10	10	10	10	10	60
C	Circumferential	10	10	10	10	10	10	60
	Axial	10	10	10	10	10	10	60
Totals:		60	110	60	60	60	60	410

* "A" basis per MIL Handbook 5

TABLE 28
PROCEDURE FOR ESTIMATING RELIABILITY DURING
CONCEPT SELECTION PHASE OF DESIGN

This method estimates reliabilities of mechanical components in a system during the conceptual development phase. It qualifies and combines the judgments of design and quality engineers, so that their resulting estimate of a component's reliability can be compared with its apportioned reliability goal or with the reliability estimates for other candidate designs. In this type of evaluation the reliability estimates have importance as relative rather than absolute values.

The method requires the system to be divided into components that will be considered as design entities. A failure mode analysis is then conducted on each of these components by design and quality engineers. In performing this analysis, the engineers consider all environments to be encountered during the entire life cycle of the component and rate the failure-producing potentials. These potentials are combined into a single rating analysis by using the following empirical table to convert the engineering judgments into numerical values:

FAILURE RATE POTENTIAL VALUES
QUALITY RATING

		1	2	3	4
Design Rating	A	1×10^{-6}	10×10^{-6}	100×10^{-6}	1000×10^{-6}
	B	10×10^{-6}	100×10^{-6}	1000×10^{-6}	10000×10^{-6}
	C	100×10^{-6}	1000×10^{-6}	10000×10^{-6}	100000×10^{-6}
	D	1000×10^{-6}	10000×10^{-6}	100000×10^{-6}	1000000×10^{-6}

TABLE 29
COMPONENT MECHANISM OF FAILURE ANALYSIS
SHEET 1 OF 2

ESTIMATED RELIABILITY - _____
DESIRED RELIABILITY - _____

System _____
Subsystem _____

ENCLOSURE (2)
Component: _____
Dwg. No.: _____
Issue Date: _____
Prepared by: _____

ENGINE FAILURE MODE ⁽¹⁾					MECHANISM SENSITIVITY ⁽²⁾		RATING ⁽³⁾			Failure Rate per 10 ⁶	JUSTIFICATION OF DESIGN RATING	JUSTIFICATION OF QUALITY RATING		
1	2	3	4	5	Ident No.	COMPONENT FAILURE MECHANISM DESCRIPTION (PART LEVEL)	Time Cycle	Stor- age	R _D	R _Q	Wt.	ANALYST:	ANALYST:	
COLUMN 1					COLUMN 2		COLUMN 3		COLUMN 4		COLUMN 5		COLUMN 6	COLUMN 7

TABLE 29
COMPONENT MECHANISM OF FAILURE ANALYSIS
SHEET 2 OF 2

ENCLOSURE (2)
Component Name: _____
Component Dwg No.: _____
Date of Issue: _____
Prepared by: _____

Failure Mech. Ident.	STRESS ANALYSIS	MATERIALS ANALYSIS	RADIATION ANALYSIS	THERMAL ANALYSIS	SYSTEM ANALYSIS	RELIABILITY ANALYSIS
Number	Analyst -	Analyst -	Analyst -	Analyst -	Analyst -	Analyst -
COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5	COLUMN 6	COLUMN 7

TABLE 30

COMPARISON OF PREDICTED CHANGES IN FAILURE RATE BETWEEN
THE FULL-FLOW AND HOT-BLEED ENGINES, NONNUCLEAR SUBSYSTEM

<u>Item</u>	<u>Type Analysis</u>	<u>% Change in Failure Rate</u>	<u>Effect NNSS</u>
PSOV	FMA	Negligible	Negligible
TPA (Single)	FMA	-53%	-35%
PDL	FMA	Negligible	Negligible
Pressure Vessel	FMA	Negligible	Negligible
DIL Line	FMA	NA	
HGBP	FMA	NA	-1%
TEL	FMA	Negligible	Negligible
TIL	FMA	-80%	-1%
TSOV	FMA	NA	+3%
TPCV	FMA	Negligible	Negligible
TBV			
TVA	FMA	Negligible	Negligible
SSCV	FMA	Negligible	Negligible
Nozzle	FMA	-4%	Negligible
Skirt	FMA	Negligible	Negligible
Skirt Extension	Qualitative	None	None
PSS	Qualitative	None	None
I&C	Qualitative	None	None
T.N.	Qualitative	None	None

Predicted % NNSS failure reduction = 34%; with dual TPA's, the predicted NNSS failure reduction = 6%

*Valves are in parallel for reliability comparison.

Project 271

F. TEST OPERATIONS

Project 271 - General Support - NRDS

Suffix b - Technology

1. Technical Support

The Technical Support Group participated in preparation of the following program plans.

a. Shielding - This plan was a joint NRO-NTO effort and was issued as RN-S-0507. In essence, a Flexible Engine Shielding Test Facility (FESTF) is proposed to accommodate early facility shielding studies in support of ETS-1, which will eventually have the capability for engine and crew shield design and test applications. XE-Backup would be the preferred neutron/gamma source.

b. Radiation Effects - An evaluation was made including heat-exchanger (10 Mw), dome-end redesign and modification costs for XE-B, and electrical rehabilitation of TCA.

c. Site Utilization - A preliminary descriptive draft was prepared describing site capabilities in several applications, including testing of the dual-pump and the full-flow concepts.

d. Cryogenic/Leak Test Facility - A conceptual study of a cryogenic/leak test facility at ETS-1 was prepared and circulated for internal NTO review.

e. Fuel Recovery - In conjunction with E-MAD personnel, process engineering was undertaken in support of a system for nuclear fuel recovery. Empirical studies of flotation methods with crushed fuel were made and a technique was developed for fuel recovery.

2. Documentation and Reporting

a. NTO-A-0050 - Engineering Procedures Manual was released for review. This procedure discusses the general area of Change Control and the format and process followed in preparation of drawings, specifications, standards and proposals.

b. Work Authorization Procedures - A format and procedure were developed in conjunction with, and approval by SNPO-N, for early release.

c. Air Force Systems Management - Techniques were further exploited in the preparation of all guiding documentation. Data Item applications to the engine program were explored.

d. ETS-1 Electrical Preventive Maintenance - Checklists were completed and issued.

e. Contributions were made to content, audit and closeout of various Program Directives.

f. Specifications for use in conjunction with the base-line drawings have been requested and this requirement is being evaluated.

During this quarter, Documentation and Reporting issued a total of 90 procedures as follows: 35 Standard Operating Procedures (SOP) (these include procedures for the checkout of XE-Prime Engine Control System, Average and Reject Circuits); six Test Operating Procedures (TOP), including XE-Prime EP-IIA; one XE-Backup procedure was made final and issued; four reports were distributed, including SPEAR Team Report on XE Prime EP-IA and EP-IB; thirty-one guides; and ten administrative procedures were made final and distributed.

3. Engineering

a. Seismic Event - In preparation for the seismic event, an analytical support and drafting effort were provided in conjunction with Source Engineering. This total effort included preliminary analysis for program impact as well as design and drafting of structural configurations for the event.

b. Seismic Design - An extension of the seismic event is in process as a permanent solution to the problem of seismic loads at NRDS.

c. RSMF Brakes and Couplers - A program of modification of the brakes and couplers of much of the NRDS rolling stock (RR) was undertaken. Design and review of design continue. Procurement of components for a test fixture is in process.

d. Failure mode analyses of E-MAD electrical controllers are complete and recommendations have been made.

e. NTO personnel participated in the preliminary reviews of the criteria for the Modular Engine Test Stand (METS).

f. Dosimetry - Recovery and analytical assistance were provided in support of ETS-1 low- and intermediate-power dosimetry EP's.

4. Drafting

a. The ETS-1 Baseline Drawing Matrix 000-3300-F-001 and Drawing Tree 000-3300-Y-001 have been finalized and approximately 300 drawings have been completed.

Project 274

A tentative matrix and drawing tree has been prepared for E-MAD and is currently undergoing E-MAD management review.

Project 274 - MAD Operations-Engine

Suffix b - Technology

1. XE-Prime

At the start of this report period the XE-Prime engine had been returned to the E-MAD hot bay for storage during the seismic event. While at E-MAD a concentrated effort was made to determine and correct the discrepancies noted during the test program at ETS-1. All work on the engine was accomplished per procedure XE-Prime-P15 and changes approved by the TRB.

The engine was returned and installed into ETS-1 on 7 January 1969 per procedure XE-Prime-P16. Checkout of the engine at this time was per XE-P9, Rev. 1. Testing is now being conducted per test specification requirements and approved procedures.

Several modifications were incorporated into the test article after reinstallation and this work was accomplished per approved changes to XE-P9, Rev. 1.

a. The following hardware changes and checkouts were performed:

- (1) Checkout of control drum actuators.
- (2) Dosimetry and insulation installation.
- (3) Rework of TE-971.
- (4) Listing of I&C channels.
- (5) Eliminate ground in Module E.
- (6) Compartment purge line seal.
- (7) Install flex lines.

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- (8) Replace fast-neutron detectors.
- (9) Repair Channel TE-900.
- (10) Install North American insulation.
- (11) Repair Channel TE-900.
- (12) Replacement of fast-neutron detectors pre-amplifier.
- (13) Replacement of CVV.
- (14) Reclamp flex lines to TBV.

b. The XE-Prime engine log supplement was prepared and presented to the TRB.

c. The spare actuator amplifier was tested as requested by WANL.

d. The XE-Prime engine pretest report, for NTO review was completed.

e. The engine installation vehicle was used for retrieval of low-level dosimetry after EP-1B.

f. A study was made to determine the problems that would be encountered if the TPCV actuator was to be replaced after EP-2, EP-3, or EP-5. This study took into account radiation levels to be encountered and actual time required for performing the work. The preliminary survey showed that by using the EIV as a work platform, the removal could be accomplished without excessive personnel radiation dosages.

g. Preparation of a procedure for retrieval of the test article after completion of the test program is in progress.

2. XE-Backup

Assembly of the Backup engine as required for the Technology Program continued with the major effort being made to assure that the same modifications were incorporated into both the Prime and the Backup engines. The assembly was performed per approved procedures and changes to the procedures approved by the TS&PRB. Problems that caused delays are as follows:

- a. Rework of the UTSM and Lower Module Assembly, Turbine Inlet Line sections at NRO.
- b. Late receipt of the TPCV D-2 actuator. To expedite the assembly a D-1 actuator was installed to permit mate-up.
- c. Malfunctions of the CVV in the XE-Prime engine at ETS-1 required that the CVV installed in the Backup engine be removed for use in the Prime engine. The replacement CVV was received 3/7/69.

A general summary of the work performed during this period is as follows:

- a. Prepared and presented to the TS&PRB the following procedure changes, which were approved:
 - (1) RN-S-0352, Change 43 - WANL Mod. 20, Rev. 1. checkout of control drum actuators.
 - (2) Relocate TBV and modify the TPCV exhaust line.
 - (3) Relocate engine purge check valve.
 - (4) Leak check of PDVV.
 - (5) Removal of CVV.
 - (6) Modify remote couplings for TIL line.
 - (7) Replace flex hoses.

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- (8) Install D-1 TPCV actuator.
- (9) Install CVV.
- (10) Checkout of control drum actuators.
- (11) Replaced accelerometer fasteners.
- (12) Seal MGO cables.
- (13) Repair channel MG-805.
- (14) Re-installation of the TIL, PDL and TBV instrumentation.
- (15) Routed cable for channel.
- (16) Incorporated TSCR's into referenced documents.
- (17) Installed bulkhead seals.
- (18) Removal of unused module pins.
- (19) Leak check of UTSM valves.
- (20) "B" nut torque check.
- (21) Replace TIL bolts.
- (22) Leak check of external shield.
- (23) Replaced damaged keensert in shield.
- (24) Installed insulated shield baffle.

b. During checkout of engine for XE-1-P4, Rev. 1, a large number of discrepancies were detected relating to instrumentation and control circuitry. These discrepancies included items that have been changed because of change in direction of assembly of Backup and Prime engine, which required removal and reinstallation of selected channels and low-insulation readings found in the magnesium-oxide shield conductors. All discrepancies were documented on QRDR's and have been dispositioned through the TS&PRB.

c. The CVV was removed for use in the Prime engine, but before removal, leak checks were performed on both the CVV and PDVV to eliminate leakage through the seats and to assure that the CVV was satisfactory for use. The leakage test showed no seal leaks in either valve.

Project 274

d. Several tests were run to determine if the torque on the "B" nuts was relaxing with time. The amount of relaxation detected agreed with data obtained from "B" nut vendors.

3. E-MAD Facility

Updating and repairs of the RTS are as follows:

- a. Replacement of the leveling units on the EIV carriage.
- b. Repair of the inching drive.
- c. Termination of the electrical connectors in the umbilical system was again completed.
- d. The railroad couplings on the MCC were reviewed to determine if the vertical movement in the coupler was per drawing. Railroad specifications called for approximately 2-1/2 in. movement in this complex. Inspection of the MCC couplers showed that the rubber bumpers used to provide flex had taken a permanent set. Parts were ordered to replace the rubber bumpers.

The Technology Program requirements were reviewed and a summary of remaining effort was prepared.

A program was started to provide operation and maintenance procedures for all E-MAD equipment.

Preparation of an operations procedure for the Master Control Room is in progress.

Project 275

Project 275 - ETS 1 Operations

Suffix b - Technology

1. XE-Prime Test Program

The ETS-1 final facility checkout test was conducted on 12 February 1969 to verify the integrity and operational readiness of systems to be used during XE-Prime EP-IA. Anomalies encountered included internal leakage in the XE-Prime cooldown vent valve, digital data system noise problems and unsatisfactory results during the loss-of-power test. Correction of these problems resulted in postponing XE-Prime EP-IA from 19 February to 20 February 1969.

Experimental Plan IA of the XE-Prime test series was performed on 20 February 1969. The objectives were successfully met and consisted of thermal calibration at 1 Mw, nuclear autostart to 100 Kw, measurement of integral worth of drums 1 and 7, and intermediate power dosimetry irradiation determinations. Test details are presented in SPEAR Report NTO-R-0166.

Experimental Plan IB of the XE-Prime test series was conducted on 27 February 1969. The primary objectives consisted of steam generator system checkout after incorporating the recommendations from EP-SL2 and verification of nonproducing interactions between the engine and facility systems. A malfunction of the steam generator main stage fuel-purge valve prevented fulfillment of all steam generator system checkout objectives. All of the remaining test objectives were met, and no engine interactions were encountered. Test details for EP-IB are contained in SPEAR Report NTO-R-0167.

Following the correction of facility and steam generator anomalies encountered during XE-Prime EP-IB, Experimental Plan II of the XE-Prime test series was started on 13 March 1969. With the steam generator

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system in operation and the reactor at a power level of 33 Kw, it was necessary to terminate the test because of adverse wind direction.

EP-IIA of the XE-Prime test series was conducted on 20 March 1969. This test was the first start, to significant power, of a nozzle-down nuclear engine firing under simulated altitude conditions. The test consisted of three nuclear-powered bootstraps to pressure and temperature loop closure. Peak power obtained was 201Mw, 204Mw, and 126Mw. The objectives of EP-IIA were met and consisted of system checkout under LH₂ flow conditions, verification of valve sequencing and instrumentation performance, verification of control system temperature loop closure, and confirmation of initial portions of XE-startup predictions. Details of the test are contained in SPEAR Report NTO-R-0168.

2. Facility Modifications

Modifications that were completed on various facility systems in support of the scheduled experimental plans included the following items:

a. Facilities

(1) Restoration of the ETS-1 facility following the seismic event of 19 December 1968.

(2) Replacement of Area 32 stainless-steel valve guides with bronze guides to prevent galling of the remotely operated stainless-steel valve stems.

(3) Vent modification for maintaining LH₂ run vessel in an inert condition and positive pressure to prevent the ingestion of airborne contaminants during none-use periods.

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(4) Means to prevent GN_2 intrusion into the GHe engine coolant and to eliminate a nonrequired valve from the liquid accumulator.

(5) Remote control and indications for the turbine bearing purge heater HT-001 and the UTSM purge system heater HT-002.

(6) Installation of fail-safe features for the V-5002 pressurization system to prevent stalling the pump and over-cooling the engine under certain malfunction conditions.

b. Control Systems

(1) Correction of TSCS/ECS design deficiencies resulting from field activation of the TSCS/ECS.

(2) Isolation of P836 meter from all data inputs to enable valid meter readings.

(3) Modification of the nozzle torus pressure and V-5002 ullage pressure differential computation to provide the ASE operator with information to maintain the V-5002 ullage pressure within acceptable limits.

(4) Provision of sufficient drive to the TPCV torque motor to overcome mechanical bias of the motor at low temperature and means to prevent activation of the TPCV override due to step opening of TPCV.

(5) Improvement of controls over bootstrap operations by providing a variable clamp on TPCV opening and disabling of TPCV schedules to eliminate an extreme TPCV transient during wet temperature autostart.

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(6) Changes in the TSCS/ECS resulting from XE-Prime engine operation requirements.

(7) Test stand simulator (TSS) modifications resulting from changes in engine cooldown requirements.

(8) Removal of interlock between the electrical actuation circuit of pump discharge vent valve (PDVV) and turbine block valve (TBV) to enable pretest leak check of pump discharge check valve (PDKV) and additional operational flexibility for minimizing TBV cycling.

(9) Increase of the turbine power control valve (TPCV) pressure compensation to eliminate marginal TPCV pressure controller loop stability.

(10) Changes in PCV-754 in the LN₂ engine cooldown system so that it will fail in the closed position in order to maintain pressure in the LN₂ engine cooldown system.

(11) Incorporation of redundant control power to TSCS valves RSV-107 and RSV-545 and an active/bypass switch on the ASE console for the V-5002 overpressure detector to enable operation of V-5002 pressure above the normal pressure.

c. Steam Generator System

(1) Adjustment of the steam generator pressure detector to enable a positive pressure-tracking rate and complete freedom of temperature and water flow adjustment.

(2) Installation of a new steam line and water separator between the steam generator and NES duct to correct structural damage of the line during thermal transients and shock loads that occurred in the previous steam line.

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(3) Addition of a system for flushing the NES duct with demineralized water following test operations to prevent scale deposits.

(4) Changes in the steam generator venturi bypass system to provide a greater water flow rate and to improve control sensitivity of the steam generator modules.

d. Instrumentation

(1) Installation of the program power Scram and Scram indicator reset to correct a safety hazard.

(2) Provision of additional analog and event channels to the engine control system and control room display, respectively, for monitoring the XE-Prime wet/dry automatic starts.

(3) Modification of the instrumentation cabling and system components from the XECF/FEP-V configuration to the XE-Prime configuration.

(4) Installation of six new differential pressure transducers in the pipe chase for determining water flow rates through the NES duct.

3. Computer Programs and Data Handling

Development of software for the data link program was continued.

Data processing was completed for the XE-Prime P-9 engine checkout tests, the ETS-1 Data Acquisition System tests, the ETS-1 Facility Final Checkout tests, XE-Prime EP-IA, EP-IB, EP-II and EP-IIA.

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4. Channel Engineering

A system was developed for identifying items in the Unit List that are in the process of being modified, thereby improving the usefulness of the Unit List. The Data Log, Transducer Inventory, and Channel Routing List formats were revised to improve their usefulness.

Channel Engineering documents were updated to reflect test specification revisions and facility system modifications. These documents included the Unit List, Power Distribution Listing, XE-Prime Data Log, Transducer Inventory, and the Channel Routing List.

5. Planning and Procedures

Detailed activity schedules in support of the XE-Prime test series were maintained to enable coordination of work and identify critical path items.

Configuration Control of the ETS-1 facility was continued and support information was provided.

The preparation of test documentation in support of the scheduled experimental plans included check lists and Test Operating Procedures for ETS-1 Facility Final Checkout, XE-Prime EP-IA, EP-IB, EP-II and EP-IIA.

6. Operations Analysis

Proposed modifications to the ETS-1 facility were evaluated, including fluid utilization studies for the XE-Prime test series.

Project 275

Analysis of XE-Prime P-9 engine checkout data was completed. Support was provided in preparing the System Performance Evaluation Analysis Review (SPEAR) reports for XE-Prime EP-IA, EP-IB, EP-II and EP-IIA.

7. Other Activities

Additional visual and audio information displays in the A&E Building multi-purpose room for use during the XE-Prime test series are being installed.

The XE-Prime Operator Qualification Program was continued. A crew was made available consisting of two qualified operators for each console, with the exception of the RIC console. A back-up RIC operator is being qualified.

Project 381

G. EQUIPMENT

Suffix h - Development Tooling

Project 381 - Other Test Zones and Laboratories - Sacramento

1. Cryogenics Laboratory

Six NERVA bearing-cage wear tests were conducted in the Cryogenics Laboratory during the quarter. The units satisfactorily withstood the test conditions.

2. Vibration Facility - Test Zone G

XE-engine components, a TBV and TPCV actuator, were vibration tested during the quarter.

Project 382 - Test Zone H

Suffix h - Development Tooling

Test Stand H-6 was activated for twin-spool TPA testing. Seven tests were conducted during the period ending 28 January, which concluded the twin-spool TPA test program.

After the conclusion of these tests the test position was readied for modification of the TSOV vessel, V-H76. Two flanged ports were provided in the vessel wall. The vessel was successfully proof tested in February.

The window assemblies to be installed in the two flanged ports in vessel V-H76 for the purpose of photographing the LH_2 flowing into a TPA had been fabricated and assembled by Lamco Industries. The assemblies were tested for leakage and were delivered to Aerojet. Figure 60 (269SP541) shows the warm side of the window assembly (to be exposed to atmosphere); Figure 61 (269SP547) shows the cold side (in direct contact with the LH_2 when propellant is flowing through the vessel into the inlet of a TPA). It had been planned

Figure 60 - Window Assembly, Warm Side

Figure 61. - Window Assembly, Cold Side

Projects 381, 383, 391

to install the window assemblies and provide the necessary purge and evacuation systems in order to have the windows operational for a Hubless Inducer TPA test program in March. However, the Hubless Program is being held in abeyance, and installation of the window assemblies will be accomplished under a lower priority.

Concurrently with the TSOV vessel window installation, installation of water-cooled camera containers in the roof of the GH_2 heater serving the H zone facility has been resumed. The cameras will film the flame pattern of the heater burners.

Project 383 - NRO Laboratory
Suffix h - Development Tooling

Procurement and fabrication of items required in support of engine controls, instrumentation and controls, and the ETS-1 test stand controls system have been started. Activities are reported under the respective projects.

H. NON-NERVA SUPPORT

Project 391 - Fluidic Control - SRT
Suffix a - Support

Activation of test complex, Bay 87 at VKC was completed and testing of the full-scale vortex valve at 75K NERVA engine full-power operating conditions was started. Figures 62 and 63 show the test setup with the vortex valve and XE turbine stator assembly connected.

Testing began with checkout tests run with both ambient and 1500°R nitrogen at a supply pressure ranging from 250 to 400 psia, and ambient nitrogen control gas. Test data indicate that the full-scale vortex valve performance was as good or better than predicted on the basis of subscale valve test data.

Figure 62. - Overall View of NERVA Vortex Valve Test Setup

Figure 63 - Closeup of NERVA Vortex Valve Test Setup

Projects 391, 393

Tests were conducted on 28 March 1969 at NERVA engine preliminary design operating conditions of approximately 200°R control and 1600°R supply hydrogen. Two test runs were successfully conducted. The performance of the valve was satisfactory, and complete shutoff of the hot-gas flow was achieved with 8% increase in control pressure above supply. The test data are being evaluated.

The design of the two-stage, in-line subscale vortex valve was completed. Fabrication will be started during the next report period.

A digital computer program has been written to predict vortex valve performance in the inviscid region. This program will consider valve geometry, gas temperature, and downstream flow impedance. Correlation of subscale vortex valve test data with nitrogen in the inviscid region has been accomplished. This program is now being modified to predict performance in the compressible flow regime.

Initial testing of subscale beam amplifiers that were manufactured to five times the original size has been initiated.

A meeting was conducted at Aerojet-Sacramento, 11 March 1969 with SNPO and SNPO-C to review the fluidic chamber pressure control system progress to date.

A program plan was submitted to SNPO-C to extend the fluidic program through September 1969.

Project 393 - Shielding Code Improvements
Suffix a - Support

The simplified geometry routine in the faster point-kernel Monte Carlo Program has been incorporated into the FMC Monte Carlo Program.

Projects 393, 394, 611

Under contract, RRA has made the following computer programs operational on Aerojet's IBM 360 computer:

- (a) ENDF/B tape data-processing codes DAMMET, CHECKER, EDIT, and CRECT
- (b) A series of codes in the COHORT Monte Carlo package
- (c) The SUPERTOG code to produce cross-section data from ENDF/B SUTABLE FOR DOT
- (d) Cross-section interface codes for the FMC Monte Carlo Program and the COHORT Monte Carlo Program

The bridging code, DASH, developed at AGC has been extended to produce boundary sources compatible with the FMC Monte Carlo Program in addition to the original DOT bridging.

Project 394 - Propellant Procurement - SRT
Suffix a - Support

Gaseous hydrogen was procured as required in support of the testing of the vortex valve at Test Bay 87, VKC. Testing began in January 1969.

I. NUCLEAR SUBSYSTEM ACTIVITIES

Project 611 - Nuclear Subsystem Activities System Analyses,
Engineering and Integration (General Surveillance)
Suffix f - NERVA

Nuclear engineering support to the NERVA Systems and Engineering Departments relative to poison wire removal requirements, revisions to the XE-Prime test specification, and consideration of the NRX-R system concept.

Project 611 and 613

Discussions were held concerning development of the nuclear subsystem and integration with the engine system; identification of alternative approaches (trade studies) and detail design planning; coordination of interfacing of trade studies between engine and nuclear subsystem designers; review and recommendation of action with regard to subcontractor capital equipment and hardware procurements.

Attendance at planning, development and design review meetings covering all areas of the nuclear subsystem; review of subcontractor progress and initiation of action where necessary to identify and solve interface problems.

Coordination of discussions and meetings between nuclear subsystem personnel and engine system counterparts concerning the systems management activities.

Project 613 - Reactor Systems Analysis

Suffix f - NERVA

1. Reactor Performance Tolerances

A preliminary set of reactor performance tolerances has been determined consistent with engine system requirements. The component three-sigma limits and sensitivities are listed in Table 31. A nominal chamber temperature of $4625 \pm 60^{\circ}\text{R}$ is required for consistency with the engine system requirements for a dual-TPA system (Table 32).

TABLE 31

REACTOR PERFORMANCE TOLERANCES

<u>Component</u>	<u>Inlet Conditions</u>			<u>Design Requirements</u>	
	<u>Pressure,</u> <u>psia</u>	<u>Temp,</u> <u>°R</u>	<u>Flow,</u> <u>lb/sec</u>	<u>Pressure Drop,</u> <u>psia</u>	<u>Temp,</u> <u>°R</u>
Reflector	737	212	67.1	51 $\pm$ 4.5	95 $\pm$ 25.2
Extension Shield	686	311	88.1	16 $\pm$ 1.6	3 $\pm$ 1
Dome Baffle	670	314	88.1	17 $\pm$ 1.7	0 $\pm$ 1
Central Shield	653	314	88.1	19 $\pm$ 2.1	2 $\pm$ 1
Core	621	320	88.1	171 $\pm$ 44.4	4293 $\pm$ 119
Structural-support Assembly	954	54.7	21.0	268 $\pm$ 34.5	220 $\pm$ 66

TABLE 32

CHAMBER INLET-TEMPERATURE REQUIREMENTS BASED
ON SPECIFIC-IMPULSE MEASUREMENT SYSTEM

		<u>Based on Minimum $I_{sp} = 825 \text{ sec}$</u>	
		<u>Single TPA</u>	<u>Dual TPA</u>
A.	Minimum chamber inlet-temperature base point, °R	4500	4500
B.	Effect of dual-TPA configuration, °R	0	72
C.	Measurement and controller (RSS D & E), °R	53	53
	D. Measurement $\pm 51.2^\circ\text{R}$ ($\pm 0.69\% I_{sp}$)		
	E. Controller $\pm 12.7^\circ\text{R}$ ($\pm 0.172\% I_{sp}$)		
F.	Nominal T_C (A + B + C), °R	4553	4625
G.	Measurement, controller, and engine-to-engine (RSS D, E, & H), °R	60	60
	H. Engine-to-engine $\pm 28^\circ\text{R}$		
I.	Maximum T_C (F + G), °R	4613	4685
J.	Minimum T_C (F - G), °R	4493*	4565

*NPRD specifies minimum of 4500°R .

Projects 613, 621

2. Reactor Operating Constraints

The trade study of pressure-temperature ramp and throttle-ability is in process. When concluded, the study should establish such reactor requirements as reactivity, insertion, ramp rates, and temperature and pressure limits. An effort is presently defined that will trade off engine-system performance with reactor safety and reliability.

3. Common Analog Model

An upgraded draft of the CAM model for R-1 was prepared during the quarter and is now being checked out.

Project 621 - Pressure Vessel and Closure

Suffix f - NERVA

Design effort was started in support of the diluent source trade study. The study investigated changing the diluent port location from the pressure vessel to the nozzle, deletion of the three bolt coolant lines external to the nozzle, and rerouting of the diluent line. Diluent source would then be from the reflector inlet plenum through the nozzle bolts (reverse bolt coolant) to the diluent line.

The pressure vessel design layout was updated, on a continuing basis, to reflect nuclear subsystem configuration revisions.

Concepts for an integrated pressure vessel/reflector design were generated as back-up material for the full-flow/hot-bleed engine presentation at SNPO-W on 12 February 1969. The objective was to develop a pressure vessel concept that would incorporate the beryllium reflector as a nonstructural member. Two-dimensional heat transfer and stress analyses have been initiated to evaluate a typical pressure vessel cross-section taken at core-midplane.

Projects 621, 641

An experimental plan was completed outlining the procedure for determining residual short transverse stress in an AA7039-T63 pressure vessel flange in an attempt to compare these results with the stress corrosion threshold stress. A machine drawing of the test specimen, AGC Drawing 1136274, was completed and released. The flange will be machined from one of the extruded AA 7039-T63 subscale vessels.

The step forgings, representing various forge reductions expected for full-scale pressure vessel forge and extrusion processes, have been completed. The material will be used to compare the anisotropic effect of forge reduction upon the strength, ductility, and fracture-toughness properties of AA 7039 and AA 6061.

The AA 7039 welded rings are being heat-treated to the T63 condition prior to delivery for material design property testing.

The results of the KSC stress-corrosion testing of uncoated AA 7039 and AA 6061 specimens remain unchanged. To date, only failures of AA 7039 specimens stressed to 45,000 psi have been observed. Test time at the end of this report period is 5-1/2 months. Surface-protected specimens for KSC stress corrosion testing are being prepared. The types of specimens to be tested include: shot peened; shot peened and coated with epoxy; epoxy coated; and metallized.

Project 641 - Structural Support Coolant Valve (SSCV)
Piping and Supports

Suffix f - NERVA

Analyses of the reference SSCV rotary blade design concept continued.

Project 641

A new disc geometry was devised that will accommodate the revised flow criteria supplied by WANL. The contour of the coolant port is complex and will require several iterations before the flow-coefficient requirement can be satisfactorily achieved.

A detailed computerized stress analysis was made of the modified disc. The results indicate that the flow-control element is structurally adequate. Large deflections that were indicated during the start transient are being investigated.

The maximum predicted torque required of the SSCV actuator is less than 125 in.-lb.

The NERVA Structural Support Coolant Subsystem (SSCSS) Trade Study has been started. The objective of the study is to investigate the SSCSS relative to the engine system to ensure that the SSCSS is optimized for both engine system and nuclear subsystem performance and reliability requirements.

Limitations of the current SSCSS design have been identified and effects of changes in the engine-system-related limits have been estimated (RN-DR-0170, Current SSCSS Limits and Effects of Changes, dated 18 March 1968).

Two design sketches were prepared for use in the nuclear analysis of candidate shields. These drawings SK 641-3, and SK 641-4 were also the basis of weight distribution calculations.

Thermal analysis was made of the candidate line location and routing to determine temperature rise of the structural support coolant and bypass fluid under flight and ground test conditions. The results are as follows:

	<u>Coolant Flow Temperature Rise, °R</u>	<u>Bypass Flow Temperature Rise, °R</u>
Ground Test	1.7	2.0
Space Flight	0.6	2.4

Project 672

J. TEST OPERATIONS

Project 672 - Test Cell C Operations

Suffix f - NERVA

NTO personnel provided support to the LASL/JTO Group for the Pewee I Reactor Test Series final report preparation; EP-IV and EP-V of the Mark 35 Turbopump Checkout Tests; and planning and data analysis effort for each of the experimental plans.

Project 673 - MAD Building Operations - Nuclear Subsystem

Suffix b - Technology

1. NRX

Radiation readings were obtained on critical hardware components from NRX-A2, 3, 4, 5 and 6 reactors and the information was transmitted to WANL.

2. NRX-A6

Seventy-five NRX-A6 beryllium samples were sent to CMB-14, Los Alamos Scientific Laboratory, New Mexico, for physical testing.

A portion of one NRX-A6 fuel element was cut into a wafer, weighed, and analyzed for fission gas products.

3. Phoebus 2A

A Phoebus 2A nozzle sample, 5 x 8 inches, was cut into six metallography samples, which were mounted, ground, polished, etched and examined. Eighteen photographs were taken of the braze, tubes, and shell materials using three different etchants.

Project 673

4. PEWEE I

Selected hot-end hardware pedestals, cups and washers were examined and sectioned into 11 metallography samples, which were mounted, ground, polished and etched for examination. Approximately 82 macro and micro photographs were taken and forwarded to WANL for analysis.

Procedure NTO-TOP-0024 was completed for Pewee I fuel examination. The fuel shipping cask was received from Los Alamos and the fuel was transferred to the hot cells.

Incremental sectioning, examination, photography and weighing was completed for 136 fuel element pieces.

Seventy-three metallography specimens were sectioned, mounted, polished, and photographed.

Eight hot support elements from Pewee I and two control support elements were sectioned and tested for stress rupture data.

The specimen illumination system for periscope photography was modified and installed in Cell 5 for the Pewee I fuel examination.

5. XE-Prime Nuclear Subsystem Disassembly Preparations

A power source (208 vac and 440 vac) was installed in the Hot Bay areas to operate disassembly equipment.

The OPS manipulator vertical drive was modified per FCO 736 to increase reliability.

The shield-lifting fixture P/L 1135 was modified per FCO 716 to enable its use in the E-MAD hot bay with a crane hook adapter.

Projects 673, 686

Certification and operational checkout of XE disassembly equipment is completed, and the hot bay is being set-up for the XE-Prime disassembly.

A preliminary draft of the disassembly and post-operative examination section of the XE-Prime test specification has been reviewed.

The first draft of the XE-Prime disassembly procedure has been completed.

K. ASSISTANCE TO LASL

Project 686 - Assistance to LASL

Suffix a - Support

Assistance was provided in discussions and review of Pewee program and components at LASL; Pewee I post-operation examination and evaluation was reviewed.

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