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SACRAMENTO PLANT

REPORT NO. RN-A-0008
TO
AEC - NASA SPACE NUCLEAR PROPULSION OFFICE

SUMMARY REPORT CY '66
FOR PERIOD ENDING 30 SEPTEMBER 1966

NERVA PROGRAM
CONTRACT SNP-1
NOVEMBER 1966

MASTER

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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View of NRX/EST Test Assembly on the Test Pad prior to Mateup

FOREWORD

The work described herein 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, with the Aerojet-General Corporation.

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I. INTRODUCTION

II. SUMMARY

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I. INTRODUCTION

This document, the fifth summary report on the progress of the NERVA engine development program and its associated tasks, is submitted in partial fulfillment of Subtask 4.3 of AEC-NASA Contract SNP-1. The report covers contract year 1966 (1 October 1965 through 30 September 1966).

Work accomplished under Subcontract NP-1 to Westinghouse Astronuclear Laboratories (WANL) is covered in a separate summary report issued by WANL.

II. SUMMARY

A. PROGRAM HIGHLIGHTS

Two major test series were performed at Test Cell A: (1) the NRX/EST series, which involved a test assembly simulating the engine configuration, and (2) the NRX-A5 test series.

The most significant accomplishments in the NRX/EST test series, which began in December 1965, were:

(1) Operation of a nuclear-rocket-engine system for the first time with the engine components connected in the flight functional relationship.

(2) Demonstration of system stability under a number of different control modes while operating the engine over a broad area of its performance map.

(3) Demonstration of the multiple-restart capabilities of the engine.

(4) Demonstration of the endurance capability of the reactor and other engine components by operating at nominal rated conditions for approximately 30 min and at or above a 1700°R chamber temperature for approximately 100 min.

Performance of the NRX/EST engine system was generally in accordance with pretest predictions.

On 3 February 1966, the first start of a nuclear rocket (NRX/EST) to power was achieved on the first attempt. The successful run essentially followed predicted performance. A second bootstrap startup was achieved the same day with a cold reflector, to successfully demonstrate the feasibility of restarting the engine in space without an external power source. Successful starts were also demonstrated with a fixed drum position and with low Dewar pressure, respectively.

On 3 March 1966, a NERVA engine was operated at full power for the first time, with full-power operation maintained for over a minute. Agreement was generally good between expected and actual performance.

The most significant accomplishments in the NRX-A5 test series, completed in June 1966, were:

(1) Operation of the test assembly for 30.4 min at close to rated conditions and for 35.3 min at chamber temperatures above 1900°R.

(2) Operational demonstration of a new eight-decade neutronic system.

(3) Checkout and operation of the reactor at rated conditions by using a temperature-control system without the neutronics power control as an inner loop.

(4) Demonstration of the acceptability of a startup from low power to near-rated conditions by using hydrogen reactivity with the drums in a fixed position.

(5) Performance of reactor initial-criticality tests after all poison wires had been removed.

Performance of the NRX-A5 was generally in accordance with pretest predictions.

The majority of components or parts for the XE-1 engine and its cold-flow counterpart (XECF) were manufactured and are available for assembly. The component development work was highlighted by the successful completion of a formal demonstration test program and the delivery of turbopump assemblies. In addition, tests of the nozzle at Sacramento and the performance of the nozzle with the NRX/EST and NRX-A5 assemblies demonstrated the suitability of the nozzle for application on NERVA technology engines XE-1 and XE-2.

Features of the XE engine assembly were developed and demonstrated at Sacramento with the aid, and by testing, of the remote assembly and disassembly aid (RADA) and the weight and envelope mockup (WEMU), both separately and in conjunction with the engine-installation vehicle (EIV) and the manned control car (MCC). The MCC and EIV were completed and checked out at Sacramento and were then shipped to NRDS in September 1966. During the test program utilizing the RADA and WEMU, significant improvements were incorporated in the functional design of the EIV and MCC. Assembly of the RADA components was completed at the E-MAD facility on 3 June 1966.

Significant overall progress was made toward activation of both the ETS-1 and the E-MAD facilities.

Inputs to the new-technology program increased by 75% during contract year 1966, and NASA published 11 REON reportable items as technical briefs.

Studies of an engine of increased size, which were based on current NERVA technology, the large-diameter reactor, and the Phoebus II nozzle, resulted in the establishment of a final design concept based on (1) 5000 Mw power, (2) a 4500°R chamber temperature, (3) a 625-psia chamber pressure, and (4) 245,000 lb thrust. Design activity was directed primarily toward meeting flight-system objectives of maximum system performance (I_{sp}) and minimum engine length and weight. Extensive studies were conducted that resulted in a long-range NERVA engine development program plan.

B. OVERALL PROGRAM ACTIVITIES

1. Propellant Feed System

Each of three successive turbopumps was endurance-tested for a cumulative duration of over 43 min at a turbine inlet temperature exceeding 1250°R, a pump pressure rise exceeding 980 psi, a pump-discharge flow rate exceeding 75 lb/sec, an NPSP of less than 10 psi, and a turbine-inlet total pressure of less than 440 psi. Turbine operation at speeds exceeding 26,000 rpm was demonstrated for approximately 2 min at a turbine-inlet total gas temperature of over 1340°R.

Propellant-feed-system components (including turbopump SN 015, 4-in. butterfly valves, the 5-in. check valve, 3/8-in. check valves, pump-inlet and turbine-exhaust lines, seals, and couplings) performed successfully in NRX/EST tests at pump-discharge flow rates of up to 89 lb/sec at pump discharge pressures of up to 1005 psia. Pump operating time reached 1 hr 40 min, of which 40 min was at speeds exceeding 18,000 rpm.

Demonstration tests were successfully completed for the 8-in. poppet valve and the 5-in. check valve for the X-engine.

2. Thrust-Chamber Assembly

Design of the XE-1 upper thrust structure (UTS) was completed, and stress analysis indicated that the design was adequate for XE-1 loads. Acceptance testing of the XECF UTS confirmed the adequacy of that design for planned XE-2 application. After thorough investigation, annealed titanium alloy 6Al-4V was selected for use in the XE-1 lower thrust structure (LTS). Detail parts have been fabricated, and the assembly is scheduled for completion early in contract year 1967. The LTS for use in the XECF engine assembly was delivered.

Analyses performed to date on the NRX/EST pressure vessel indicate satisfactory demonstration of the structural integrity of the vessel in a full-power environment.

Pressure-vessel hardware was finished for the NRX-A5, NRX-A6, and XE-1 test programs. A test program was successfully conducted for the pressure vessel and hot-bleed-port nozzle.

Nozzles for NRX/EST backup, NRX-A5, NRX-A6, NRX-A6 backup, and XE-1 were completed; and tests to determine heat-transfer margins were completed for the XE-type nozzle. Performance evaluations after the NRX/EST and NRX-A5 test series showed that the nozzles performed as expected in every respect.

3. Systems Analysis

Data obtained from the CFDTS and NRX/EST series were used to improve the transient engine simulation program, which has now reached a state of development that permits prediction of startup with a high degree of accuracy.

Thirteen major improvements were made in the NERVA transient digital model to increase operating speed, the number of problems that could be analyzed, and accuracy of calculation techniques. Five similar-type improvements were made in the steady-state program.

4. Radiation Effects

Six radiation-effects tests were performed during contract year 1966: three on diagnostic instrumentation, two on materials, and one on explosives. A report was completed that summarizes radiation-effects information obtained from NRX-A2 and NRX-A3; a similar report is 50% complete for NRX/EST.

5. Engine Support Systems and Functions

Thirteen NRX/EST and five NRX-A5 items of support equipment were delivered to NRDS. The operational support plans for NRX-A6, XECF, and XE-1 were published. The design-criteria documents for 40 items, the design or design modification of 25 items, and the fabrication of 27 items of XE support equipment were completed.

6. Instrumentation

The superiority of resistance-type temperature transducers was demonstrated in the NRX/EST and NRX-A5 tests. Uncertainties in temperature measurements were reduced over the temperature ranges of maximum interest.

The ability to provide acceptable engine-control input signals by means of remotely located pressure transducers having infinite-impedance terminations was demonstrated.

7. Ground-Operations Safety

The program for auditing the safety of operational facilities became fully functional, and procedures were established for periodic audits of all phases of NERVA safety operations.

8. Product Assurance

A failure-mode analysis of NRX/EST was issued prior to testing. Catastrophic and critical failure modes were examined to ensure that all actions had been taken to minimize the effects of such failures.

9. Materials Development

Significant advances were made in determining the properties of materials subjected to irradiation and in the evaluation of self-lubricating wear-resistant materials for bearing retainers.

10. NRDS and Advanced-Facilities Support

The design and test specification was completed for the engine-test-compartment gas-coupling and analyzing system, and the design and procurement package for the fill-and-drain system of the engine external shield was completed.

The design package for modification of the LN_2 portion of the engine cooldown system was completed; this modification enables introduction of LN_2 into the common cooldown line at a point downstream of all other fluids to avoid any possibility of LN_2 solidification in the line from contact with entrapped LH_2 .

11. Central Data System

The central-data-control development plan, which outlines the long-range objectives of data and documentation control systems that will be used for collection, storage, retrieval, and dissemination of technical data, was completed.

12. Sacramento-Plant Special Test Equipment

In the successful demonstration of the bootstrap concept during CFDTIS testing on Test Stand H-5, two-stage nozzle and turbine exhaust ejectors provided a controlled range of back pressures through the use of GH_2 spoiler gas injected into the system to combine with the hardware effluent flows.

TPA and TPCV tests were conducted on Test Stands H-6 and H-4A, respectively, by using hot hydrogen provided from the GH_2 heater in Test Zone H.

13. ETS-1 Activation

In August 1966, the steam-generator system performed successfully in a full-duration (1000-sec) test at full-steam output. Switching to the standby module was successful, but full-steam operation of the standby module was not achieved. This long-duration test concluded the steam-generator development program.

The process-system portion of the test-stand control system (TSCS) was installed and checked out, and the Phase-4 facility tests and process-water-system tests were completed.

Installation of the NES duct was completed 27 September 1966, and the development plan for the E/STS-2/3 nuclear exhaust system was completed.

14. E-MAD Activation

The cold area in the E-MAD facility was activated on 12 September 1966, and work on the heating, ventilation, and air-conditioning system for the facility progressed rapidly.

The postoperative cell material-transfer system (POCMTS) was installed, checked out, and final-acceptance-tested.

Testing of the floor-mounted handling system was completed, and deficiencies were corrected.

15. Program Milestones

The status of major milestones in the NERVA program on 30 September 1966 is shown in Figure 1.

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III. TECHNICAL DISCUSSION

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A. ENGINE DEVELOPMENT

Task 1

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III. TECHNICAL DISCUSSION

A. TASK I. ENGINE DEVELOPMENT

1. Engine System (1.1)

a. Engine System Integration, Design, and Documentation

(1) XE-1 Engine Layout and Assembly Drawings

During CY '66 the layout drawing (Figure 2) was continuously upgraded to incorporate additional design information that became available. Details of vent lines and valves, purge lines and valves, pneumatic lines and valves, control-drum actuators, interface connectors, instrumentation-transducer modules, control-drum-actuator pedestals, control-drum-actuator shaft housings, and the TV camera installation were added to the layout. Changes were made in the CSV location; diluent-control valve size and location; pump discharge and cooldown-line, vent line configuration; diluent-line location; location of the fluid-line interface plane at the engine-to-test stand adapter junction; and the brackets and actuators for these fluid-line connectors.

Subassembly drawings of the upper thrust structure module and the lower engine and the top assembly drawing for the XECF and XE-1 were started. A pictorial drawing of the NRX/EST engine system is shown in Figure 3.

(2) Interface Control

During CY 66 the nuclear subassembly interface control drawing (#1013843) and the XE-1-to-Engine Test Compartment interface control drawing (#1010058) were updated by the incorporation of twenty-five I.C.O.R.'s. Three additional I.C.O.R.'s were in progress at the end of the year.

	LWR #	LWR ID	MTL	COORDINATES				SPR	FLANGES	
				X	Y	Z	IN		OUT	
PROPULSION INLET	1	6.60	CRSS 304L	A	3.000	0.000	0.000	ALG	1.50	1.50
				A	4.00	0.00	0.00	INMAN	2.00	2.00
				B	10.00	0.00	0.00	STANDARD		
PUMP DISCHARGE	5,000	4.68	CRSS 304L	A	10.750	-1.850	0.000	STANDARD		
				B	10.00	-1.00	0.00	STANDARD		
				B	10.500	-10.250	-1.750	STANDARD		
				A	10.00	-5.00	1.50	STANDARD		
TURBINE INLET	4,000	8.95	HAZ 304	A	10.00	-5.00	-2.50	STANDARD		
				B	10.00	-10.00	-3.00	STANDARD		
				A	10.00	-4.25	-1.45	STANDARD		
				B	10.00	-3.75	0.00	STANDARD		
				B	10.00	-4.00	-3.00	STANDARD		
				B	10.00	-3.75	-0.50	STANDARD		
TURBINE EXHAUST	6,625	6.36	CRSS 304L	A	10.00	-4.00	-3.00	STANDARD		
				B	10.00	-3.50	-1.00	STANDARD		
				A	10.00	-3.50	-1.00	STANDARD		
				B	10.00	-3.50	-1.00	STANDARD		
COOLDOWN SUPPLY	8,000	4.68	CRSS 304L	A	10.00	-3.50	-1.00	STANDARD		
				B	10.00	-3.50	-1.00	STANDARD		
DILUENT	3,500	3.76	CRSS 304L	A	10.00	-3.50	-1.00	STANDARD		
				B	10.00	-3.50	-1.00	STANDARD		
ENG COMP 4 IN PURGE	4,000	4.30	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
PURGE COM 4 IN PURGE	1,000	8.00	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
TR. PURGE 1.000 INCH	5,000	4.68	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
4 IN SUPPLY TRCV	1,000	8.00	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
ENGINE TRN SHIELD	1,000	8.00	ALUM	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
TR. SHIELD CONTROL	1,000	8.00	ALUM	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
TR. SHIELD VENT	1,500	1.300	ALUM	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
PURGE/VENT TRCV	2,000	1.870	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50
PURGE/VENT TRCV	2,000	1.870	CRSS 304L	A	0.00	-1.00	0.00	INMAN	1.50	1.50
				A	0.00	-1.00	0.00	INMAN	1.50	1.50

Figure 2
NRX/EXT Engine Layout Drawing

Figure 3

(3) Pneumatic System Design

The pneumatic system design effort progressed from general layout, to subsystem determinations and layouts, to routing and detail drawings. Three subsystems have been evolved: the TSA subsystem, the upper thrust structure module (UTSM) subsystem, and the lower engine subsystem.

The original TSA subsystem was modified to move the remote fluid connector interface with the upper thrust structure module connectors from Station 42.89 to Station 41.42, so that all fluid coupling interfaces are now at the same station. This also eliminated an interference between a fluid-connector guide on the UTSM and a pneumatic-connector guide on the TSA. Fabrication of this subsystem was nearly complete at the end of the year.

The upper thrust structure subsystem design was completed and fabrication is nearly complete.

The lower engine subsystem design, which interfaces with the control drum actuators, was completed and fabrication was started.

(4) Component Cooling

Since the instrumentation cabling near the pressure vessel would require cooling, it was decided to use the pressure vessel as a heat sink. Different methods of attaching the cabling to the pressure vessel surface were investigated, and aluminum flame spraying appears to be the best method. Further studies of engine-heating problems were made, indicating that there is no need for instrumentation cooling except for the neutron-detector cannister on the pressure-vessel dome. It is also unnecessary to provide for shield water circulation.

(5) Wiring Harness and Electrical System

Candidate components of the electrical harness, such as connectors and cabling, were tested, found satisfactory, and selected types were incorporated in the XE harness design. Complete harness layout and design were accomplished, and procurement and assembly have been initiated.

(6) Brackets and Supports

All brackets for the TSA, the XE-1 and XECF upper thrust structure module, and lower engine subassembly have been designed and are being fabricated. These include lines, valves, instruments, connectors, and blast-shield brackets.

(7) XE-1 Documentation

Design criteria for the engine vent valves, turbine-block valves, and the GHe and GH_2 pneumatic systems were prepared. These criteria were assigned numbers NDC-137, NDC-138 and NDC-120, respectively.

The engine design specification was revised, and the format for engine design information was changed to that of an NDC. NDC #132 was assigned to the engine design criteria.

An XE-1 documentation schedule was issued and revised to accommodate the revised test schedule.

Input for the safety analysis and facility safety reports was furnished and updated. Topical report documents are described separately in various sections of this report.

(8) XECF/XE-1 Test Planning

(a) XECF

The XECF test plan (RN-S-0295) was prepared, revised, and issued during CY 66; the XECF test specification review draft was distributed in September to SNPO-C, NTO, and WANL for comments. This specification provides the engineering basis for preparing detailed procedures for the conduct of the XECF tests at NRDS. Included in the specification are instructions for receiving inspection of test articles; assembly and checkout; installation in ETS-1 operational testing; and disposition after testing.

(b) XE-1

The XE-1 test plan (RN-S-0310) was prepared, revised, following NRX/EST, and issued in CY 66. This test plan includes test objectives, test run requirements and pre- and post-test operations needed to initiate the test specification and conduct operational planning.

(c) Documentation Schedule

A test planning documentation schedule was prepared, issued, and revised to meet the new test schedule.

(9) Measurement Requirements List

The measurement requirements list format was issued in its final format during the 4th quarter of the contract year. The XE-1 list has been submitted for approval, and the review draft of the final XECF list has been distributed for comments.

(10) Failure Mode Analysis

Failure-mode analyses of the engine non-nuclear subsystems, the ETS-1, including the exhaust system, the XE-1 reactor, and the XE-1/ETS-1/TSA assembly were conducted during the year. Analytical results have been fed back into the various subsystem designs as necessary, and analyses of the design modifications are continuing. A limiter circuit has been determined satisfactory for overspeed protection for the TPA and will help eliminate unnecessary shutdowns resulting from use of an overspeed trip circuit.

The preliminary XE-1 test parameter limits document was completed.

(11) Operations Planning

XE-1 checkout requirements, test sequence schedule, assembly procedures, test procedures, disassembly procedures, and non-nuclear components post-operative requirements have been prepared for input to the test specifications.

(12) Systems Analysis

(a) Cooldown

Cooldown sequences for both normal and emergency shutdowns from various power levels have been prepared and analyzed. Studies of reactor operations were requested to investigate the possibility of allowing core temperatures greater than 1400°R for the introduction of N₂. WANL recommended that the temperature limitation should be retained. Information required for analog and digital computer models of the cooldown system was gathered and coordinated. All models were checked out and analyses covering the use of GHe, GH₂, and GN₂ were initiated. The analyses will determine optimum facility and controls requirements during cooldown.

Modifications to the facility cooldown system were recommended to improve system performance.

(b) Failure-Modes Analysis

A failure-modes analysis revealed the need for a device to prevent damage to the TPA in the event the TPCV failed in the open position. Apparently, a turbine-inlet blocking valve is necessary.

The restart capability of ETS-1 was determined for no-refill and topping-off conditions.

(c) Piping and Instrumentation

The P&I diagrams for the XECF and XE-1 were prepared and updated to indicate changes based on systems analysis and design modifications. A single piping diagram for the XECF and XE-1 is also maintained.

(d) Nuclear Analysis

1 XE-1 Component Heating

Heat-generation rates for instrumentation-mounting brackets were determined. Heat-generation rates in the XE-1 pressure vessel, dome, and nozzle were predicted for additional points required for heat-transfer analyses.

2 XE-1 Dose Rates

Gamma flux maps for the interior of the XE-1 upper thrust are shown in Figures 4, 5, and 6. The unperturbed levels are shown in Figure 7. Figure 5 shows the effect of the largest penetration, the turbine exhaust line. The effects of penetration shielding on these lines are shown in Figure 6.

Figure 4

Gamma Radiation Dose Rates (rad 1/hr) above XE External Engine Shield,
No Shield Penetrations (Scale 1-in. = 1 ft)

- VALUES GIVEN ARE FOR XE-1 ENGINE AT FULL POWER OPERATING IN THE ETS-1 ENGINE COMPARTMENT
- INDICATES SEPARATE REGIONS WITH DIFFERENT ORDERS OF MAGNITUDE. ORDERS OF MAGNITUDE SPECIFIED BY LARGE UNDERLYING NUMERALS

Figure 5
Gamma Dose Rates in Vicinity of XE-1 Turbine Exhaust Line,
Penetration with Penetration Shield

— VALUES GIVEN ARE FOR XE-1 ENGINE AT
FULL POWER OPERATING IN THE ETS-1
ENGINE COMPARTMENT

- - - INDICATES SEPARATE REGIONS WITH
DIFFERENT ORDERS OF MAGNITUDE.
ORDERS OF MAGNITUDE SPECIFIED BY
LARGE UNDERLYING NUMERALS

Figure 6
Gamma Dose Rates in Vicinity of XE-1 Turbine Exhaust Line,
Penetration without Penetration Shield

Figure 7

Comparison of Predicted XRX/EST Post-Neutron Distributions
with Experimental Results

3 XE-1 Dosimetry

Thermoluminescent dosimeters were calibrated using the Aerojet cobalt source (Figure 8) and the AGNIR reactor (Figure 9). A cross calibration between these data and the NTO system indicates that there may be some discrepancy. The possibility that this may affect previously reported NRX results is being investigated.

The results in Figure 6 indicate the feasibility of using these dosimeters to measure thermal neutron flux rather than rapidly decaying foils. Experiments have been planned using the NTO Pu-Be source and the Phoebus-1B experiment to confirm and develop this capability. Since the dosimetry specification for XE-1 will depend on the results of these investigations, preparation of this specification is being deferred until the results are available.

(13) Remote Reassembly Development

To incorporate a remote-reassembly capability in the XE-1 engine the following major steps were accomplished in CY 66:

- a. The project design engineers were given a remote handling presentation at E-MAD.
- b. The configuration of the propellant-feed piping interface at the pressure vessel was finalized and long lead time couplings ordered.
- c. The remote interface between the upper thrust structure module and the shield was established and incorporated into the upper thrust structure and shield designs.
- d. Additional requirements for remote handling equipment and stands were established.

Figure 8

Thermoluminescent Dosimetry Calibrations, Co-60 Source

Figure 9

AGNIR Dosimetry Measurements in Core and Graphite Thermal Column

e. A fabrication method for construction of two interchangeable upper thrust structure modules was developed.

f. Guiding-fixture installations on the shield and UTSM were designed.

g. The designs of the control drum shaft housings and mating actuator pedestals were modified improving access for semiremote removal of control-drum actuator pedestals and shafts as units.

h. The remote assembly design aid evaluations at E-MAD were initiated to determine engine and handling equipment design adequacy.

(14) Interface Connector Development

The remotely operated fluid, electrical, and structural connectors at the engine-to-test stand adapter interface were tested to evaluate their performance and to demonstrate the design adequacy of the overall interface.

The TSA/UTS design aid was used in the simulated engine test stand at Sacramento. Repeated matings of the two halves of the design aid were accomplished and the interface was improved.

After the first phase of testing, the TSA portion of the design was updated to the latest configuration of the XE-1 interface. The UTS was updated and used in the build-up of the UTSM of the weight and envelope mockup. The latter unit and the updated TSA were then used to verify the adequacy of the design modifications of the XE-1. The demonstrations were completed successfully and the entire test set-up was moved to NRDS for training and evaluation.

The remote assembly design aid was completed and shipped to NRDS for use in E-MAD to evaluate the UTSM remote concepts and the handling equipment.

Reports of the component connector development tests and the engine-to-test stand adapter interface were prepared and issued. An interim report of the remote reassembly development program was prepared.

b. Cold Flow Development Test System (CFDTS) (1.1.2)

(1) Testing

Two series of CFDTS tests were conducted during CY 1966. One series of 21 tests was completed in October and the other series of four tests was completed in November. Major test objectives were to: (1) evaluate the effect of tank pressures and back-pressures on system start characteristics; (2) evaluate dry-pump starting; (3) evaluate performance of the closed-loop chamber pressure control system; (4) provide data for upgrading the analytical models for the XE-1 and NRX/EST; and (5) determine the effect of the modifications on the TPA by comparing the most recent data with data obtained prior to these changes.

The tests were conducted in the H-5 test stand at Aerojet-Sacramento. In general, one test was run each day, with rapid warm-up of the engine to ambient temperature between tests by the introduction of 100°F nitrogen into the pump discharge line. No major failures of hardware occurred during these tests.

Test data indicated significant improvement in system performance resulting from the modification of the TPA. With a tank pressure of 70 psia and a back-pressure of 14 psia, the maximum pump speed increased from 5260 rpm with the original configuration to 7530 rpm with the modified configuration.

The tests also showed that the system bootstrapped satisfactorily under a variety of conditions of tank pressurization and back-pressure. Neither warm pump tests nor very low tank pressures caused the pump to overspeed or resulted in significant system instability even with zero NPSP, indicating that the required propellant tank pressure in a flight engine will be governed by full-power NPSP requirements rather than by start-up conditions.

It also indicated the possibility of simplifying the engine system by eliminating the pump discharge valve.

The tests demonstrated the feasibility of closed-loop pressure control of the TPCV to control chamber pressure during engine start-up, even with a warm pump. Start-up could be accomplished with the pressure controller activated at the initiation of start-up, eliminating the need for TPCV position control and increasing reliability by simplifying the system.

Detailed component and system operational data were provided for development and refinement of the analytical computer models.

The CFDTS test article was removed to the fabrication assembly area and disassembled.

(2) Analysis and Report

Detailed analysis of the test data and verification of the mathematical models of the engine are reported under Subtask 1.8.

A preliminary test report for each of the 25 tests was completed after the conclusion of each test. A test data summary report was prepared, tabulating major performance parameters for each test series. Digital data printouts of approximately 200 measurements per test were prepared and were transposed on Cal-Comp plots.

The final CFDTS report (RN-S-0298) was completed and distributed.

c. Engine External Shield Design and Development (1.1.3)

The shield design and development effort consisted primarily of engineering the modifications necessary for the remote-reassembly capability,

revising penetration configuration because of revised nuclear streaming estimations based on NRX/EST data, designing instrumentation installations, and providing engineering support of fabrications operations.

The shield assembly for the XECF was completed, and the shield for XE-1 was approximately 50% completed at the end of the year.

A segment of the shield was built to check fabrication techniques and for use in ball-loading technique evaluations. The segment is now being prepared for use in evaluating the effects of possible N_2 condensation in the UTS area above the shield during test operations.

Corrosion studies were made during CY 66 to investigate the corrosion of P-714 and A356T6 cast aluminum and stainless steel in the boron solution at temperatures ranging from 32°F to 200°F. These studies were described in the shield design report.

d. Test Cell "A" NRX/EST Design and Development (1.1.4)

The NRX/EST assembly, test preparation, and full-power test were completed at NRDS. The test program objectives were accomplished and post-test evaluations were started.

The engine system was disassembled and prepared for post-test examination. Engine valves and valve actuators were disassembled and inspected. The disassembly and inspection of the TPA was initiated.

Nuclear-analysis results were as follows:

(1) NRX/EST Results

The NRX/EST high-power dosimetry report was published as NTO-0070. Except for fast neutrons the high-power test results were generally

compatible with the previously published low-power test results. The results obtained with nickel foils are compared in Figure 9 with the low-power sulphur data and analytical predictions. The discrepancy between the experimental data is modified to represent neutrons greater than 0.9 mev instead of 2.9 mev, and there is good agreement with analytical predictions.

(2) NRX/EST Final Report

The nuclear analysis portion of NJD-8 was prepared summarizing the results of the NRX/EST experiment. The document is in the process of publication.

(3) NRX/EST Secondary Gamma Rays

The neutron economy based on a pretest analysis is being reviewed. Preliminary results indicate that calculations of secondary sources from pad and wall capture may have excluded a significant portion of the neutrons.

e. Engine Design and Assembly Aids (1.1.5)

TSA/UTS prototype design aid, which was used in initial development testing of the engine-to-TSA interface, was updated to the improved configuration. The upper thrust structure portion was used as the UTS for the weight and envelope mockup. The TSA portion was updated for use in evaluating the WEMU.

The remote reassembly design aid design was completed early in CY 66 so that fabrication could be completed in the second quarter. The RADA was completed and shipped to NRDS during the third quarter for use in E-MAD training and remote-handling evaluation.

The weight and envelope mockup design was completed and fabrication was initiated after the UTS from the UTS/TSA design aid became available. The WEMU fabrication was completed, and the WEMU was subjected to final engine-to-TSA interface-mating demonstrations. After successful completion of these demonstrations the WEMU was shipped to NRDS for use in training and operational evaluation.

f. Engine Adapter and Gages (1.1.7)

(1) NRX Gages

The NRX gage program was reviewed relative to the use of current NRX gaging for NRX-A5, NRX-A6, and XE-1. Except for the incorporation of the "G" change to master match plate T-603094 for use with NRX-A5, no further effort has been necessary.

(2) XE-1 Gages

A match plate (Part Number 1115928) for use in fabricating the upper thrust structure and the external shield was designed and two plates were fabricated. This match plate will ensure satisfactory interface mating of the two engine components during remote reassembly. During shipment from vendor to vendor, part number 1115928-49 was dropped and had to be scrapped. It was decided to use part number 1115928-39 for all subsequent fabrication.

New part numbers and titles were assigned to XE-1 match plates to identify them as interface-match plates:

- (1) Part Number 1115926, (TSA/UTS)
- (2) Part Number 1115927, (UTS/Shield/LTS)
- (3) Part Number 1115928, (UTS/Shield 18 in. interface)

(3) Test Stand Adapter

The design and detail drawing of the TSA were completed early in 1966.

Development testing of the TSA interface with the engine revealed improvements that can be made in component details and locations, which would result in more confidence in remote matings. These design changes were included in the package sent out for production bids. These design changes were proven in the final WEMU/TSA demonstrations. The TSA structure (part number 1114010-9) has been completed by the vendor. The structure will be shipped to Aerojet during the first week of CY 67.

The TSA assembly drawing number 1117088-9 has been completed and assembly planning initiated. A checkout procedure for the TSA was prepared and distributed for approval. A TSA/ETS-1 installation drawing is being prepared.

2. Propellant Feed System (1.2)

This section describes the design, evaluation, and development of propellant-feed-system components achieved during contract year 1966.

Each of three successive turbopumps was endurance-tested over an accumulated duration in excess of 43 min at a turbine inlet temperature in excess of 1250°R, a pump pressure rise in excess of 980 psi, a pump-discharge flow rate in excess of 75 lb/sec, an NPSP of less than 10 psi, and a turbine inlet total pressure of less than 440 psi. Stall in liquid hydrogen was demonstrated, and the calculated stall margin was 17.6% minimum and 22.07% maximum for the speed required for the above pump conditions. Turbopump operation was demonstrated at speeds of over 26,000 rpm for roughly 2.0 min and at a turbine inlet total gas temperature of over 1340°R.

Propellant-feed-system components performed successfully in NRX/EST tests at pump-discharge flow rates of up to 89 lb/sec at pump discharge pressures of up to 1005 psia. These components included the turbopump (SN 015), 4-in. butterfly valves (four units, for high-temperature GH_2 and cryogenic LH_2 service), 5-in. check valve, 3/8-in. check valves, (four units, for high-temperature and cryogenic service), pump-inlet and turbine-exhaust lines, seals, and couplings. Test time included 1 hr 50 min of pump operation, with 40 min at speeds exceeding 18,000 rpm.

Designs were completed, engineering drawings were released, stress-analyses were performed, and materials were evaluated for the 8-in. poppet, 5-in. butterfly, 5-in. check, 4-in. butterfly, and 3/8-in. check valves to be used in the X-engine system. Demonstration tests were successfully completed for the 8-in. poppet and the 5-in. check valves.

Effort during contract year 1966 was directed primarily toward supplying developed propellant-feed-system components for the X-engine system. Included in this effort was the design, fabrication, and testing of the 5-in.

butterfly valve; redesign, fabrication, and testing of the 8-in. poppet valve; and the modification, fabrication, and testing of the 3/8-in. and 5-in. check valves. The pump inlet line for XECF was fabricated and delivered, and the turbine exhaust line was designed and fabricated.

Prior to and after the successful endurance testing of the three demonstration turbopump assemblies, support was provided to the NRX/EST testing activity by conducting laboratory investigations and analyses and by participating in the Dragon Team effort.

The Aerojet materials-wear tester, which is the only known materials tester that will permit high-load and high-surface-velocity testing in a liquid-hydrogen environment, was designed, fabricated, and assembled.

a. Lines, Seals, and Couplings (1.2.1)

(1) XE Pump Inlet Line

The pump inlet line design for the X-engine was modified and made compatible with established criteria, (remote assembly-disassembly requirements at the engine interface). The XECF and XE-1 lines were fabricated and the XECF line delivered.

(2) XE Turbine Exhaust Line

The turbine exhaust lines were designed and fabricated.

b. Valves (1.2.2)

(1) NRX/EST Posttest Valve Inspection

After being used in the NRX/EST test program, the following valves were inspected at the San Ramon hot-cell facility on 17 July 1966:

Turbine power-control valve (TPCV), 4-in. butterfly type
Hot-bleed vent valve (HBVV), 4-in. butterfly type
Turbine block valve (TBV), 4-in. butterfly type
Diluent control valve (DCV), 4-in. butterfly type
Pump discharge valve (PDV), OBU-86, 5-1/2 in.

(a) HBVV, TBV, and DCV Inspection

No malfunction of the HBVV, TBV, or DCV was observed during the NRX/EST test program; therefore, these valves were not disassembled or functionally tested. Visual inspection revealed no discrepancies other than slight external damage incurred during removal of the valves from the test car assembly and some slight abrasion of the TBV butterfly.

(b) TPCV Inspection

The TPCV was functionally tested as a valve and actuator assembly. The valve closed fully without any apparent binding, and no operating abnormalities were observed in the assembly. The valve and actuator were then separated, and extensive functional tests were performed on the actuator while the valve was being disassembled. Torque measurements indicated that maximum valve closing torque was 90 in.-lb. Body bore scuffing caused by seal-ring sliding contact was considered normal wear.

One roller element on the lower bearing (far side from actuator) had a chip approximately the size of a pinhead on one end. A check of the seal-ring-to-disk groove depression showed that ring motion with respect to the disk was normal.

Surface abrasion on portions of the disk and axles indicated that high-velocity particles in the turbine-inlet gas stream were striking the disk and shaft. The abrasion pattern indicated that the valve disk was approximately 45° open.

Radiation levels were measured on contact with the valve butterfly as installed. The gamma and beta values were 300 mr and 8 r, respectively. On 1 August 1966, the Bendix actuator (SN 018) measured 300 mr beta and 30 mr gamma.

(c) Pump Discharge Valve

Visual inspection revealed no discrepancies other than slight rotary scratches on the butterfly. A continuity check of the position switches indicated normal operation. When the valve was cycled open and closed, a maximum actuation pressure of 24 psig were required, which demonstrated that no binding occurred at ambient temperature.

(2) Propellant Shutoff Valve (PSV; 8-in. Poppet Valve)

An 8-in. poppet valve (PN 259300) was refurbished to reflect the X-engine PSV design configuration (PN 1116000) for development and verification tests (Figure 10). The tests were conducted in the cryogenic laboratory, and valve performance proved the design to be adequate for use with liquid hydrogen. Leakage rates after 300 open-close cycles with liquid-hydrogen were as follows:

	<u>Actual</u>	<u>Specified Limit</u>
Poppet seal leakage (at LH ₂ temperature, 50-psid pressure in the valve)	<0.835 scc/sec (GH ₂)	50 scc/sec @ 50 psid
Shaft seal leakage (vented) (at LH ₂ temperature, 500-psig GHe in the actuator)	90 scfm (GH ₂)	90 scfm @ 500 psid
Piston Seal leakage (vented) (at LH ₂ temperature, 500-psig GHe in the actuator)	15 scfm (GH ₂)	15 scfm @ 500 psid

The first of five valves was assembled and tested in accordance with the demonstration test plan* (Figure 11). Ten specific tests were

*RN-TP-0016, Demonstration Test Plan for X-Engine System 8 in. Propellant Shutoff Valve

Figure 10
Eight-In. Cryogenic Shutoff Valve (PSV)

Figure 11
Eight-In. PSV Overall View Assembled Valve

conducted, including proof, leak, actuation timing, failure mode, and endurance cycling. Upon completion of the 300 open-close endurance cycles with liquid hydrogen, leakage rates were as follows:

	<u>Actual</u>	<u>Specified Limit</u>
Poppet seal leakage (at LH ₂ temperature, 500-psid pressure in the valve)	<0.835 scc/sec (GH ₂) ²	50 scc/sec @ 50 psid
Shaft seal leakage (vented) (at LH ₂ temperature, 500-psi GHe in the actuator)	55 scfm (GH ₂)	90 scfm @ 500 psid
Piston seal leakage (Vented) (at LH ₂ temperature, 500 psi GHe in the actuator, 55-psig run-tank pressure)	0.7 scfm (GH ₂)	15 scfm @ 500 psid
Timing (LH ₂ temperature) switch to:		
Full open	0.97 sec	5 sec max
Full closed	1.54 sec	5 sec max

A posttest examination of the disassembled valve revealed the following minor discrepancies (see Figure 12):

- a. There were wear abrasions approximately 0.001 in. deep on the poppet and valve housing.
- b. The potentiometer shaft was bent 10°; however, its operation was not impaired during the test. Investigation indicated that the bending occurred during installation of the valve in the tank.
- c. Minor galling was found between the actuator-cover center post and the inner spring. Aluminum chips were found between the piston static seal and the top of the piston.
- d. Normal galling occurred on the piston shaft and the actuator housing.

Figure 12

Eight-In. PSV Post-Demonstration Test, Disassembled

e. Aluminum cutting chips were found lodged in a groove between the poppet and seal (Figure 13). The chips were determined to result from machining the seal on the poppet subassembly during initial buildup. This condition will not be possible under the new cleaning and assembly procedures.

End-item units for X-engine use are being assembled. Acceptance testing will be in accordance with RN-TP-0019*.

- (3) Shutoff and Vent Valves for Pump Discharge and Cooldown PDSV, CSV, PDVV, and CVV; 5-in. Butterfly Valves

Early in contract year 1966, prospective valves were evaluated for possible use as the pump-discharge-shutoff and the cooldown-shutoff valves for the XE-engine system. A comparison of the two prospective configurations was presented in report RN-TM-0275, Design Selection Report Discharge Shutoff Valve and Cooldown Shut-off Valve for the XE System, dated 6 October 1965. The valve selected for the X-engine system (Figure 14) was a modified Titan II 5-in. butterfly valve. After a design review, a thermal analysis, and successful cryogenic testing, new drawings were made and released and fabrication was initiated.

Development to date on the valve has included evaluation of Kel-F and metal lip seals, actuator operation at LN_2 temperatures, actuator-spring endurance cycling at LH_2 temperature, potentiometer cycling at LN_2 temperature, and valve endurance cycling at ambient and LH_2 temperatures.

A Kel-F lip seal was evaluated with LH_2 at 1200 psi and a 30- to 40-lb/sec flow rate. The lip seal failed after three cycles; failure occurred 90° to the shaft axis and was attributed to forces involved with the full pressure differential of 1200 psi and the mass flow rate acting across the unsupported portion of the seal when the gate was 85% closed. The postdevelopment

*Acceptance Test Plan for X-Engine 8 in. Propellant Shutoff Valve

Figure 13
Eight-In. PSV Post-Demonstration Test View

Figure 14
Five-In. Cryogenic Shutoff Valve

history of the Kel-F lip seal in other programs was reviewed, and conclusions indicated that further development with this type of lip-seal material would be unwarranted. Consequently, a decision was made to use metallic lip seals.

Metal lip seals chosen for evaluation included formed CRES 302 annealed material and CRES 302 1/4-hard material. The basic problems encountered with the metal lip seals were as follows:

1. Establishing the correct method of installing the seal to prevent the seal flange from being distorted. A seal compressor tool was designed and fabricated to compress the seal simultaneously on the gate and the valve body with an even force (3000 to 4000 lb) before bolting the seal in position (Figure 15).

2. Controlling the lip-seal leakage and the bending stresses induced in the seal during assembly. Close control of the seal standoff was necessary. Stress analysis and tests established that the seals should be installed in the valve with a radial deflection of 0.003 to 0.006 in., which is equivalent to a lip-seal standoff of 0.007 to .011 in. (Figure 16). The lip-seal standoff dimension is maintained by shimming under the seal.

3. Tests were conducted to select the best material and surface combination of the metal lip seal and the gate for minimum gall and friction and maximum wear resistance (refer to RN-TM-0393*). Testing was conducted under equivalent contact-stress, surface-velocity, temperature, and atmospheric conditions. The equipment used to conduct the tests consisted of a metal machining lathe having a dynamometer tool-holding fixture with a force-measuring instrument that measured in three directions. The gate materials were tested as rotating mandrel specimens, and the seal materials were tested as static, rectangular, flat specimens. Material combinations tested were Inconel 718 on Inconel 718, Inconel 718 on 301 stainless steel, electrolized coated Inconel 718 on 303 stainless steel,

*Friction Evaluation of Materials for Valve Applications, Sept. 1966

Figure 15
Five-In. Butterfly Valve Lip Seal Installation Tool

Figure 16
Five-In. Butterfly Valve Lip Seal Standoff vs Deflection

and electrolyzed coated Inconel 718 on gold-plated 301 stainless steel. On the basis of tests conducted, the optimum combination was on electrolyzed Inconel 718 gate and a 302 CRES lip seal with a 0.005- to 0.0025-in.-thick gold plate. A gold-plate thickness of 0.0015 in. was selected as optimum for cycle-life wear endurance.

During development tests with metal lip seals, the non-correlation of gate leakage rates among various lip seals (Figure 17) led to an investigation to determine the cause of the anomaly. A dimensional check of the lip seals revealed an out-of-round condition of from 0.001 to 0.007 in. and a lack of flange flatness that was excessive (0.010 in.). The following procedure was established as a result of the lip-seal investigation.

- a. Select seals that are no more than 0.003 in. out-of-round.
- b. Lap the bottom seal flange flat to within 0.004 in. maximum.
- c. Gold-plate the sealing surface from 0.00025 to 0.0025 in. thick.
- d. Install the seal in the valve by orienting the major axis of the seal with the axis of the shaft.

These procedures are made simple by using the Talyrond indicator, a device that measures diameters to 0.00001 in. and produces a contour trace of the measured diameter. Orienting the seal minimizes seal deflection in the axis area, where galling between the disk and seal is more likely to occur.

Evaluating the three contour traces of the ID of the metal seals shown in Figure 18 indicated that seal No. 1 would be used in a 5-in. butterfly valve and seals No. 2 and 3 would be rejected because of their out-of-round condition and distorted contour. The excessive ID distortion of seal No. 2 was due to the seal being held on the OD by a three-jaw chuck during the gold-plate process. The method of holding the seal during the plating process has since been corrected.

Five-In. Butterfly Lp Seal Development Test History

Figure 17

TEST NO.	VALVE S/N	SEAL			CYCLES	TEMP	INLET PRESS. DURING CYCLING, PSI	LEAKAGE @ 50 PSIG		REMARKS
		MATERIAL	PLATING & THICKNESS	STANDOFF IN.				PRE TEST SEC/SEC	POST TEST SEC/SEC	
1	MODIFIED TITAN II VALVE WITH NERVA GATE AND SHAFT	KEL-F	NONE	.039	3	LH ₂	1200 LH ₂	0	OVER 1000 GH _c	SEAL FAILED 90° TO THE SHAFT AXIS
2	MODIFIED TITAN II VALVE WITH NERVA GATE AND SHAFT	302 CRES ANNEALED (TITAN SEAL CON-FIGURATION	NONE	.011	110	AMBIENT	ZERO	2.06 GH _e	237 GH _e	SLIGHT GALLING BETWEEN GATE AND SEAL
					34	LH ₂	1200 LH ₂	237 GH _e	300 LH ₂	GALLING INCREASED
3	MODIFIED TITAN II VALVE WITH NERVA GATE AND SHAFT	302 CRES ANNEALED (TITAN SEAL CON-FIGURATION	GOLD PLATE .00025 IN.	.012	203	LH ₂	1200 LH ₂	0 GH _e	OVER 4500 LH ₂	SEAL FAILED 90° TO THE SHAFT AXIS
4	880001	302 CRES ANNEALED TITAN SEAL CONFIGUR-ATION	GOLD PLATE .00025 IN.	.011	503	AMBIENT	ZERO	1.47 GH _e	1.2 GH _e	THE SAME SEAL WAS USED THRU 907 CYCLES. THERE WAS NO EVIDENCE OF GALLING BETWEEN THE SEAL & GATE
					200	LH ₂	ZERO	1.27 GH _e	3 LH ₂	
					204	LH ₂	1200 LH ₂	3.0 LH ₂	15 LH ₂	
5	880002	302 CRES 1/4 HARD NERVA SEAL	GOLD PLATE .00025 IN.	.004	400	AMBIENT	1200 GN ₂	0.1 GH _e	100 GH _e	GALLING BETWEEN THE SEAL AND GATE ALONG THE SHAFT AXIS
6	880002	302 CRES 1/4 HARD NERVA SEAL	GOLD PLATE .00025 IN.	.004	500	AMBIENT	1200 GN ₂	0 GH _e	100 GH _e	GALLING BETWEEN THE SEAL AND GATE DUE TO ALUMINUM CHIPS IN GATE CAUSED BY SHIM AND GATE INTERFERENCE

Figure 17

TEST NO.	VALVE S/N	SEAL			CYCLES	TEMP	INLET PRESS. DURING CYCLING, PSI	LEAKAGE @ 50 PSIG		REMARKS
		MATERIAL	PLATING & THICKNESS	STANDOFF IN.				PRE TEST SEC/SEC	POST TEST SEC/SEC	
7	880003	302 CRES 1/4 HARD NERVA SEAL	GOLD PLATE .00025 IN.	.004	125	AMBIENT	1200 GN ₂	0 GH _e	1120 GH _e	GALLING BETWEEN THE SEAL & GATE
8	880003	302 CRES 1/4 HARD NERVA SEAL	GOLD PLATED .00025 IN.	.010	300	AMBIENT	1200 GN ₂	0 GH _e	85 GH _e	GALLING BETWEEN THE SEAL AND GATE ALONG THE SHAFT AXIS
9	880003	302 CRES ANNEALED TITAN SEAL	GOLD PLATE .00025 IN	.003	400	AMBIENT	1200 GN ₂	.07 GH _e	700 GH _e	GALLING AT THREE POINTS ON THE SEAL ≈ EQUALLY SPACED
10	880003	302 CRES 1/4 HARD NERVA SEAL	GOLD PLATED .00025 IN.	.010	500	AMBIENT	ZERO	0 GH _e	0 GH _e	NO GALLING BETWEEN SEAL AND GATE
					200	LH ₂	ZERO	0 LH ₂	0 LH ₂	
11	880003	302 CRES ANNEALED NERVA SEAL (KING)	GOLD PLATE .00025 IN.	.010	500	AMBIENT	ZERO	26.6 GH _e	54 GH _e	NO GALLING BETWEEN SEAL AND GATE
12	880003	302 CRES ANNEALED NERVA SEAL (KING)	GOLD PLATE .0015 IN.	.009	500	AMBIENT	ZERO	.15 GH _e	.33 GH _e	NO GALLING BETWEEN SEAL AND GATE AFTER 1500 DRY CYCLES
					500	AMBIENT	ZERO	.33 GH _e	.67 GH _e	
					500	AMBIENT	1200 GN ₂	.67 GH _e	125 GH _e	
13	880004 DEMONSTRATION VALVE	302 CRES ANNEALED TITAN SEAL	GOLD PLATE .00025 IN.	.010	500	AMBIENT	ZERO	12 GH _e	26.6 GH _e	NO GALLING BETWEEN SEAL AND GATE. TEST WAS TERMINATED DUE TO LINKAGE FAILURE
					22	LH ₂	1200 LH ₂	26.6 GH _e	-	
					75 (TIMING)		ZERO LH ₂	-	-	
14	880005 DEMONSTRATION VALVE	302 CRES ANNEALED NERVA SEAL (KING)	GOLD PLATE .0015 IN.		500	AMBIENT

SPECIMEN NO. 1
0.0016 IN. OUT OF ROUND

SPECIMEN NO. 2
0.004 IN. OUT OF ROUND

SPECIMEN NO. 3
0.006 IN. OUT OF ROUND

Figure 18
Five-In. Butterfly Valve Lip Seal Contour Traces of Inside Diameter

Cryogenic-LN₂ tests were conducted on the valve actuator. The actuator was cycled 50 times with a 500-psig actuation pressure with no evidence of binding or sticking.

A test program was conducted to determine the effect of cycling the actuator spring at cryogenic temperatures. The spring material is a low-alloy steel (MIL-W-16632) that has less than 1% elongation at LH₂ temperature. The springs were immersed in LH₂ and cycled 500 times at a rate of one cycle each 0.8 sec; there were no changes in the spring parameters as a result of the cycling.

LN₂ cryogenic tests were conducted on the potentiometer to establish confidence in its use at cryogenic temperatures. No change in the potentiometer trace was noted in the record. The torque to rotate the potentiometer shaft increased from 1/2 to 5 in.-lb in going from ambient temperature to LN₂ temperature; however, the increase in torque will not impair the function of the potentiometer.

To date, seven valves have been assembled; the first three were used for development testing. The fourth valve was being used as the demonstration test valve. During the demonstration tests, the clevis (PN 1114805) failed during cycle 22 of the LH₂ high-pressure cycle test (Figures 19 and 20). Investigation indicated the failure resulted from a combination of causes:

1. A 0.001-in. fillet radius on the inside of the fork tines (a 0.020-in. minimum radius is specified on the drawing; notch sensitivity was increased).
2. Impact loading of the actuator piston on the housing, causing failure due to the low impact strength of 7075-T3 aluminum at cryogenic temperatures.
3. Misalignment of the linkage, creating high bending stresses in the clevis.

The investigation is continuing. To avoid recurrence of the clevis failure, the material has been changed to Inconel 718.

Figure 19
Five-In. Butterfly Valve Clevis Failure

Figure 20
Five-In. Butterfly Valve Clevis Failure

The demonstration test will be repeated with a valve that has been assembled with the new Inconel 718 clevis and arm.

- (4) Swing (Figure 21), Cooldown (CKV), and Pump-Discharge (PDKV) Check Valves (5-in.)

Analysis and study of the NRX/EST 5-in. check-valve design for use with the X-engine system resulted in a modification to the flapper damping device. The modification incorporated a spring that axially loaded the Kel-F friction sleeve to make it relatively independent of coefficients of expansion and contraction at the extremely low thermal conditions involved. The configuration was designated a -19 change. Also incorporated was a shorter linkage rod (PN 1115730) that prevented the internal parts of the damping device from protruding outside its guide when the valve was full open, thereby eliminating a possible locking in the open position. As a result of modifications, the test at ambient and liquid-nitrogen temperatures was conducted without flapper chatter.

The 5-in. check valves were then acceptance-tested. Excessive internal leakage occurred in the check direction for one test valve during the cryogenic (-40°R) test. Posttest inspection revealed the flapper sealing surface and the housing seat area to be damaged from flapper chatter during the low-flow portion of the test. Because of this failure, the valve damping device was re-evaluated. Analysis revealed that the Kel-F sleeve (PN 1115732-1), at LN_2 and LH_2 temperatures, had contracted to such an extent that contact was lost with the spring guide, rendering the damping device inoperative. Consequently, an aluminum (6061-T6) friction sleeve was fabricated to replace the Kel-F sleeve. The aluminum expansion-contraction coefficient was more compatible with that of the spring guide material. Flow tests with liquid nitrogen at -320°F and gaseous nitrogen at ambient temperature proved the modified valve to be effective in eliminating flapper chatter. Drawing 1115728-29 was released after the modification was incorporated, and the valve was reassembled in accordance with the drawing. Demonstration tests on the valve were successfully conducted in accordance with RN-TP-0017*, and the following data were obtained.

*RN-TP-0017 Demonstration Test Plan for X-Engine System 5" Cryogenic Check Valve

Figure 21
Five-In. Check Valve

	<u>Actual</u>	<u>Specified Limit</u>
Internal leakage (ambient)	= 12 scc/min at 1200 psig	50 scc/sec @ 1200 psig
(LH ₂)	= 70 scc/sec at 719 psig	3000 scc/sec @ 700 psig
Cracking pressure (ambient)	= 1.4 psid	5 psid maximum
(LH ₂)	= 2.3 psid	5 psid maximum
Reseating pressure (ambient)	= 0.3 psid	2 psid maximum
(LH ₂)	= 0.45 psid	2 psid maximum
200 LH ₂ flow endurance cycles		
Internal leakage (LH ₂)	= 63 scc/sec at 717 psig	3000 scc/sec @ 700 psig
Cracking pressure (LH ₂)	= 1.73 psid	5 psid maximum
Reseating pressure (LH ₂)	= 0.32 psid	2 psid maximum

The demonstration test series incorporated all phases of the acceptance test series in addition to endurance cycles at low flow rates and additional cracking, reseal, and internal leak checks after the endurance cycles. Inspection of the flapper and seat after the demonstration test series revealed no noticeable degradation.

Valves destined for acceptance test and delivery for XECF and XE-1 are currently in the initial phases of acceptance testing.

(5) 4-in. Butterfly Valve (Figure 22)

The NRX/EST design configuration of the valve was reviewed to evaluate the existing design for use on the X-engine system. The basic configuration required some improvements. The butterfly drive-shaft spline on the NRX/EST-configuration valve did not permit any misalignment of the valve with respect to the actuator. A design change made the former straight spline (flat root - side-fit tooth) a crowned spline, thus allowing approximately 3° of angular movement. Figure 23 compares the two tooth forms on the drive shaft.

A second design modification was completed to permit use of the 4-in. butterfly valve as a fast-acting (100-millisecond response) turbine-drive-fluid shutoff valve. Previous high-speed actuation of the valve had indicated that

Figure 22
Four-In. Butterfly Valve

STRAIGHT SPLINE

NRX/EST
CONFIGURATION

INVOLUTE-EXTERNAL
FLAT ROOT-SIDE FIT
(UNMODIFIED)

TYPICAL TOOTH

CROWNED SPLINE

XE-1
CONFIGURATION

INVOLUTE-EXTERNAL
FLAT ROOT-SIDE FIT
(AT PRESSURE ANGLE ONLY)

Figure 23

Four-In. Butterfly Valve Actuation Shaft Tooth Modification

deceleration loads imposed on the valve shaft and butterfly assembly would result in shear loads exceeding the yield strength of the valve shaft-to-butterfly connecting pin (Inconel X-750). Cycle tests of a valve assembly in the test setup shown in Figure 24 resulted in pin failure after 40 ambient-temperature open-close cycles at a total time of 42 millisec from command signal to valve closure. (Valve closing time was 8 millisec.) Consequently, the pin material was changed from Inconel X-750 to heat-treated, work-hardened A-286 with a 110-ksi minimum yield strength in single shear and a 200-ksi minimum ultimate strength. Cycle tests of one assembly with the revised pin under the conditions indicated above, demonstrated 152 open-close cycles prior to pin failure; the design requirement was 100 duty cycles. The allowable torque that can now be applied to the valve on the basis of pin strength is approximately 4800 in.-lb at XE-1 operating temperature.

Two hydrogen-gas-flow development tests were conducted in accordance with Test Plan Report 1.2-66-TR-001* on a 4-in. butterfly valve. The purpose was to determine valve actuation-torque requirements at several different inlet pressures for a constant temperature.

A plot of actuation torque versus valve inlet pressure at plotted lines of constant valve butterfly-shaft position is contained in Report RN-TM-0396.**

A stress analysis of the 4-in. butterfly valve was completed (see RN-TM-0341).*** The calculations show positive margins of safety for all components, based on operation of the valve at a 650-psia inlet pressure and 1300°R temperature.

*Heated Hydrogen Flow Test Plan Four (4) Inch Butterfly Valve
**Four (4) Inch Butterfly Valve Heated Hydrogen Flow Test Report
***Summary of Structural Analysis, XE Valves

Figure 24
Four-In. Butterfly Valve Actuation Test Setup

Sufficient component hardware was fabricated to permit assembly of ten valve assemblies. Four valves are scheduled for development and demonstration testing, and the remaining six are for X-engine-system delivery. Four valves were assembled during this report period for use on XECF and XE-1.

(6) Turbine Power-Control Valve

Design of the turbine power-control valve (TPCV) assembly was completed, and the drawing (1116909) was released. The assembly consists of a 4-in. butterfly valve assembled to the Bendix NT-D1 actuator. Attached to the actuator is a five-micron (absolute) filter for actuator-drive-gas filtration and a protective shield to prevent liquid nitrogen from dripping directly on the actuator. Figure 25 shows a drawing of the assembly.

The TPCV (SN 880023) for the XE-1 engine was assembled.

(7) Turbine Block Valve Actuator

A redesign of the NRX/EST configuration of the turbine block valve (TBV) actuator was initiated in May. Criteria for the redesign include response time from command signal to valve closure of less than 100 millisecon and ability to function properly in a 140 to 600°R environment. An analysis to determine the feasibility of using the existing NRX/EST-configuration TBV actuator in the low-temperature application indicated that thermal coefficients of the dissimilar metals within the actuator would cause component interference at temperatures below -50°F. An NRX/EST-configuration actuator was assembled and subjected to progressively-lower-temperature actuation cycles. The actuator failed to respond at a temperature of -150°F. As a result, redesign of the actuator was initiated. Modifications to the existing design included material changes of the body from aluminum to stainless steel (casting in both cases) and of the rack and pinion from vanadium to maraging steel. All seals within the valve were changed. Former buna-N O-rings were replaced with omniseals of Kel-F material, and a piston dynamic seal with Teflon slipper rings backed by metal expanders was selected.

Figure 25

Turbine Power Control Valve Assembly

Figure 25

Turbine Power Control Valve Assembly

The piston stroke was reduced to 1 in., or an equivalent 73° of valve rotation, which results in less pressure loss through the valve and improved actuation response time. The design of the actuator output shaft was changed to a one-piece configuration with a crowned gear tooth to permit angular motion and offset of the actuator with respect to the valve. The potentiometer was replaced with a low-operating-temperature unit, which was successfully tested at temperatures from ambient to 140°R. Two three-way 28-vdc pilot valves, mounted to the actuator, were selected to provide position control. An assembly drawing (PN 1117188) was released (Figure 26).

Hardware fabrication sufficient for five actuator assemblies was initiated; all hardware for two assemblies was completed. Three units are scheduled for X-engine use, one for a demonstration test, and one as a spare.

(8) X-Engine Filters

Five 3/4-in. (PN TA-105-2-12), twelve 1-in. (PN T-5-81660), and eight 2-in. four PN T-8-81658 and four PN T-8-81658) Vacco company filters were purchased and have been received for the X-engine system. In the X-engine system, the 2-in. filter is located in the reactor control-drum-actuator supply line, the 1-in. filter is located in the valve-actuator (GHe) supply line, and the 3/4-in. filter is located in the TPCV-actuator (GHe) supply line.

Successful development tests on the 3/4-in. filter included 1500-psig proof testing and a 200-psig GHe external leak test. A 20-psig GHe leak test at LN₂ environmental temperature disclosed excessive external leakage. Investigation revealed a buna-N O-ring was causing the leakage and was unacceptable for cryogenic service. An O-ring was manufactured from KYNAR (a polyvinylidene-fluoride material), assembled in the filter, and tested as above; leakage was less than 1×10^{-5} scc/sec, which was acceptable. Radiation resistance of KYNAR is 1×10^9 ergs/gm carbon. Acceptance-test plans have been written.

Figure 26
Turbine Block Valve Actuator

(9) High-Temperature and Cryogenic 3/8-in. Check Valves

During development tests of the 3/8-in. check valves, one problem of major consequence became apparent. The valve became nonoperative during cryogenic testing. An engineering design analysis performed by using an enlarged layout of the spherical poppet sealing area and the housing seat, made it apparent that the $15^\circ \pm 30'$ housing seat and the 0.280/0.285-in. spherical poppet sealing area were wedging in the closed position. A change of the spherical radius to 0.100/0.105 in. and of the seat angle to $45^\circ \pm 1^\circ$ was made on one unit, and subsequent development tests proved the modification to be successful (Figure 27). Internal leakage at ambient temperature was zero and was 12.5 scc/sec at LN_2 temperatures with gaseous helium at a 200-psig pressure. Increasing the pressure to 800 psig reduced the leakage rate to 3.0 scc/sec. To prove that the poppet would not wedge in the seat, an 800-psig pressure was held on the closed poppet position for 5 min, after which the cracking and reseating pressures were measured; both were below 5 psid. A high-temperature test followed, with 530°F gaseous nitrogen flow used. No internal leakage was detected at pressures from 100 to 500 psig, and cracking and reseating pressures were below 5 psid.

Drawings were changed to incorporate this modification, and nine units were modified to the new dimensions and will be used on the X-engine-system purge lines for both hot and cold service. Assembly is in process; demonstration- and acceptance-test plans have been completed.

(10) 3/8-in., Three-Way, Two-Position Solenoid Pilot Valve

Laboratory tests were conducted on NRX/EST-system vent valves 1 and 2 in support of NRX/EST testing activity and are reported in RN-TM-0322.* One of the components of the vent-valve assembly is a Barksdale 3/8-in. four way solenoid pilot valve, which failed to activate as commanded when the valve-body temperature was reduced to less than -75°F. Separate solenoid pilot

*RN-TM-0322, 11 May 1966; Failure Investigation of NRX/EST Vent Valves 1 and 2
AGC P/N 1114747-19 S/N 880078 and 880079

Figure 27
Three-Eight-In. Check Valve

tests were conducted on a Barksdale 3/8-in. four-way and on a 3/8-in. three-way Marotta to determine low-temperature operational capabilities. The following results were obtained:

	<u>Barksdale</u>	<u>Marotta</u>
Minimum acceptable operating temp, °F	-75	-150
Nonoperating temp, °F	-100	-200

Subcontractors were surveyed to find a suitable pilot valve for cryogenic service in the XE program. Most of the subcontractors' products had not been tested at cryogenic temperatures, so the evaluation was based on test results of only those that had been tested at cryogenic temperatures. As a result of the survey, the Marotta valve was selected for X-engine use.

Demonstration testing was initiated on two of eight Marotta 3/8-in. solenoid pilot valves (Figure 28). The two valves successfully completed the electrical tests at ambient conditions but did not perform when tested at cryogenic temperatures because of excessive internal leakage. The subcontractor was contacted, because these valves had been certified for cryogenic (LN_2) service. The subcontractor requested that the valves be returned for further modification and testing, and the following modifications were made:

- a. The internal static-seal material was changed from a synthetic rubber to Kel-F to be compatible with cryogenic temperatures.
- b. The dynamic poppet seal adjacent to the retaining nut was changed from Mylar to Kel-F to reduce friction.
- c. The poppet return spring was changed; its load-deflection rate was doubled to ensure positive poppet return in a cryogenic environment.

Figure 28
Three-Eighth-In., Three-Way Solenoid Pilot Valve

d. The solenoid armature stem was replaced with a zirconium stem to provide a contraction rate similar to that of the solenoid core at cryogenic temperatures. Subsequent testing with three modified valves (SN 113, 114, and 115) revealed that two (SN 113 and 115) satisfactorily completed the demonstration tests, including the cryogenic-environment tests, with acceptable internal leakage rates. The third valve (SN 114) did not qualify on the internal leakage at LN_2 temperature (250 scc/sec at 500-psig pressure, GHe) and was returned to the subcontractor for rework.

The subcontractor reworked 12 valves for the X-engine system in accordance with the above modifications and performed the acceptance tests (RN-TP-0021*), except for response timing. The valves satisfactorily completed the tests and will be shipped to Aerojet for completion of the acceptance tests.

c. Turbopump Assembly (TPA) (1.2.3)

Performance, acceptance, and specification-performance-demonstration tests of the turbopump were performed during the contract year. Performance tests conducted on one turbopump established the need to modify the backvane for reduced axial thrust, to increase the first-stage nozzle area, and to smooth the inlet conditions into the diffuser vane in the pump housing. To ensure optimum performance of the first-stage nozzle and the pump housing, each component that was to be used in future turbopumps was tested individually, cold-flow tests were conducted on the turbine manifold and first-stage nozzle assembly, and water-flow tests were conducted on pump housings.

Four turbopumps were acceptance tested, and each was accepted and delivered. One turbopump was delivered to Lewis Research Center and three were delivered for use in the XE system. One turbopump is presently installed in the upper thrust structure of the XECF system.

*Acceptance Test Plan for X-Engine System 3/8 - 3-Way Marotta Solenoid Valve Model #583KC, P/N 806235

Specification-performance-demonstration tests were conducted on three turbopumps. Each of the three turbopumps was successfully endurance-tested in excess of 40 min at the following conditions:

Pump total pressure rise	980 psi or greater
Pump flow rate	75 lb/sec or greater
Turbine-inlet total temperature	1230°R or greater
Net positive suction pressure	10 psia or less

The turbine flow characteristics were determined from results of the endurance test.

The stall-margin and overspeed characteristics were determined from two separate tests conducted on one turbopump.

The results of the specification-performance-demonstration tests are discussed in REON Technical Memorandum RN-TM-0368, Specification Performance Demonstration Test Results, NERVA Mark III Mod 4 Turbopump.

The turbopump (PN 708800-69, SN 015) that was used in the NRX/EST series conducted at the Nevada Test Site was disassembled at the Aerojet facility at San Ramon, California, between 21 September and 26 September 1966.

Visual inspection of the turbopump components revealed no mechanical defects except in the first- and second-stage nozzles. The first-stage nozzle had a very slight crack on one of the blades. The second-stage nozzle had no cracks, but a cratering effect was noticed on 75% of the blades that may have been caused by products in the drive gas impinging on the nozzle blades. The area of the cratering effect was approximately a 1/4 in. in diameter. This component had an excessively high radiation count compared with other components.

A more detailed discussion of the disassembly of the turbopump (SN 015) will be reported in RN-TM-0375, REON Technical Memorandum, NRX/EST Turbopump S/N 015, Disassembly Post-Mortem P/N 708800-69.

The model specification was written in the fourth quarter of the contract year and is pending approval. The model specification discusses the design criteria, performance characteristics, operational limitations, handling requirements, and configuration of the turbopump.

3. Reactor System Integration (1.3)

a. NRX-A Project Operations

A major accomplishment during the contract year was completion of the NRX-A5 Test Series in June 1966. In addition, the NRX-A6 test specification was drafted into final form. Approval and issuance of the test specification will be delayed until CY 67 because the NRX-A6 test has been rescheduled to mid-1967.

Effort was divided into two areas: system design and system operations. System-design activities included nonnuclear assembly design, REON/WANL interface control, instrumentation installation design, establishment of measurement requirements, and review of ground-support equipment. Relative to system operations, activities included test-planning documentation, establishment and coordination of component assembly and checkout requirements, acceptance and shipment of components to the test site, the coordination of test-site activities by other Aerojet organizations, REON representation on the various boards controlling the tests, and interpretation and the dissemination of information resulting from the test to other Aerojet organizations.

(1) NRX-A System Design Efforts

(a) Nonnuclear Assembly

Components used for the NRX-A5 and the general requirements for accomplishing this assembly were defined in the Nonnuclear Assembly Drawing, REON No. 1114727. This drawing was prepared under the supervision of NRX-A Project personnel after detailed discussions with the component designers and technical-support personnel. Some of the major design changes from the NRX-A3 assembly were: elimination of the transducer cooling manifold from the aft end of

the pressure vessel assembly; conversion of flanged-spool pieces on the propellant feed line to a welded configuration; and modification of the instrumentation boom and brackets. This drawing formed a part of the overall test assembly drawing prepared by WANL, number 937J504, and was incorporated in the NRX-A5 test specification.

In addition, all Aerojet components for the NRX-A6 assembly and the general requirements for accomplishing the assembly were defined, nonnuclear assembly drawing, REON No. 1117076, was released 10 June 1966.

(b) REON/WANL Interface Control

The interface control drawings formed a part of the NRX-A5 test specification defining the requirements for the test assembly. The ICD drawings prepared by NRX-A project personnel are the work documents for hardware control, which regulate the design, fabrication, and inspection of the interface components at REON and WANL. System-design personnel determined the REON component design requirements, and, together with the WANL-supplied reactor requirements, created the ICD drawings that documented the mechanical interface details for the NRX-A5 test assembly, and controlled all subsequent changes to the ICD. In addition, the ICD for NRX-A6 was completed and released. The primary problem in the establishment of an NRX-A6 interface document was the selection of an aft-end, reactor-support design that was required due to the change in reactor design. Several meetings were held by AGC and WANL at which various designs were proposed, discussed, and evaluated. The design was documented in the NRX-A6 interface control document released in December 1965.

(c) Measurement Requirements

In conjunction with REON analytical and component design groups and WANL engineering personnel, NRX-A system design personnel prepared a measurement requirements list (MRL) defining the measurement and instrumentation requirements for the NRX-A5 and NRX-A6 test assemblies. This document is a computer

printout defining each parameter to be measured, its location, general quantitative and qualitative performance requirements, part number, historical record of change, and other pertinent data. The approved MRLs were transmitted to WANL for integration into a combined REON/WANL list, which was then forwarded to SNPO-C for review and approval. After SNPO-C approval, the MRLs become a technical direction document requiring approval of changes by participants and by SNPO-C.

The MRL forms a portion of the test specification and is the basis for procurement, instrumentation and schematic drawings, component configuration, test car wiring, and much of the operational planning for the test at the test site.

(d) Instrumentation Installation

To implement the MRL the NRX-A system design group prepared the requirements for and supervised the preparation of instrumentation installation drawings and their accompanying electrical schematic drawing. These drawings, as released for NRX-A5, define the location, type, installation requirements, and wiring orientation of all REON instrumentation. For NRX-A6, these drawings were prepared and were released in accordance with milestone date requirements. The drawings were prepared in cooperation with instrumentation, component and design analysis personnel to assure proper choice of instrumentation and correct installation and operation. Coordination of the overall NRX-A5 and NRX-A6 test assembly instrumentation was maintained by official test car and wiring meetings held monthly between REON, WANL, NTO, and ACFI.

(e) Unique Components

The design and fabrication of unique components to complete the reactor nonnuclear assembly (i.e., special attachment brackets, auxiliary test fixture, etc.) were accomplished. The design and fabrication of

hardware for the special chamber pressure transducer evaluation system were completed, installed, and tested on NRX-A5 test series. Reports on the results of the evaluation will be issued by the Instrumentation Design personnel.

(2) Systems Operations

(a) Test Planning

Several test-planning documents were generated to establish test objectives and requirements for particular test assemblies. The two major documents are the test plan, which establishes the overall test objectives and the test specification, which defines all of the detailed engineering, operational, and safety requirements applicable to the accomplishment of the specified test objectives.

Since the NRX-A5 Test Plan was completed during CY 65, the first test-planning document prepared in this report period was the NRX-A5 test specification. This document specified the requirements for test hardware inspections, assembly and disassembly operations, operational tests, and post-operative examinations and the detailed information concerning test limits needed for the safe operation of the test article in general, and all Aerojet-supplied hardware in particular.

The REON and WANL requirements were combined to form a preliminary test specification draft, which was reviewed and commented on by AGC/WANL and SNPO-C. A coordination meeting was held with all participants; and the final test specification was then drafted into final form, and approved by REON and SNPO-C.

Preparation of the NRX-A6 test specification was accomplished as previously discussed for NRX-A5, and a preliminary copy was issued by WANL on 26 September 1966. Final review and approval of this document will be delayed until CY 1967 due to the change in the NRX-A6 test schedule.

(b) Component Assembly, Acceptance, and Shipment

A design review was initiated during the final quarter of CY 1965 to determine possible design modifications that would reduce the hydrogen leak potential during the NRX-A5 test. As a result, detailed planning was completed to enable the welding of the guide tubes to the pressure vessel and installation of bimetallic-brazed adapters and purge-port adapters. This installation was similar to that accomplished on NRX-A3; however, the work was accomplished at The Marquardt Corporation prior to delivery of the pressure vessel to WANL-Large for reactor installation. Design and development of the all-welded and brazed instrumentation ports for NERVA reactors is described in WANL-TME-1465. A propellant feedline weld evaluation program was conducted at NRDS to determine the best method of field welding the ACFI and Aerojet propellant feed lines on the test car. These were flanged joints on previous NRX tests and were possible points of leakage. Details of the propellant feed-line weld program are presented in NTO-R-0056, field weld evaluation study, final report. These modifications to the NRX-A5 hydrogen flow system reduced the possible hydrogen leak paths by approximately 50% in the NRX-A5 test assembly.

Concurrently with the final phase of the NRX-A5 test specification preparation, the final inspection, cleaning, and packaging of the Aerojet-supplied hardware were accomplished. The Aerojet-supplied hardware was shipped directly to NRDS for final assembly with the exception of the pressure vessel, which was sent via WANL for reactor installation.

A detailed evaluation of the as-fabricated component dimensions was made to ensure compliance with the interface control document. Differences were coordinated with REON, WANL, and SNPO-C, and were accepted or rejected in accordance with established quality control procedures.

The NRX-A6 Aerojet-supplied hardware has been delivered during CY 1966 in the same manner as that for NRX-A5, with the exception of a small amount of instrumentation which should arrive at the Test Site by 1 December 1966. The pressure vessel is currently at WANL awaiting reactor assembly and installation.

(c) Test Procedures

Detailed test procedures for receiving, assembly, checkout, testing, and post-operative examination based on requirements of the test specification were prepared by NERVA test operations personnel, with assistance from REON in the form of drawings, operating maps, handling constraints, handling equipment instruction manuals, etc. After approval by REON and WANL, NTO personnel revised and reissued the procedure for the NRX-A5 Test Series. Once released, the procedure passed to control of the test specification and procedure review board or test review board.

(d) Test Site Assembly Operations

The detailed test procedures prepared for NRX-A5 were used for the assembly of the reactor/pressure vessel, nozzle, and related hardware on the test car at the R-MAD Facility. Starting with the arrival of the reactor/pressure vessel assembly from WANL, field welding of the ACFI and Aerojet propellant feed lines on the test car were satisfactorily completed. The new transducer cooling system, consisting of a closed network of tubing from the nozzle

manifold to the transducers in series, was installed. Prior to the transfer of the NRX-A5 test assembly to Test Cell A, a final central poison-wire removal operation was performed at R-MAD for the first time. This work was accomplished at R-MAD instead of at Test Cell A as in the previous reactor tests, and demonstrated (1) the feasibility of the operation for use in conjunction with the XE engine program, and (2) reduction in the number of experimental plans and time required at the test cell. NRX-A5 central-poison-wire removal was completed at R-MAD on 18 April 1966 in accordance with NTO-R-0064 and NTO assembly procedure NRX-A5-P9. The operation was accomplished with no apparent anomalies, and the final reactor shutdown margin was $3.48 \pm .008$. Assembly operations at R-MAD were completed on 19 April 1966 and the NRX-A5 test article was transferred to Test Cell A.

(e) Test Specification and Procedure Review Board
(TS & PRB) and Test Review Board (TRB)

To establish control over the changes required in the NRX-A5 Test Specification and to provide engineering assistance in both the assembly and testing of the reactor system, the TS & PRB and TRB activities for NRX-A5 conformed with procedures used for previous tests. The TS & PRB was active from the receipt of the reactor/pressure vessel assembly at NRDS until arrival at the test cell. The TRB then became responsible until completion of the last reactor run, at which time the TS & PRB resumed control over all disassembly and post-mortem operations. NRX-A project personnel were assigned as the REON representatives to both of these boards during the entire NRX-A5 test series.

(f) NRX-A5 Reactor Test

The NRX-A5 reactor test series were started on 26 May 1966. This test series consisted of four experimental plans: (1) for initial criticality, checkout and calibration; (2) for neutronics calibration and power test; and (3 and 4) for full-power duration testing. The NRX-A5 test program

was completed on 23 June 1966. The tests successfully demonstrated the fixed-drum start, no-flux loop temperature control, and the eight-decade log power system with test-car-mounted detectors; however, a maximum drum angle of 145 degrees occurred after only 30 minutes of the planned 40 minutes of full-power operation. During EP-IV, the final test, the control temperature (Station 26) was manually trimmed based on measured chamber temperature and pressure. This resulted in operation of the unit at or above full temperature for essentially the entire EP (14 minutes) for the first time during the NRX test program.

JATO units were fired during the second full-power test to mark the effluent cloud from the reactor. Smoke from the JATO's aided the pilots in finding the inversion layer while taking air samples of the effluent cloud. All test specification modifications and procedures were prepared, published, and approved.

Detailed discussion of the results of this test series will be published by Aerojet and WANL in the first two quarters of CY 1967.

(g) Disassembly and Post-Mortem Operations, NRX-A5

The NRX-A5 disassembly operations began on 6 July 1966 at the R-MAD Facility, NRDS and continued until the final fuel cluster was disassembled in the upper bay on 9 August 1966. The post-mortem examination started approximately 20 July 1966 and was basically complete by 30 September 1966. Results of the post-operative examination of the nonnuclear components were made available to the component design personnel for evaluation.

During the disassembly operations and post-operative examinations the test specification and procedure review board was in session at NRDS with NRX-A project personnel representing REON. All procedural changes were reviewed by the board members, and by cognizant source engineering personnel. By

12 August, operations had progressed to the point that full-time residence by board members was not necessary.

(h) Test Cell C

Due to the high residual reactivity, the lack of capability for long-duration tests without multiple starts, and the cost of operating and maintaining Test Cell A, the testing of NRX-A6 was redirected to Test Cell C.

During December 1965, Aerojet received a SNPO-C request to propose on the additional work scope and funding required to conduct the NRX-A6 Test Cell C. Coordination meetings were held with NRDS to determine the facilities that would be available in Test Cell C by December 1966; proposal guidelines were prepared and work was initiated on the proposal preparation. Coordination was maintained with WANL, NTO, and ACFI relating to the NRDS Test Cell C facilities and configuration.

Test Cell C rework is currently near completion. System and shield checks are being conducted in conjunction with the LASL Phoebus IB test series and compatibility studies, and hardware changes are in process to adapt the NRX-A6 test car and system mechanically and electrically.

(i) Conclusions

From the overall NRX-A program standpoint, work accomplished during CY 66 was highly satisfactory. Although the expected duration of 40 minutes at full power was not achieved on the NRX-A5 test series, the fixed-drum start, no-flux loop temperature control, and the eight-decade log power system

with test-car-mounted detectors was successfully demonstrated. In addition, the reactor corrosion problem encountered during NRX/EST was essentially duplicated, indicating the need for extensive work prior to conducting another reactor test.

The Aerojet-supplied hardware such as pressure vessel, nozzle, propellant feed line, and instrumentation performed excellently throughout the test series. Postoperative examinations indicated that these major components are capable of withstanding 60-minute-duration testing at full power.

b. Nuclear Subsystem Development Program

General goals of this program were to provide a source of reactor subsystem technical information for the technology engine program and the NERVA engine program and support related to the reactor to groups concerned with assembly, test planning, test data review, and stress, heat-transfer, nuclear, and system analyses.

The fuel-element development program was monitored to evaluate its effect on reactor capabilities and availability. A continuing review of the NRX-A5, NRX-A6, and XE-1 fuel production program was maintained to assure that the schedules of SNPO-C, Aerojet, and WANL are compatible. Fuel-status reports and NRX-A5 fuel-element corrosion testing status reports were prepared for management.

Technical information was gathered and liaison was provided by attendance at component test program review meetings, and thermal, fluid-flow, nuclear and mechanical design review meetings.

Monitoring of the nuclear-subsystem effort was maintained. Specific activities conducted in reference to these and other WANL projects are as follows:

- (1) Reviewed WANL CY 66 and CY 67 work programs.
- (2) Submitted a technical evaluation of WANL's CY 65 effort.
- (3) Coordinated the technical reviews of all WANL proposed-add-on's for CY 66.
- (4) Conducted technical review of all WANL procurement packages, change proposals, VR, and ERB reports.
- (5) Reviewed recommendations concerning WANL's overtime work requests.
- (6) Reviewed and compared Aerojet Report RN-S-0269, Development Plan, Large Diameter Reactor Engine, with the LDRE reactor design concepts.
- (7) Participated in the initial preparation of the NERVA Nuclear subsystem specification draft.
- (8) Manned the REON office at WANL.
- (9) Reviewed the WANL CY 67 and PFRT development plans.

4. Thrust-Chamber Assembly (TCA) (1.4.0)

Effects of gamma-radiation heating in the pressure vessel and nozzle were reanalyzed to permit accurate evaluation of the performance of these components during NRX-A3 testing. Heating rates were also determined for NRX/EST, NRX-A5, NRX-A6, and XE.

Stress and dynamics support effect was provided for the NRX/EST and NRX-A5 data-review teams at NRDS.

Effort was directed toward upgrading computer programs 14007 (Frame Program) and 14063 (Finite Element of Axisymmetric Structures) to increase their capacity and effectiveness in solving TCA component problems.

a. Thrust Structure (1.4.2)

(1) XE-1 Upper Thrust Structure

Design of the upper thrust structure (UTS) was completed during contract year 1966. Numerous design changes were made after drawing release, as XE requirements became more firm. The design has been frozen since June 1966, and the XE-1 UTS assembly will be delivered early in contract year 1967. Acceptance-test procedure RN-TD-0007, released 15 August 1966, defines the loading* and dimensional requirements the UTS must meet for acceptance. RN-TM-0331, Stress Analysis of the Upper Thrust Structure, as also completed this year and indicates that the UTS design (Drawing 1115459) is adequate for XE-1 loads.

* All loads based on RN-TM-0159, Basic Loads and Structural Design Criteria for XE-1 Engine.

(2) XECF Upper Thrust Structure

The XECF upper thrust structure was delivered to Aerojet-Sacramento after acceptance testing on 15 July 1966 and is currently being used in the XECF upper-thrust-structure module assembly (Figure 29). The part conforms to all requirements for the XE-1 UTS and will be used for XE-2 after the XECF program is completed. The acceptance test was successfully conducted in accordance with the requirements of RN-TD-0005 and confirmed the structural and functional capabilities of the design for XE-2 application.

(3) XE-1 Lower Thrust Structure

After thorough investigation, annealed titanium alloy 6Al-4V was selected for use in the XE lower thrust structure (LTS). The change from aluminum resulted from extending the test duration from 5 to 20 min. The high nuclear-heating rates aft of the engine external shield and the longer test duration would cause lower thrust structures of either aluminum or 300-series CRES to overheat. Analytically, both the selected titanium alloy and Inconel 718, heat-treated and aged, seemed adequate. The decision to use the titanium alloy was based on the vast amount of industry experience in sheet-metal fabrication with this alloy compared with little experience with Inconel 718. The findings of the materials-evaluation effort are set forth in Report RN-TM-0315.

The XE-1 LTS design, the acceptance-test procedure (RN-TD-0008), and the LTS stress analysis (RN-TM-0332) have all been completed.

Detail parts for the assembly have been fabricated, and the assembly is scheduled to be completed near the end of the first quarter of contract year 1967. The acceptance-test procedure defines the loading and dimensional requirements the part must meet for acceptance. The stress analysis indicates that the design will withstand all expected test loading conditions.

Figure 29
XECF Upper Thrust Structure

(4) XECF Lower Thrust Structure

During contract year 1966, the XECF LTS assembly was designed, fabricated, acceptance-tested, and delivered for use in the XECF engine assembly (Figure 30). This assembly is the first titanium LTS fabricated, and its compliance with all acceptance criteria specified in RN-TD-0006 confirmed the design's structural and functional capabilities.

A material cracking problem (reported in the third quarterly report) developed in preforming 6Al-4V titanium sheet metal heated to 1000 to 1100°F. Analyses indicate that the material heats that were subject to cracking had not been fully annealed by the material supplier. Even though the material satisfactorily met all specified chemical and physical requirements, the microstructure was not optimum for preforming in the temperature range used. Preforming was successfully accomplished at temperatures of 700 to 800°F.

(5) Design Aid and CFDTS Thrust Structures

Report RN-TM-0288, Upper Thrust Structure to Test Stand Adapter Fit Up Test, was published this quarter. The fit-up test was conducted to determine if the alignment devices on the design-aids UTS and the test-stand adapter TSA would function properly. Test results showed that the alignment system is adequate and that the feature will permit the remote assembly of the X-engine in ETS-1.

The CFDTS Lower Thrust Structure Structural Test Evaluation Report, (RN-TM-0339) was published this year.

b. Pressure Vessel

During the contract year, pressure-vessel hardware was furnished for the NRX-A5, NRX-A6, and XE-1 test programs, a pressure-vessel/hot-bleed-port nozzle test program was conducted; and NRX pressure vessel test data were analyzed and evaluated.

Figure 30
XECF Lower Thrust Structure

(1) NRX-A3 Pressure Vessel

The performance of the pressure-vessel assembly, including the pressure-vessel cylinder (PN 706989-3A, SN 006), pressure-vessel closure (PN 703887-5C, SN 003), nozzle-cylinder seal (PN 702154-N/C, SN 056), cylinder closure seal (PN 286766-D, SN 089), 120 closure bolts (PN 28664-3G), and 120 closure-bolt K-seals (PN 1010108), was evaluated during the NRX-A3 program. In general, the validity of the NRX-A3 data was helpful in evaluating the structural and functional integrity of the pressure-vessel assembly. All vessel hardware except the cylinder-closure seal performed well within design limits. From data obtained from the leak-detection system, it was concluded that the seal permitted leakage in the initial power ramps during transient conditions. However, no conclusive evidence could be compiled to indicate any leakage occurred at the full-power steady-state hold points. In an attempt to solve the closure sealing problem, the NRX-A3 seal (PN 286766) will be superseded by a new seal (PN 286770), and a new closure-cylinder joint (designed to improve joint compatibility and sealing characteristics) will be incorporated on future pressure vessels. Both design concepts were presented in detail in the CY 1965 Summary Report, RN-A-005. The NRX-A3 pressure-vessel evaluation is documented in Report RN-S-0303, Evaluation of NRX-A3 Pressure Vessel.

(2) NRX/EST Pressure Vessel

An evaluation report that provides an analysis of the pressure vessel during the NRX/EST test program, was started during the contract period. The analysis to date has indicated that the structural integrity of the pressure vessel was again demonstrated in a full-power environment. The report will be published as RN-TM-0372.

(3) NRX-A5 Pressure Vessel

A decision was made that joints between the guide tube and closure, the instrumentation and closure, and the emergency purge system and closure would be welded in an attempt to minimize potential leakage paths on the NRX-A5 assembly. The welding was performed at the facility of the pressure-vessel

subcontractor, and the closure-flange interface was final-machined after welding to ensure that the required tolerances in this area were maintained. The pressure-vessel cylinder, closure assembly, guide-tube-to-closure weld joint, and instrumentation-to-closure weld joint are shown in Figures 31, 32, 33, and 34, respectively.

The NRX-A5 pressure vessel was fabricated, acceptance-tested, and delivered. Acceptance and acceptance testing were in accordance with Report RN-TD-0001, Acceptance Procedure, NRX-A5 Aluminum Pressure Vessel. In conjunction with the NRX-A5 acceptance test, strain gages and deflection instruments were installed, and the metallic cylinder-closure seal (PN 286770) was assembled for a helium leak test to verify the expected behavior of the redesigned closure-cylinder joint. As no seal leakage was detected, the test successfully demonstrated that the redesigned joint improved the compatibility of the forward-cylinder and closure flanges. The adequacy of the new design was also demonstrated by the reduction in meridional stress and the decrease in differential flange rotation. Report RN-TM-0359, NRX-A5 Aluminum Pressure Vessel S/N 010 Structural Evaluation of Redesigned Cylinder/Closure Joint, covers the test analysis and vessel evaluation.

(4) NRX-A6 Pressure Vessel

Detailed fabrication drawings were completed that reflected a closure assembly almost identical to that of NRX-A5 and a cylinder that provided interfaces for an aft reactor support system. The redesigned aft pressure-vessel flange and reactor support schematic are shown in Figure 35.

Pressure-vessel cylinder and closure forgings were purchased, and the vessel was fabricated, acceptance-tested, and delivered. The acceptance procedure for the NRX-A6 pressure vessel is detailed in Report RN-TD-0004, "Acceptance Procedure, NRX-A6 Aluminum Pressure Vessel."

Formal, detailed NRX-A6 heat-transfer and stress analyses were completed in which the pressure vessel was evaluated for Test-Cell-C test conditions. The analytical results of the heat-transfer and structural investigations will be published in Reports RN-S-0335 and RN-S-0336, respectively.

Figure 31
NRX-A5 Pressure Vessel Cylinder

Figure 32
NRX-A5 Pressure Vessel Closure Assembly

Figure 33
Weld Detail, Guide Tube/Closure Joint

Figure 34

Weld Detail, Bimetallic Reactor Instrumentation Adapter/Closure Joint

Figure 35
NRX-A6 Reactor/Pressure Vessel Aft Support Schematic

(5) XE-1 Pressure Vessel

Design of a pressure-vessel cylinder-and-closure assembly for XE-1 was completed. The closure assembly incorporated WANL-furnished bimetallic adapters welded to the closure for reactor instrumentation, and Marman flanges were provided for attaching the guide tube to the closure. The closure also had a Marman flange for diluent-line attachment, and 36 radial holes were tapped in the outside of the closure flange for thrust-structure attachment. The cylinder aft flange was redesigned (identical to NRX-A6 redesign, reference Figure 35) to accommodate either a forward- or aft-supported reactor assembly.

Pressure-vessel fabrication, acceptance testing, and delivery were completed. The acceptance procedure for the XE-1 pressure vessel (consisting of proof and leak testing after fabrication, inspection with reactor gages, final cleaning, and packaging) is described in Report RN-TD-0002.

Detailed heat-transfer and stress analyses of the pressure vessel for XE conditions were completed, and results will be published in Reports RN-S-0337 and RN-S-0338, respectively.

(6) XE-Spare Pressure Vessel

Forgings were procured and fabrication was initiated for an XE-spare pressure vessel. Fabrication is expected to be completed early in contract year 1967, with acceptance in accordance with Report RN-TD-0002.

(7) XE-2 Pressure Vessel

Cylinder and closure forgings were procured in preparation for the fabrication of an XE-2 pressure vessel in contract year 1967.

(8) Pressure-Vessel Development

The hot-bleed-port nozzle and the pressure vessel underwent successful structural testing in the Structural Test Laboratory at Aerojet-Sacramento. A development pressure vessel (SN 003) of aluminum alloy and a

stainless-steel nozzle (SN 008) with hot-bleed port were used. The hydrostatic test was performed at ambient temperature to determine strains at critical areas and deflections of the cylinder-nozzle and cylinder-closure joints, compatibility of the hot-bleed-port nozzle and pressure vessel, and the ultimate pressure and mode of failure of the pressure vessel. The deflections, rotations, and strains at proof pressure were within the limits of the theoretical predictions. The pressure vessel ruptured at 1380 psig, with the failure initiating between two tapped instrumentation pass-through holes in the forward section of the cylinder. Photographs of the test assembly and the pressure-vessel failure area appear in Figures 36 and 37. Test data will be evaluated and published in Report RN-S-0339, Hot Bleed Port Nozzle/Aluminum Pressure Vessel Hydrostatic Proof and Burst Test Evaluation.

c. TCA Lines

(1) X-Engine Lines

The major TCA line effort in contract year 1966 involved the design and fabrication of the pump discharge line (PDL), turbine inlet line (TIL), diluent lines (DIL), cooldown line (CDL), and vent lines located in the upper-thrust-structure module (UTSM). Where possible, the lines were similar to the NRX/EST lines. The most significant design considerations involved the interchangeability of the UTSM for the remote program, reduction of loads on the nozzle and TPA, and minimizing of tolerance buildup.

During the first half of the contract year, the lines were analyzed for the engine operating condition and for assembly tolerance buildup. Results showed that it was possible to have excessive angular deflection of the gimbaled bellows and high reaction loads at the TPA and nozzle flanges. To reduce the tolerance-buildup problem, a custom-fit technique was established for one segment each in the PDL, TIL, and CDL in the UTSM. This technique will be discussed later in more detail. Flange loads were further reduced by using nickel plating and lubricant on moving parts of the bellows.

Figure 36

Hot-Bleed Port Nozzle/Pressure Vessel Hydrostatic Test Assembly

Figure 37

Pressure Vessel Failure Area, Hot-Bleed Port, Nozzle/Pressure
Vessel Hydrostatic Test

In addition to the extensive structural-loads analyses, each line design was stress-analyzed. Heat-transfer analyses were performed on the Marman flanges and the TIL bellows adjacent to the nozzle.

Fabrication of all XECF and XE-1 hardware was initiated, and this year-end status for each segment is given in Figure 38. Control of in-process cleaning of each bellows and line assembly was initiated to minimize the need for removal of contamination in final cleaning. Final line-segment cleaning was performed in accordance with Aerojet Process Specification 90082-2A by using both the ultrasonic techniques with a high solvent flow rate and a high-velocity solvent spray into each bellows assembly.

Upon completion, each of the XECF upper-module segments was shipped to Aerojet-Sacramento and assembled into the UTSM for the custom-fit fabrication program. With the UTS, including TPA, mounted on a specially designed assembly stand, shield segments were located at predetermined positions relative to the shield-simulator penetrations and the remote flange. With the remaining PDL and TIL prefabricated segments installed, a toolmaster was positioned to bridge the missing segment. The toolmaster was assembled by means of bolts and dowels (Figure 39). A similar tooling approach was used for the CDL after the line remote interface had been properly position.

Weld fixtures were made by using the toolmasters as gages (see Figure 40). The line assembly was then trimmed to fit the fixture and was welded. Figures 41 and 42 show the PDL and CDL in their respective fixtures. The segments were successfully checked after welding by installing them in the UTSM. At the end of the contract year, all three XECF custom-fit segments were ready for hydrostatic testing, helium leak check, and final cleaning.

Results indicate that the custom-fit technique is satisfactory for providing interchangeable UTSMs. A fit-up with the lower module early in contract year 1967 will confirm this assumption.

<u>Line</u>	<u>Part No.</u>	<u>XECF</u>	<u>XE-1</u>
PDL: Pump segment*	1114239-9	Ready for hydrotest	CY 1967 work
5 in. valve adapter	1116237-9	Available	Vendor inspection
Shield segment	1116236-9	Available	Available
Nozzle segment	1114240-9	Ready for hydrotest	Ready for hydrotest
TIL: Jacketed section	1114242-39	AGC inspection	N/A
Jacketed section	1114242-19	N/A	AGC inspection
Shield segment	1114241-9	Available	Vendor inspection
Elbow segment*	1117111-9	Ready for hydrotest	CY 1967 work
Pump segment	1116132-9	Available	Available
Diluent line	1116296-9	Available	N/A
Diluent line	1114243-9	N/A	Available
Cooldown line*	1114238-9	Ready for hydrotest	CY 1967 work
Pump vent line	1115415-9	Bellows in fab	Bellows in fab
Cooldown vent line	1115416-9	Bellows in fab	Bellows in fab

* Custom-fit line segment.

Figure 38
Status of X-Engine TCA Line Hardware

Figure 39
Toolmaster, Pump Discharge Line

Figure 40
Weld Fixture Gaged from Toolmaster

Figure 41
Customfit PDL Segment in Weld Fixture

Figure 42

Custom Fit Cooldown Line in Weld Fixture

(2) NRX/EST Lines

The NRX/EST TCA lines remaining from contract year 1965 were delivered in early October 1965 when the pump discharge flange and bellows assembly was final-cleaned and shipped to NRDS. All line segments were successfully assembled on the test car. Visual observation during the test runs and post-test operation revealed no leakage, malfunction, or damage.

(3) NRX-A Propellant Feed Lines

During the first quarter, the NRX-A5 propellant feed line (PFL) was reworked, proof- and leak-tested, cleaned, and shipped to NRDS for installation on the test car. The rework consisted of additional welding of bellows seam welds, welding of several instrumentation taps to close them, and preparing the upstream end for field welding with a Y-ring consumable-weld insert. Ultrasonic cleaning was performed in accordance with the new cleaning specification, AGC-90082-2. Upon receipt at NRDS, the line was welded to the facility line at the upstream end and was attached to the nozzle at the downstream end. During the testing, no indication of leakage or part malfunction was observed. Preliminary evaluation indicates the line performed satisfactorily.

Design of the NRX-A6 PFL was completed during the third quarter. The configuration was the same as that for the NRX-A5 PFL except for the following:

1. A qualified, X-engine, pump-discharge, gimbaled bellows (PN 1114084-1) with upgraded pressure capabilities was used.
2. Instrumentation bosses reflected the NRX-A6 MRL.
3. The turbine material was changed to 0.188-in.-thick, Type-304L stainless steel from 0.125-in.-thick, Type-347 stainless steel.

The line (PN 1117422-9) was completed and delivered to NRDS during September. In-process cleaning controls were maintained both in the assembly of the bellows and the fabrication of the line. Final cleaning was performed in accordance with Specification AGC-90082-2A by using both the ultrasonic technique with a high solvent flow rate and a high-velocity solvent spray into each bellows assembly.

Evaluation of the NRX-A3 propellant feed lines was completed (Report RN-TM-0323), and it was concluded that the PFL performed satisfactorily.

(4) Development Lines

A turbine-inlet jacketed line section, initiated in contract year 1965, was completed and delivered for testing during the second quarter. To acquire a history of environmental exposure for the new X-engine 4-in. gimbaled bellows, spare development turbine inlet segments were reworked to include these bellows. These line segments and the jacketed section were installed and tested with the hot-bleed-port nozzle during the optimization tests.

Because of the nozzle test objectives, the TIL was subjected to pressure and temperature conditions in excess of those expected for the X-engine operation in ETS-1. The most severe condition was reached when fluid pressure and temperature were 760 psia and 1200°R, respectively (see Figure 43). There was no apparent damage or malfunction in the bellows or the turbine-inlet-line assemblies. X-engine design conditions are 550-psia pressure and 1140°R temperature.

(5) Bellows Development

The major bellows development effort covered the successful qualification of the X-engine 5-in. gimbaled bellows. Convolution yielding evident in initial proof tests resulted in changing the Type-321 stainless-steel convolution material to Inconel 718. During the subsequent qualification test

Turbine Inlet Line Parameters for Nozzle Test No. 1.2-14-MMM-010

Figure 43

series, high friction moments were caused by galling of the gimbal pin with the gimbal ring. Two units were assembled with nickel-plated pins and with several different lubricants on the hole surfaces of the gimbal ring and holder lugs (see second quarterly report for details. The pin design was also changed to permit freedom of movement in the holders. On the basis of test results, a molybdenum-disulfide compound, Electrofilm 77S, was selected. The resulting friction moment over the cycle life was determined to be satisfactory for X-engine use. A complete qualification test program was satisfactorily conducted on two production-type assemblies. Testing included angular cycling, vibration dwell at the most severe natural frequency, proof pressure cycling, helium leak check, and burst testing. Of four units tested to destruction, the maximum pressure varied between 2890 and 3050 psig. The design requirement was 2250 psig. All units failed at the gimbal ring.

The X-engine 4-in. gimbale bellows, which was qualified in contract year 1965, underwent product improvement to increase capability and part reliability. A revision to the design for welding the pin to the holder lugs raised the maximum pressure capability about 400 psig. Results of two tests were 1950 psig and 2000 psig. The results of the plating and lubrication program for the 5-in. bellows were incorporated in the 4-in. bellows design by nickel-plating the pins and applying Electrofilm 77S to the gimbal-ring hole. Friction values were reduced as before.

During the contract year, a total of thirty-one 5-in. and eight 4-in. X-engine-type, production, gimbale bellows were fabricated.

Three of the 5-in. bellows were welded into a pump discharge line for TPA testing. To date, one LH_2 test has been run with successful bellows operation. The maximum discharge pressure attained was 1010 psia.

(6) Seal and Remote-Joint Development

To provide a backup configuration for the Marman semi-remote conoseal joint, a screw-type joint was designed that would satisfy the PDL pressure requirements (Figures 44 and 45). A test fixture was fabricated and successfully subjected to hydrostatic testing to 1500 psig to demonstrate structural integrity. The coupling was retained by one segment of the line, and the threads were lubricated with Electrofilm 77S.

In conjunction with this joint configuration, a pressure-actuated seal similar to the large-diameter pressure-vessel seal was designed. Twelve seals were fabricated and helium-leak-tested in the remote-joint test fixture. Test results for all twelve seals showed leakage to be less than 1×10^{-4} cc/sec/in. of seal diameter at a pressure of 750 psig. The engine specification limits seal leakage to 1×10^{-2} cc/sec/in. of seal diameter at a helium pressure of 50 psig. A typical crushed seal is shown in Figure 46.

g. NERVA Nozzle Development Program (1.4.7)

During contract year 1966 nozzles for NRX/EST backup, NRX-A5, NRX-A6, NRX-A6 backup, and XE-1 were completed. These units all have the same basic U-tube design as that used on NRX-A3, and NRX/EST. Because of the basic similarity between the recently completed nozzles and the previous ones, only minor design modifications were made during the past year. The heat transfer margin tests of the XE type nozzle were also completed in Contract Year 1966.

(1) Nozzle Development

A critical element in the nozzle fabrication cycle is the boring of the hole for the hot-gas bleed port. Thirteen coolant channels are intersected by the bore and the coolant is routed past the bleed port in an exterior manifold. These channels are blocked at the bore by end caps, which are thicker than the tube wall, enabling flexibility in positioning of the hole and channels in the axial direction. The wall of the first tube (on each side of the

Figure 44
Five-In.-Diameter Remote Joint

Figure 45
View of Remote Joint

Figure 46
Five-In.-Diameter Line Pressure-Actuated Seal after Test

bore) that is not intersected comes tangent to the bore, and this wall is relatively thin (.014 in.). Since no metal can be removed from the tube wall, the position of these two tangent tubes establishes a maximum bore diameter. The original nominal design diameter was 6.204 in. Because it was difficult to achieve this diameter due to interference with the tangent tubes on the first several units fabricated, the nominal bore diameter was reduced to 6.178 inches. When additional difficulties were encountered with other units, a detailed tolerance study was made. This study showed that with allowances for all tolerances, the maximum bore could be as small as 6.120 inches. Because this condition is not likely to occur, a bore size of 6.156 in. nominal was established. A design revision was made to the hot-gas bleed port to assure its compatibility.

A significant nozzle design change was the reduction of potential leak paths by plugging and welding all unused instrumentation bosses and welded attachment of the bolt coolant lines. These lines had previously been attached with standard threaded fittings. Nozzle design was also modified to conform to the instrumentation requirements of each of the overall test systems.

During normal hydrostatic testing on the NRX/EST backup nozzle of the bleed port-to-nozzle joint, it was difficult to achieve a satisfactory seal. A detailed evaluation of the seal and joint indicated that the seal was marginal. A test plan, nozzle hot-bleed port-seal evaluation, RN-TP-0006, was initiated to determine the most suitable seal configuration. Four types of seals were evaluated: (1) E-Seal from Pressure Science, Inc. (This was the original marginal seal used); (2) K-Seal from Harrison Manufacturing Co.; (3) "O" Val Seal from Del Manufacturing Co.; and (4) the Omega Seal designed by Aerojet-General. Cross-sectional views of the four seals are shown in Figure 47.

Test results are shown in Figure 48, indicating the Omega seal is significantly better than the others. The decay rate is relatively small and the results are consistent. One K-seal showed good sealing qualities; other results were inconsistent. Test results with the E-seal and "O" Val seal were not promising.

E - SEAL

K - SEAL

"O" VAL SEAL

OMEGA SEAL

Figure 47
Seal Cross Sections

SEAL	P/N	S/N	FLANGE SEPARATION			PRESSURE DECAY, psi (3 CYCLES) (5-Min Hold)		
			0	100	400	200	400	800
Harrison "K"	266744-A	880001	.002	.002	.002	16 3 2	15 11 9	52 38 37
Harrison "K"	266744-A	880002	.003	.003	.003	0 0 0	1 1 3	11 8 10
Omega (Hydro Dyne Corp.)	1114180-25	880375	.002	.002	.002	0 0 0	0 3 1	4 5 3
Omega (Hydro Dyne Corp.)	1114180-25	880374	.006	.008	.008	2 0 0	2 1 0	3 3 5
*Omega (Std.Tool & Die)	1114180-25	880380	.0015	.0015	.0015	0 0 0	2 3 0	2 6 11
Omega (Std.Tool & Die)	1114180-25	880383	.010/.015	.010/.015	.010/.015	9 -- --	5 -- --	19 -- --
Omega (Std. Tool & Die)	1114180-25	880378	.006/.008	.006/.008	.006/.008	1 0 0	5 1 1	13** 5 3
"E"-Seal (Pressure Science)	1115237	19	.002	.002	.002	0 -- --	10 -- --	335 -- --
"E"-Seal (Pressure Science)	1115237	18	.002	.002	.002	0 0 0	2 0 1	20 17 14

Figure 48
Seal Test Data

SEAL	P/N	S/N	FLANGE SEPARATION			PRESSURE DECAY, psi (3 CYCLES) (5-Min Hold)		
			0	100	400	200	400	800
"E"-Seal (Pressure Science)	1115237	17	.002	.002	.002	20	42	115
						20	30	98
						10	35	80
"O" Val	DA14C-112	11	.003	.003	.003	0	5	50
						0	3	43
						0	2	38
"O" Val	DA14C-112	20	.0015	.0015	.0015	0	70	390***
						0	0	7
						2	1	10
"O" Val	DA14C-112	14	.011/.015	.011/.015		No helium tests run due to excessive leakage during preliminary water tests		
Packing "O" Ring	MS29513	--	.003	.003	.003	1	48	12
						--	--	--
						--	--	--

* Seal used to evaluate S/N 029 Nozzle Seal Groove

** Fitting on tool was leaking

*** O-Ring in tooling leaked

During the evaluation, the test method was improved and test conditions varied slightly from the test plan. Flange rotation was insignificant, and recording of this item was discontinued. Pressure-decay tests as high as 800 psig using helium as the test medium were found to be the most satisfactory.

Based on these tests, the Omega seal has been selected for use.

(2) Nozzle Analysis

Following the NRX/EST and NRX-A5 test series, nozzle-assembly performance was evaluated. In all instances, the nozzle performed as expected with no abnormalities. Pressure drop and temperature rise through the nozzle-coolant circuit were well within the capabilities of the prediction analyses. Pressure drop through the bleed-port diluent circuit was nominal.

Of particular significance are the gas-side, tube-wall temperatures that occurred in the nuclear test series. Data relative to actual temperatures achieved are available from analysis of the braze alloy deposits on the tube walls. The mechanics of this means of data collection were discussed in the contract year 1965 summary report. Braze alloys having different remelt temperatures are applied to the hot-gas side of the coolant channels. Following the test the alloy patches are examined for evidence of remelt, which indicates the temperature reached by the metal of the tube crown. Results of the NRX-A3, NRX/EST, and NRX-A5 test series are shown in Figure 49. The predicted data line is based on analytical model predictions of the as-run conditions. These data show that the analytical model is not accurate at all axial points on the nozzle. In the nozzle throat where the most severe conditions occur, the analytical model provides a satisfactory predicted value. Forward of the nozzle throat, the analytical model tends to predict temperatures that are generally lower than the actual data; aft of the throat, the model predicts temperatures that are generally higher than actual data. The results of the three test cases cannot be directly compared due to variations in actual test conditions; however, the trends (especially aft of the nozzle throat), are readily discernible. Actual test data obtained forward of the throat

Figure 49
Nozzle Wall Temperature Measurement Summary

are questionable due to deterioration of the braze patches as a result of the impact of solid particles. These investigations indicate that modification of the analytical model is desirable.

Increased secondary radiation, due to the engine shield on NRX/EST, caused increased heating of the main nozzle flange. The original design of the flange coolant system was based on an analysis that did not include use of the shield. Analyses that incorporated the additional heating showed flange-skin temperatures that were slightly higher than desired during full-power conditions, and the flange coolant system was modified to reduce the temperatures.

(3) Heat-Transfer Margin Tests

(a) Test Plan

The objective of this test program was to determine the maximum safe operating limit relative to the heat-transfer capability of the XE type nozzle as outlined in REON Test Plan RN-TP-002.

Initially, the test plan indicated a constant mixture ratio of 4.5 to 1 (approximately 5.5:1 between injector baffles), a gradual increase in chamber pressure in steps from 650 psia to 850 psia, then reduction of nozzle-coolant flow in steps until incipient erosion of nozzle tubes is achieved. Heat-transfer predictions were obtained for hot-gas-side, tube-wall temperatures at various nozzle-coolant flow rates and chamber pressures. With 850 psia chamber pressure tube failure was expected to occur at approximately 32 lb/sec nozzle-coolant flow. Figure 50 shows predicted tube-wall temperature at various nozzle chamber pressures and coolant-flow rates.

Since operational chamber pressures were to be much higher than the components were originally designed for, it was necessary to make stress analyses to verify the performance of all hardware and test support equipment under chamber pressures ranging up to 850 psia.

Figure 50
Predicted Tube Wall Temperature of S/N 027 Nozzle at $MR = 5.5$
(Between Injector Baffles) and Varying Coolant Flow Rates

Only the KAMT51-1 pattern injector and the fuel and oxidizer thrust chamber valves did not perform satisfactorily with chamber pressure at 850 psia. Injectors with this pattern would have a pressure drop of about 300 psid across the oxidizer face plates, which is approximately 100 psi above the allowable value.

To correct the high pressure drop across the KAMT51-1 pattern, the injector was modified to a KAMT51-3 pattern by enlarging the oxidizer orifices.

Operation at 850 psia chamber pressure would require pressures of approximately 1200 and 1300 psia, respectively, in the oxidizer and fuel tanks. Because Kel-F lip seals have cracked or broken when thrust-chamber valves were subjected to fluid pressures higher than 1000 psia, a study was made to resolve this problem.

Attempts were made to build up an oxidizer thrust-chamber valve with a metal lip seal, but this approach would require a major development program. Because of the schedule and cost factors involved in redesign of the valve body to provide more support for the Kel-F lip seal, and the limited number of tests remaining where these valves would be used, staging of propellant tank pressures was apparently the most feasible method of minimizing lip-seal failures during start.

Reducing tank pressure at shutdown, prior to closing the thrust chamber valves was not practicable because of the time required to vent down-tank pressure in the event of an emergency shutdown. To protect the oxidizer valve from being subjected to high pressure during shutdown, a throttling valve without a lip seal was installed upstream of the main thrust-chamber valve. Since leakage of fuel at shutdown was not considered to be as dangerous as leakage of oxidizer, the fuel valve was left unprotected during shutdown.

(b) Test Setup Procedure

Test procedures are shown in Test Specification RN-DR-0061 and Test Series 1.2-14-NNN (Figure 51 shows the test installation.)

The test setup and procedures were essentially the same as those for tests of SN 021 nozzle during contract year 1965, except for staging the fuel-tank pressure at start, the use of a throttle valve upstream of the oxidizer thrust chamber valve, and a wire-mesh screen downstream of the oxidizer thrust-chamber valve. The wire mesh screen downstream of the oxidizer thrust-chamber valve, and a finer mesh screen downstream of the fuel thrust-chamber valve, were used to prevent small pieces of Kel-F lip seal or other particles from obstructing flow in nozzle tubes or injector orifices.

Difficulties were encountered when the oxidizer tank pressure collapsed during staging to the higher pressures. When high-velocity gaseous nitrogen was introduced into the propellant tank, it apparently agitated the liquid oxygen and caused the nitrogen to cool rapidly, resulting in a collapse of pressure. By adding the pressurant gas at a slower rate, a constant pressure-rise rate could be achieved but this necessitated a longer start transient. After a series of pressure-rise rate tests at different tank levels and with limiting of the opening of the pressurization valve, it was determined that the optimum oxidizer tank-pressure rise rate was about 100 psi/sec.

(c) Test Results

The test objective was achieved in the tenth test, when moderate erosion occurred in six tubes. Three of the tubes were eroded through with small cracks approximately 0.010 by 1/8 in. long. Figure 52 shows a typical photo of a damaged tube.

Figure 51
Test Installation

Figure 52
Typical Damaged Pipe

Test conditions during Test 1.2-14-NNN-010 were:

- 1 Chamber pressure: 801 psia
- 2 Mixture ratio: 4.63 (5.7 between injector baffles)
- 3 Nozzle coolant flow: 43.2 lb/sec

A summary of test series results is shown in

Figure 53.

The first test was a satisfactory 15-sec system-checkout test with a chamber pressure of 674 psia and a mixture ratio of 4.7 to 1. Three attempts to operate at 750 psia chamber pressure all resulted in a premature shutdown by a combustion-stability monitor.

Two factors were different from those of previous stable tests: (1) The injector oxidizer orifices had been enlarged to enable operation up to 900 psia chamber pressure without exceeding the allowable pressure drop across the oxidizer face plates, and (2) tests were made at a lower start-transient mixture ratio while approaching steady-state chamber pressure. Figure 53 shows a comparison of Tests 1.2-14-NNN-003 and 1.2-11-NNN-010.

To correct the combustion instability, an injector with the KAMT51-1 pattern, which has a history of good stability, was installed in place of the KAMT51-3 pattern, and the start transient was modified to provide a higher mixture ratio.

Use of the KAMT51-1 pattern necessitated limitation of the chamber pressure to 800 psia and operation at nozzle coolant-flow rate and mixture ratio that would cause tube burn-out at this chamber pressure.

The new operating conditions were approved, and amendment No. 1 was issued to Test Plan RN-TP-0002, indicating the change in test conditions.

Summary of Test Data for Test Series 1.2-14-NMN on Hot-Bleed
Nozzle S/N 880027

Figure 53

TEST NO.		DURATION SEC	STEADY-STATE DURATION SEC	Pc PSIA	MIXTURE RATIO NOMINAL BETWEEN BAFFLES		W _f NOZZLE (LB/SEC)	MAXIMUM PREDICTED HOT-GAS SIDE TUBE WALL TEMP, °F	MAXIMUM MEASURED TUBE-WALL TEMP BY BRAZE SAMPLE, °F
001	Planned	15	7.8	650	4.5	5.6	70	1670	>1742
	Actual	15.1		674	4.7	5.8	72.9	1648	
002	Planned	20	0	750	4.5	5.6	70	1790	
	Actual	1.7							
003	Planned	20	0	750	4.5	5.6	70	1790	
	Actual	6.5		721	3.6	4.5	77.1		
004	Planned	20	0	750	4.5	5.6	70	1790	
	Actual	3.5							
005	Planned	20	0	750	4.75	5.9	70	1810	
	Actual	5.8		645	5.0	6.2	56.7	1679	
006	Planned	20	13.3	750	4.75	5.9	70	1810	>1742
	Actual	20.8		736	4.85	6.0	71.3	1745	
007	Planned	20	11.5	800	4.75	5.9	70	1880	
	Actual	20.5		789	4.66	5.8	72.8	1806	
008	Planned	20	11.9	800	4.75	5.9	59.0	1970	
	Actual	20.8		801	4.63	5.7	54.6	1900	
009	Planned	20	0	800	4.75	5.9	44	2055	
	Actual	1.3							
010	Planned	20	11.5	800	4.75	5.9	44	2055	>1742
	Actual	20.4		801	4.63	5.7	43.2	1997

To control mixture ratio within the limits required by the new test plan it was necessary to more accurately control the pressure-rise rates of the oxidizer and fuel tank pressurization. This was accomplished by using servo-controlled pressurization valves and slaving the fuel-tank pressure to the oxidizer-tank pressure to follow a prescribed curve, such as shown in Figure 54. This approach provided satisfactory control of mixture ratio during the start transient. Figure 55 shows the relationship of mixture ratio to chamber pressure of the modified start transient as compared with previous tests.

The six remaining tests were all satisfactory, except Test 009, which resulted in a premature shutdown by a chamber-pressure monitor. Failure to obtain a chamber pressure reading was traced to an obstructed transducer line.

The predicted hot-gas-side, tube-wall temperature for Test 010 is 2000°F; however, braze alloy melt temperatures indicate predictions are at least 200°F low from the throat forward; approximately correct just aft of the throat; and probably 600°F high at the extreme aft end. Figure 56 shows a comparison of braze alloy temperatures and predicted hot-gas, side-tube wall temperatures.

Temperature data are still being analyzed, and a final test report will be prepared, but test data further verify that the nozzle will perform satisfactorily when maximum tube-wall temperatures are several hundred degrees higher than the temperatures expected during 100% nuclear power conditions.

(d) Hot-Bleed-Port Test Results

The prototype hot-bleed port P/N 706967-39, SN 0088 was used in all 10 tests of the heat-transfer-margin test series.

This bleed port further demonstrated its capability to operate satisfactorily under conditions more severe than those during exceeding nuclear simulation in all of the five tests where steady-state conditions were achieved. The hot-bleed port showed only slight discoloration, with no erosion during these tests.

Figure 54

Oxidizer and Fuel Vessel Pressurization Schedule for Test 1.2-14-NMM-007
NTA S/N 027

Figure 55

Modified Start Transient to Prevent Instability

Hot-Gas-Side Tube Wall Temperatures

Figure 56

5. Engine Controls (1.5)

a. Control-System Integration and Design

(1) XE-1 Engine Control System

Detailed design, fabrication, and checkout of the XE-1 engine control system (ECS) were completed. A summary of the major activities follows.

(a) Programmer-Controller Chassis

The detailed circuitry and the mechanical design of the ECS programmer-controller chassis were completed. Fabrication of the chassis was also completed (Figure 57). Features included in the final design were:

1 Replacement of the pressure-demand trim with a trim on the measured-temperature-to-pressure-demand function generator with available pressure ramps of 1, 2, 4, and 8 psia/sec.

2 Addition of a pressure-loop manual-closure feature.

3 Redesign of the temperature-demand generator to allow independent adjustment of the reactor period during bootstrap and the closure point of the temperature-control loop.

4 Remechanization of the pressure-error override circuit to allow ramping of the manual temperature demand through the improved temperature-demand generator. Maximum override output causes manual temperature demand to ramp at -167°R/sec . Circuits to signal override operating or failed status remotely are included in the new design.

Figure 57
Top View, ECS Controller/Programmer Chassis

(b) Chamber Pressure-and-Temperature
Average-and-Reject Chassis

The detailed design and fabrication of the chamber pressure-and-temperature average-and-reject chassis was completed (Figure 58). The following features were included in the design:

- 1 Remote display of individual temperatures and pressures
- 2 Automatic reject
- 3 Remote manual reject
- 4 Remote reject-status indication
- 5 Remote manual-reset control
- 6 Automatic lockout
- 7 Remote lockout-status indication

(c) TPCV Control Chassis

The detailed design and fabrication of the TPCV control chassis was completed (Figure 59). The design was modified to incorporate switching logic for the turbine blocking valve (TBV), time-controlled closure of the propellant shutoff valve (PSOV) and switching logic for automatic venting of the pump-discharge vent valve (PDVV) upon closure of the TBV. The TPCV position-feedback circuits were improved by incorporating a full-range feedback averaging system in which three feedback potentiometers supply an average position analog for control. The averager permits combined failure of two potentiometers to open circuit, short circuit to SRC, short to excitation, or provide a combination of the above without undesirable TPCV position excursions.

(d) Packaging Scheme

A standardized packaging scheme was adopted for use in all three chassis. The active and passive circuit elements are packaged on

Figure 58

Top View, Chamber Temperature and Pressure Average and Reject Chassis

Figure 59
Top View, TPCV/Valve Control Chassis

separate printed-circuit boards that minimize the number of required spares. The scheme simplifies maintenance procedures and equipment checkout and allows the incorporation of an improved circuit for balancing amplifier circuits (Figures 60, 61, and 62.

(e) Equipment Racks

The design and fabrication of Racks 49 and 50 were completed. All internal wiring of the racks was completed. The design of the redundant ± 15 -v and ± 10 -v power-supply auctioneering was improved by placing the supplies in a primary-secondary configuration rather than in a load-sharing connection. The improved configuration demonstrates a voltage-regulation improvement of one order of magnitude over that of the original circuit.

(f) System Checkout

The XE-1 ECS was checked out in conjunction with the test-stand control system (TSCS) and test-stand simulator (TSS). All functions of the ECS subsystems and chassis were checked out except the following:

- 1 Linear-power picoammeters
- 2 TSCS log-power averager
- 3 P-T controller
- 4 Drum amplifiers
- 5 10-Channel averager (Racks 48 and 63)
- 6 ± 24 -v power supply
- 7 Neutronics high-voltage power supplies

The above items are WANL-supplied equipment for inclusion in the overall system and had not been received at the end of the period.

Figure 60
Printed Board Circuits Used in ECS Controller/Programmer Chassis

Figure 61

Printed Board Circuits Used in Chamber Temperature and Pressure
Average and Reject Chassis

Figure 62
Printed Board Circuits Used in TPCV/Valve Control Chassis

(g) Documentation

The ECS operating characteristics, as related to safety considerations in the safety-analysis report, were established. A draft of NDC-124 "Design Criteria, Reactor Control System," was completed. NDC-121, "XE-1 Engine Control System Design Criteria," was completed and published.

(h) Laboratory-Model XE-1 Engine Control System

The laboratory-model XE-1 ECS was checked out and updated in preparation for system checkout. Operational tests were conducted in conjunction with the TSCS and TSS.

(2) NRX/EST Engine Control System

Liaison was maintained with the NRX/EST tests at NRDS through participation in checkout, tests, data review, and Dragon-Team activities.

Control System evaluations were performed, and the power and chamber-pressure controller was modified as necessary on the basis of previous test data.

The NRX/EST control-systems drawings were continually updated to reflect the as-built configuration and the modifications made during the test series.

Reduction and correlation of all control-system response data has been completed. These data will be entered in the program for the engine model and will be used to update controllers for succeeding engine and reactor tests. A draft of the report on control results for NRX/EST has been completed.

(3) Technical Coordination

Technical coordination of Subtask 1.5 was provided on a continuing basis throughout this report period and included:

Engineering design cognizance was provided for the engine controls, and technical liaison was maintained with NRDS, WANL, and SNPO. This effort included participation in a review of additional instrumentation-channel requirements as related to sinusoidal and cross-correlation transfer-function measurements, definition of the requirements for signal-averaging and -rejecting circuits for the XE engine, review of the measurement-requirements list (MRL), review of WANL-requested modifications to the MRL associated with engine-control-mode status, review of the XE test plan in conjunction with controls, and review, with WANL representatives, of the status of the system functional diagram (ETS-1 TSCS concept drawing, No. 1114292) and the schematic diagram (XE control system, ECS/TSCS, Drawing No. 711J128).

Assistance was provided to the TSCS project to aid in the integration of the XE engine control system with ETS-1 and the TSCS.

b. Control-System Analysis (1.5.1)

(1) NRX/EST

Development and updating of the common analog model (CAM-II) used in control-systems analysis for the NRX/EST program was completed. Agreement on CAM-II was reached by REON and WANL, and very good correlation was obtained between the two models. A digital-computer program was developed to calculate the accuracy of CAM II parameter readouts. This program has increased the accuracy of the simulation to the extent that the computation errors are less than 1%.

In the course of updating CAM-II, new compensation networks were designed for the flux loop and the temperature loop. The new flux-loop compensation was basically the same as that used in the KIWI and NRX series. The temperature-loop lower clamp was removed and a rate limit corresponding to a 5-sec reactor period for upward excursions was added for use during the Phase III mapping runs. The PCV-41 gas-coolant simulation used for flow shutdowns was improved by adding choking in the nozzle coolant tubes and effects of liquid expulsion in the

line downstream of the NERVA engine pump (the effects are the time of expulsion and the changes in load conditions when liquid in the coolant tube is replaced by gas). The initial P_4 demand signal for the PCV-41 controller was replaced by a signal that is a function of T-26.

CAM II was used for various studies, including both design and evaluation studies. Malfunction studies were made, and an investigation of the TPA overspeed resulting from loss of suction pressure, and showing the effects of speed signal filtering, was conducted.

The pump tailoff system for reactor scram for NRX/EST was studied because of revised reactor analysis requirements specifying various values of P_c depending on the particular test conditions. Several configurations have been evaluated, and the most satisfactory is a double-time-constant circuit. However, because the degree of improvement over the installed system is not great and changes to the test system had to be kept to a minimum, no change was made. An optimized setting for the present pump tailoff was determined for power runs. The final value of this setting was 120 psi for the chamber-pressure demand.

Also, a series of step- and frequency-response tests were run to examine parameter amplitudes and frequency responses at frequencies and parameter step changes corresponding to NRX/EST plans. The step responses were run at $T_c = 2000^\circ\text{R}$ and $P_c = 170$ psi. The frequency responses were run at design conditions and at $T_c = 2000^\circ\text{R}$ and $P_c = 170$ psi. The input frequencies ranged from 0.01 to 16 cps, and θ_{TPCV} , θ_{DRUMS} , P_c DEMAND and T_c DEMAND were individually perturbed.

All controllers, limiters, and scheduled operating modes for NRX/EST were evaluated by simulated runs on CAM-II. The various scram and flow-shutdown circuits and related interaction with limiters were evaluated along with the scram and flow-shutdown systems operations (Figure 63). Turbopump overspeed was analyzed to determine adequacy of the trip level and establish the required overspeed-trip system-response requirements (Figure 64). The interaction of the pressure-error limiter was also studied under conditions that would (without the limiter) result in turbopump overspeed.

Figure 63

Predicted and Required Nozzle Torus Flow vs Time Following Shutdown
from Rated Conditions with 3000 psia Tank Farm Pressure

Figure 64

Pump Overspeed Due to Total Cavitation of Pump in 10 Millisec; 10 Millisec Delay in Overspeed Trip Circuit; Trip Set at 24,000 rpm

Alternative control methods and associated conditions for bootstrap were studied on CAM-II. Fixed-drum startup and the no-flux loop controller were studied on CAM-II by simulated NRX/EST runs and loop response tests. This analysis was used to determine acceptability for NRX/EST operation and to evaluate test data. Alternative control systems for future engines were also studied. These studies included (1) reversal of the control loops where chamber pressure controls the drum position and chamber temperature controls the TPCV, (2) operation of the engine without a flux loop from source level through full power, (3) fixed-drum operation, and (4) fixed-TPCV operation. Both the closed pressure loop and the TPCV schedule with loop closure were studied with variation in the pressure demand, power schedule, Dewar pressure, valve schedule, and temperature-loop open-close status. Frequency responses were run on the CAM-II model to establish the required frequencies and amplitudes for the NRX/EST test and to supply comparative model and test data.

During the NRX/EST test series, data were obtained that required studies involving alteration of the CAM-II model to match test data or simulate nonlinear conditions that occurred in testing, as described in the following paragraphs:

In EP-IA and EP-IIA of the NRX/EST, the power loop was oscillating with self-limiting amplitude and other test data indicated a deadband type of nonlinearity in the control drums. A linear curve fit to the small-amplitude response data of the drums was made on the ESIAC root-locus plotter, and CAM-II was run with this modified drum response. The power-controller instability during transients was readily shown on the modified CAM-II model. This study, combined with analysis of effects on performance of the other engine-control loops, led to a recommendation for a reduction of 6 db in the power-controller gain. The reduced-gain controller was used successfully for succeeding EPs.

Another nonlinearity was noted in EP-IIB when the TPCV performance degraded and resulted in a significant deadband in valve position. EP-IIB data, while highly distorted by the nonlinear valve motion, also indicated

pressure-transmission phase shift in excess of that predicted by CAM-II, and the chamber-pressure controller was redesigned to accommodate the added phase shift. The deadband effects with both the original controller and the revised controller were studied by using the basic CAM-II model and a modified model reflecting the added phase shift indicated by EP-IIB data. Satisfactory pressure-loop operation with significant TPCV deadband was demonstrated.

A further discrepancy in test-data analysis was found in PCV-41 flow-shutdown control during EP-IIC (Dragon Memorandum EST 125). Model changes were made to reflect test differences. The results of succeeding analyses were reviewed by cognizant personnel, and flow-shutdown performance was found to be satisfactory.

NRX/EST exhibited a steady-state oscillation at chamber conditions of approximately 1500°R and 140 psia. The CAM-II was used with the digital-computer program TAF (time and frequency) to investigate the possibility that the hot-bleed loop under these conditions might have caused the instability. Bode plots were prepared for three sets of chamber conditions, and the poles and zero's of the hot-bleed system for each case were plotted. While no definite conclusion could be drawn from this study, a very marked change in the pole zero configuration was noted at different chamber conditions. This work is continuing.

The results of the transfer-function measurements on NRX/EST were compared with the data from CAM-II to evaluate predicted control-system performance. The results showed very good agreement, although there was more phase shift in the pressure system at low power levels than indicated by the model. Studies were undertaken to eliminate the model deficiency. This control-system evaluation was presented at the program review in Sacramento from 3 to 5 May 1966.

(2) X-Engine Common Analog Model

As a result of the NRX/EST tests, equations for the X-engine analog model were revised to produce better intermediate-power steady-state

points. The preliminary analysis for development of the overspeed and loss-of-flow emergency control systems was completed. The best control appears to be a combination of flow shutdown that is based on the rate of decay of chamber pressure and an overspeed cutback on the TPCV that activates at speeds greater than 24,000 rpm.

Also investigated was the operational procedure for arming and disarming the emergency shutdown LH_2 system by using the blowdown method of shutdown. The most feasible method appears to be pressurization of V5002 to 100 psia until a 2000°R chamber temperature is reached during startup. The tank should then be pressurized quickly to 275 psia, and the SCV may be opened at the peak speed during bootstrap. Potential temperature problems in the nozzle coolant tubes are being investigated, however.

Model development is continuing and includes the addition of the emergency high-pressure liquid-hydrogen facility. These changes are being made and checked on the analog computer. Control-system analysis and malfunction studies are also being continued with this model.

(3) Steam-Generator Analog Model

The design of a model of the steam generator of ETS-1 was completed to study the interactions and dynamics of the system. The simulation will also be used as an operator training aid for NRDS personnel. The simulation will be programed on a TR-48 computer and will be used in conjunction with the existing cold checkout unit. The simulator can be used to check operator response to malfunctions that can be introduced into the model. The design was based upon the following ground rules.

- (a) The simulation would cover single-module operation only.
- (b) The model would have to be capable of being programed on a TR-48 computer.

- (c) The accuracy of the model can be sacrificed to conserve equipment as long as general performance characteristics are represented.
- (d) The model should respond to corrective action taken by the operator.

The design of a similar simulation for the duct is now in progress.

(4) TAF Digital Program

Program TAF developed at LASL has been placed in operation on the Aerojet IBM 709⁴ digital computer. This program will take a system of up to 70 first-order, nonlinear, ordinary differential equations and solve them simultaneously to yield (1) steady state solutions, (2) frequency response (Bode plots), and (3) transient responses as desired. Programing of the TAF model was completed and the runs are being evaluated.

(5) XE Steady-State Check Program

A computer program to check the accuracy of each individual equation in the XE model has been written for the IBM 1130. A check case has been run.

c. Control Actuator (1.5.2)

(1) Actuators, Model NT-D1

TPCV actuators, Model NT-D1, Serial Numbers 15, 16, 17, and 18, were successfully acceptance-tested by Bendix Corporation and shipped to Aerojet, Sacramento (Figures 65 and 66). This shipment completed the Bendix Corporation commitment for the Model NT-D1 actuators. Bellows seal problems incurred during acceptance testing of the actuators by the Bendix Corporation were found to

Figure 65
Turbine Power Control Valve Actuator Model NT-D1 (with Dome Removed)

Figure 66

Cutaway View of Turbine Power Control Valve Actuator, Model NT-D1

be caused by bimetallic differential coefficients of thermal expansion. The seal was redesigned with a larger-diameter bellows to develop a more positive sealing force and with thicker material to improve weld quality and increase reliability.

Actuator Model NT-D1 (SN 18) was acceptance-tested by REON and shipped to NTO for use in the NRX/EST test program. The actuator was installed, checked out, and operated satisfactorily during the NRX/EST EP-III, EP-IV, and EP-IVA tests.

Post NRX/EST tests were conducted on this actuator at San Ramon. During testing, an electrical noise problem was detected in the servo-amplifier (see Report RN-D-0082, "Post NRX/EST Evaluation and Results of"). This noise (predominantly 400 cps) was observed as a ± 10 -v saturated square wave at the third-stage operational-amplifier output. The noise was traced to the 400-cps signal from the Burr-Brown ac-to-dc converter into the amplifier. Corrective solutions are discussed in the referenced report.

Actuator Model NT-D1 (SN 17) was acceptance-tested at REON, after which it was subjected to vibration tests. The actuator was then installed in Aerojet Test Area H-4A in the TPCV hydrogen test system, for testing at elevated interface temperatures.

Four tests were performed as follows:

- (a) High-temperature, high-pressure hydrogen with the actuator at low temperature (near cryogenic).
- (b) Low-pressure, low-temperature hydrogen with the actuator at ambient temperatures.
- (c) Low-pressure, low-temperature hydrogen with the actuator at approximately cryogenic temperature.
- (d) High-temperature, high-pressure hydrogen with the actuator at ambient temperature.

The actuator performed satisfactorily throughout all tests. One of the two potentiometers developed what appeared to be considerable noise during low-temperature actuator tests. The potentiometer was removed and tested under controlled conditions of temperature, shock, and potentiometer operation in an effort to duplicate, isolate, and define the cause of the malfunction. The initial test was performed with the potentiometer operating at ambient to cryogenic temperatures (-315°F) and failed to duplicate the malfunction. During warmup (return to ambient temperatures), the humid ambient atmosphere was permitted to replace the previous dry nitrogen atmosphere to determine whether or not the formation of frost on the potentiometer surfaces would cause the malfunction. Further tests were conducted to simulate the mechanical loading on the potentiometer due to changes in temperature and high-frequency vibration tests.

None of the tests conducted could duplicate the potentiometer noise, and it was concluded that the noise problem in H-Area testing was caused by the test-stand control wiring. This noise problem should not be confused with the amplifier noise problem in the post-NRX/EST tests on actuator SN 18. Actuator SN 17 is presently being used in the qualification test program.

Actuator Model NT-D1 (SN 16) was provided for assembly to the XE-1 TPCV assembly. This assembly has successfully completed leak and functional tests. Actuator SN 15 is being held as backup for the qualification test program.

TPCV actuator requirements for the XE program were reviewed in detail, and the requirement for five additional TPCV actuators was revealed. A proposal was transmitted to SNPO-C for approval to proceed with the procurement of the additional actuators. Approval was received to proceed with procurement on long-lead-time items.

(2) Qualification Test Program

The plan for the qualification test program was completed and tests were initiated. The proof-testing portion of the program was completed,

and preparations were initiated for vibration and shock testing of the actuators. Additional actuator testing is also planned in conjunction with TPCV development testing.

(3) Actuators, Model C

TPCV actuator Model NT-C2 (SN 11) was refurbished at Sacramento. The actuator was checked out and shipped to NTO to replace actuator NT-C2 (SN 13), which showed performance degradation during NRX/EST EP-II testing.

Actuator NT-C2 (SN 11) was later replaced with actuator NT-D1 (SN 18) when it showed performance degradation during NRX/EST EP-IIC testing.

Actuators SN 11 and SN 13 were returned to Sacramento for disassembly, inspection, and investigation of the cause of performance degradation that developed during the NRX/EST tests.

The actuators were then sent for refurbishment to Bendix Corporation Research Laboratory, Southfield, Michigan, on 23 February 1966. The REON engineering investigation and analysis with respect to the actuators was terminated and was resumed at Bendix Research Laboratory, Southfield, Michigan.

(4) Dynamic-Seal Tests

Bendix Corporation, South Bend, tested the dynamic bellows seal to improve the life of the seal. A Hydro-Dyne seal was used in lieu of a bellows to perform a series of tests on a dynamic seal of Linde flame-spray material (LC-4 on LC-4). The Hydro-Dyne seal was an acceptable bellows substitute because the tests were primarily wear tests of seal face materials.

Approximately 54 hr of continuous testing time was accumulated on the seal in an environment of N_2 gas at ambient temperature and 400-psi pressure. The tests were stopped at this time because the breakaway torque

increased to 45 in./lb. Inspection showed the seal surfaces were highly polished, had no surface breakdown, and were generally in good condition. The increase in breakaway torque was believed to result from an undetermined contamination that could have been introduced as a result of one of the previous inspection disassembly operations.

The final phase of seal testing involved a seal design having Linde flame-spray LC-4 on LC-4 for an intended 100-hr duration test. These seals were tested for approximately 4 hr at ambient and at temperatures up to 1000°F. The torque varied from 15 to 55 in.-lb during these tests. The seal torque increased to approximately 100 in.-lb after return to ambient temperature with a 650-psi GN₂ pressure across the seal. In addition to the high torque, some warpage of the sealing surfaces occurred.

Seal performance during both actuator usage and seal development is being reviewed, and plans for further seal development will be based on the results of this review. New materials that have become available will be considered for possible use in this development.

d. Electronics Development (1.5.3)

New circuits were developed for use in the XE-1 engine control system and components associated with the circuits were evaluated. These circuits provided an improved trim technique in the measured-temperature-to-pressure-demand function generator, a pressure-loop manual closure, an autostart bypass switch, and a detector circuit in the power and temperature-override summing amplifier. These circuits were reported under subparagraph a in this section.

Additional circuit development and component evaluations during this report period are summarized in the following paragraphs:

The Beckman-motor-operated follow-up potentiometer for use on the deliverable TSCS was evaluated. Results indicated the desirability of replacing the present TSCS follow-up subsystems.

The Magsense module was evaluated for use in the circuitry of XE engine control system. The results revealed the following advantages of replacing the conventional operational-amplifier trip circuit with the Magsense module: (1) elimination of relay driver stages, (2) greater flexibility in establishing adjustable hysteresis, and (3) complete isolation between signal input and 28-vdc power circuits. The unit evaluated has been completely qualified by the Military.

A technical memorandum was prepared that describes the results of the performance evaluation of the power-demand signal generator for the manual LnN demand circuit in the XE engine control system.

Technical Memorandum RN-TM-0292, "Signal Average and Reject Circuit," was transmitted to SNPO-C on 24 January 1966. This technical memorandum describes the signal average-and-reject circuit for the NRX/EST control system and possible for application to the XE engine control system. The method used to average the chamber temperature and pressure effectively suppresses undesirable control transients resulting from catastrophic failure of a given measurement channel.

Integrated circuit test units of conventional and FET-input operational amplifiers were procured for evaluation and possible use in the advanced engine control system.

e. Harnesses and Connectors (1.5.4)

The following tests and engineering evaluations were completed for various harness and connector components and their applications in support of the XE-1 control system:

1. Evaluation tests of metal-sheathed cable assemblies.
2. Evaluation tests of metal-sheathed cable seals, including humidity, high-temperature, and simulated-gamma-heat-ing tests.
3. Insulation and capacity-effects tests.

4. Recommendations for handling of sheathed cable assemblies.

Technical Memorandum RN-TM-0329 was completed and describes the test results and recommendations for the above listed items.

Preliminary torque tests were conducted on No. 8 and 10 shell-size connectors and backshell interfaces. Leak rates were much less than 10^{-8} cc/sec at ambient temperatures.

Cable and hook-up wire from various manufacturers was evaluated, and recommendations were made for use in the XE-1 upper thrust structure.

Inputs were provided for Report RN-S-0236, "Final Test Report for Radiation Effects Tests on Instrumentation Cables 23/R601 and 23/R701."

A memorandum was prepared for attaching instrumentation cables on NRX-A6 and XE-1. This memorandum outlines:

- (1) A development test specification for flame-sprayed sheathed cable
- (2) Cable bonding by flame-sprayed aluminum
- (3) General procedures for installing instrumentation cable.

Reports RN-TU-092, "Termination Design, Hermetically Sealed Metal Sheathed Cable;" RN-TU-101, "Metal Flame Spray Provides Thermoconductive Cooling for Electrical Cables in Extreme Environment;" and RN-TU-090, "Insulator Design Provides Reliable Metal Sheathed Multi-conductor Field Splice," were prepared and submitted.

6. Systems Analysis (1.8)

a. Nonnuclear Systems Analysis (1.8.1)

Data obtained from the CFDTS and from the NRX/EST series were used in analytical studies to improve transient engine simulation program (12013). The current status of development of this computer program is presented in Performance Analysis of CFDTS and NRX/EST as Related to the X Engine (RN-S-0323). The program has been developed to a degree that prevents prediction of engine startup with a high degree of accuracy. The following table compares the calculated and actual peak rpm's for five CFDTS runs:

CFDTS Run No.	<u>Pressure, psia</u>		<u>Peak rpm</u>		<u>Time at Peak rpm, sec</u>	
	<u>Tank</u>	<u>Back</u>	<u>Calculated</u>	<u>Actual</u>	<u>Calculated</u>	<u>Actual</u>
009	70	12.7	7600	7700	16.5	11.5
010	50	12.7	6600	6850	33.5	25.5
011	35	12.7	1000	1500	65	65
015	35	7.6	9000	8200	33.5	30
018	35	0.25	9000	8700	14.5	13.5

Power and TPCV position duplicating an actual NRX/EST ramp have been incorporated in the program, and excellent agreement has been obtained between the calculated and actual engine ramps.

Low-speed correlations have been developed for the turbopump to predict head rise, flows, and efficiencies. A bearing-coolant correlation has been developed that fits both the NRX/EST and CFDTS data. The heat transfer and pressure drop in all engine components except the nozzle jacket have been upgraded from models developed on the basis of NRX-A1, A2, and A3 tests; and these data are duplicating actual data. A minor problem exists on the nozzle jacket chillover.

The program is being continually analyzed, and further refinements are being studied that should give even closer agreement between calculated and actual engine ramps.

The results and conclusions obtained from the CFDTS tests were:

The MK III Mod 4 turbopump did not appear to windmill during the pump chilldown operation prior to opening the TPCV. The turbopump began to rotate at very low flow rates within a second after the test start, when chamber pressure had reached only 3 psi above the system back pressure.

Testing with a turbine of NRX/EST design showed that, if a pump speed of about 3000 rpm were reached, the resulting peak speed was only slightly affected by tank pressure. However, the peak speed was strongly related to tank pressure at low tank pressures when the turbopump did not reach 3000 rpm. Reducing the back pressure from 12.7 to 7.6 psia reduced the tank pressure required to reach a pump speed of 3000 rpm from 45 to 30 psia. The effect of back pressure from 14.2 to 0.3 psia was determined.

Testing demonstrated the feasibility of bootstrap startup without prechill of the turbopump. Until liquid is established at the pump, turbopump speed oscillates between 3000 and 6000 rpm at a frequency of 0.4 cps, with associated flow oscillations of 3 to 6 lb/sec. Once an all-liquid condition is established at the pump, the system response is similar to that obtained with a chilled pump.

Closed-loop pressure control of the TPCV was also determined to be feasible to control nozzle chamber pressure during engine startup, even with a warm pump. Startup could be accomplished with the pressure controller activated at initiation of startup, thus eliminating the need of TPCV position control and increasing system reliability through simplification.

For the NRX/EST predictions that were made, tank pressure and TPCV position were entered in the program. The results for EST Run 6 are shown in Figure 67 and are compared with data from CFDTIS Run 013. The major differences are due to the various systems lines; the digital predictions show a faster acceleration to a higher speed.

A parametric study of conditions during chilldown was continued. Among the effects analyzed were feed-line length and diameter, tank pressure, and valve opening time. On the basis of the results obtained, configuration of the feed line (rather than the particular momentum and the heat-transfer correlations selected) has the dominating influence on the frequency and amplitude of flow oscillations. The results of suction-line oscillations in NRX/EST EP-IA⁴ are being used for comparison of analytical and test data.

The NRX/EST, NRX A2, and NRX-A3 steady-state holds have been analyzed to determine the ability of the steady-state nozzle-tube program to predict bulk-coolant temperature rise and pressure drop. Figure 68 shows predicted and actual pressure drops, and Figure 69 shows predicted and actual temperature rises. Agreement with data has generally been good.

Testing of nozzle SN 21 has been analyzed in detail. In addition to overall temperature rises and pressure drops, the following areas were explored: temperatures and pressure profiles within the coolant tubes; contributory effects of the entrance, exit, bends, and bleed ports; flow distributions; and temperature asymmetries.

Effects of the hot-bleed port on flow distribution are seen in Figure 70, which shows flows calculated by the program and the data obtained for uninterrupted tubes and bleed-port tubes, both forward and aft of the plenum, for a hot firing. Figure 71 (RN-Q-0038) shows the asymmetry determined from water testing (forward of the bleed port) compared with that predicted for a water test.

Figure 67
NRX-EST Chillo down

Figure 68
Nozzle Tube Pressure Drop, Predicted vs Actual

Figure 69
Nozzle Tube Temperature, Predicted vs Actual Temperature Rise

Figure 70
Flow-Distribution Effects of Bleed Port, Nozzle S/N 021,
In-House Testing

Figure 71
Nozzle-Tube Water-Flow Test, NERVA Nozzle S/N 021

b. NRX Systems Analysis (1.8.2)

The NRX-A5 test article was analyzed to establish the operating performance of nonnuclear components and verify the analytical programs from test data to be generated in the NRX-A5 test. An NRX-A5 Performance Analysis Data Book, Report RN-S-0320, was prepared to catalog the latest component test data, the configuration for the NRX-A5 engine model, and the transient and steady-state pretest predictions. Agreement was reached with WANL on the state points at 100, 81, and 45% power. The analysis was performed with the transient engine simulation program (documented in Report RN-S-0114) in the NRX mode. A modification to the transient program that increases its utility by providing the capability to calculate steady-state points in a reasonable computing time was used for the first time in this analysis. With this added flexibility, any steady-state point can be held for a specified number of time points before proceeding immediately to a transient.

Predictions are based on component acceptance data, information from previous tests, and design drawings. Engine-system constraints are presented in Figure 72. The \$1 and \$2 reactivity feedback lines are taken from WANL-TME-1211, Supplement 3, dated 30 January 1966. The maximum structural temperature constraints and the nozzle chamber-pressure and temperature limits were taken from WANL-TME-1417, NRX-A5 Parameter Limits Justification, May 1966. Figure 72 summarizes the steady-state operating limits imposed by maximum structural temperature, maximum chamber temperature and pressure, and reactivity feedback discussed above. The steady-state design operating point of a chamber temperature of 4090°R and a flow rate of 71.3 lb/sec is designated by a . The operating line to be followed is shown for a ramp of 0.88 lb/sec² and 50°R/sec.

The systems model used to make these predictions was essentially the same as that used for NRX/EST except that the turbopump and hot-bleed-port models were eliminated. The parameters describing the nozzle were upgraded to the NRX-A5 configuration.

Figure 72

NFX-A5 Performance Envelope

Figures 73, 74, 75, 76, and 77 show the test predictions for Runs 1, 3, 4, and any additional runs that might have been required. In these runs, the demand flow was ramped at a rate of 0.88 lb/sec^2 from an initial flow of 2 lb/sec; power was first increased from 1 Mw (on a 2.5-sec period) for 10 sec, at which time power was scheduled to give a 50°R/sec chamber-temperature ramp rate. Holds were made at 2000°R (24.4 lb/sec) and at 4090°R (71.3 lb/sec). The figures show the system flow rate and the temperatures and pressures expected throughout the system.

Figures 78, 79, 80, 81, and 82 show the test predictions for Run 2. Drum position was constant in this test. Because the calculation of power during the fixed-drum portion of the test required a modification to the 12013 program that was impossible to complete in time, no predictions were made for the initial portion of this region. The figures show the system temperatures, pressures, and flow rate during the remainder of the test.

A common analog model for NRX-A5 was developed between Aerojet and WANL. Initial check runs were made by entering nozzle inlet conditions in the program, and the results were supplied to WANL.

In addition to the pretest analysis performed, support was provided to the test-data teams during NRX-A5 test operations, by such personnel as members of the DRAGON team, including the Aerojet representative on the steering team and a member of the data-review team.

c. Engine Systems Analysis (1.8.3)

(1) NRX/EST

The NRX-EST test-predictions report (RN-S-0232) was issued along with supplements required by modifications to Test Specification NJD-2.

Figure 73
Nozzle Inlet and Outlet Pressures

Figure 74
Nozzle Inlet and Outlet Temperatures

Figure 75

Engine-System Component Inlet Pressures

Figure 76
Engine-System Component Inlet Temperatures

Figure 77
Engine-System Flow Rate

Figure 78
Nozzle Inlet and Outlet Pressures, Fixed-Drum Start Profile

Figure 79
Nozzle Inlet and Outlet Temperatures, Fixed-Drum Start Profile

Figure 80
Engine-System Component Inlet Pressures, Fixed-Drum Start Profile

Figure 81
Engine-System Component Inlet Temperatures, Fixed-Drum Start Profile

Figure 82
Engine-System Flow Rate, Fixed-Drum Start Profile

Six supplements were issued in all. The objectives of the test-prediction report were to: (1) ensure that the tests would be accomplished in a safe manner, (2) provide means of quickly evaluating test data during test phases, (3) ensure that emergency safety measures were adequate, and (4) provide a means of evaluating analytical programs. All of these objectives were achieved.

Steady-state operating points for all planned power holds are included. For example, Figure 83 lists the steady-state operating points at design conditions. In addition, engine constraint maps were prepared to define the safety area for engine operation.

For the cold-flow test in Phase I, both CFDTS and digital analysis were used to define the expected performance.

Analysis was completed on each run of Phase II: bootstrap to intermediate power, low-power mapping and transfer-function response, and control-system test. A typical output obtained by using the common analog model of the engine is shown in Figure 84. Successful bootstraps were predicted for all tests planned.

(a) Bootstrap to Intermediate Power

On 3 February 1966, the first start of a nuclear rocket to power was achieved. The run was successful on the first attempt and approximately followed the predictions of performance. In the first bootstrap to an appreciable power level, the reactor was brought up to 1 Mw by using an automatic startup. The liquid-hydrogen Dewars were set at 70 psia because of the long suction line. The turbopump was prechilled by means of a vent line downstream of the pump. Upon initiation of the bootstrap, the propellant-discharge and turbine blocking valves were opened, the vent valve was closed, and chamber temperature was programed at a nominal rate of $50^{\circ}\text{R}/\text{sec}$ to 2500°R . The chamber-temperature controller can add +15 to -50% to a scheduled power demand. The power demand overrides the temperature controller at the beginning of the bootstrap and thus

NRX/EST ENGINE ASSEMBLY DRAWING NO 1013700

OVERALL ENGINE THRUST lb	49,847
MAIN THRUST CHAMBER THRUST, lb	48,229
TURBINE EXHAUST NOZZLE THRUST lb	1,618
OVERALL ENGINE SPECIFIC IMPULSE sec	648
CHAMBER SPECIFIC IMPULSE, sec	689
TURBINE NOZZLE SPECIFIC IMPULSE, sec	234
TURBINE POWER CONTROL VALVE POSITION, deg	44.6
AMBIENT PRESSURE, psia	12.76
REACTOR POWER LEVEL, MW	1,124.5
TURBOPUMP POWER, MW	4.5
PUMP EFFICIENCY, %	66.9
TURBINE EFFICIENCY, % (TOTAL/STATIC)	38.0
NPSP, psi	18.66
TURBOPUMP SHAFT SPEED rpm	21,338
NOZZLE EXPANSION RATIO	10:1
TURBINE EXHAUST NOZZLE AREA RATIO	1:1

NO.	STATION	FLOW lb/sec	PRESSURE psia	TEMP °R	HEAT FLUX btu/sec
1	TANK OUTLET	76.9	70.0	38.0	
2	PUMP INLET	76.9	38.3	38.3	
3	PUMP OUTLET	76.9	925	51.1	
4	NOZZLE MANIFOLD INLET	76.9	882	51.1	
5	NOZZLE OUTLET	76.9	727	134	2.534×10^4
6	REFLECTOR OUTLET	76.9	685	222	2.443×10^4
7	SHIELD OUTLET	71.6	675	226	
8	CORE OUTLET	71.6	563	4090	1.042×10^6
9	NOZZLE CHAMBER	70.0	563	4090	
10	DILUENT BLEED INLET	5.4	680	222	
11	DILUENT BLEED OUTLET	5.4	648	258	
12	HOT BLEED	1.6	563	4090	
13	MIXING RING INLET	6.9	559	1172	
15	TPCV INLET	6.9	527	1140	
16	TURBINE INLET	6.9	413	1140	
17	TURBINE OUTLET	6.9	61.8	959	
18	TURBINE EXHAUST NOZZLE	6.9			

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Figure 83
NRX/EST 100% Power Hold

Figure 84
Bootstrap to Intermediate Power, Phase II, Run 1

Figure 84
Bootstrap to Intermediate Power, Phase II, Run 1

Figure 84
Bootstrap to Intermediate Power, Phase II, Run 1

restricts the power increase to a 2.5-sec period, as can be seen in both the test data and the predictions. The demand of the nozzle-chamber-pressure controller was generated as a function of measured chamber temperature, with a minimum demand of 50 psia. A comparison of pretest predictions with the actual results is shown in Figure 85.

Transient performance was generally as expected. The final chamber pressure was higher than expected because of the calibration of the pressure demand.

(b) Cold-Reflector Start

For restarts in space, the energy in the reflector may already be depleted prior to initiation of bootstrap. However, energy can be generated in the reactor core for bootstrapping the turbopump. The second bootstrap was run (on the same day as the first) to demonstrate this operation. Dewar pressure was set at 70 psia, the pump was prechilled, and the pump discharge valve was opened. Dewar flow then started and reactor power was increased to 35 Mw on a 20-sec period. The TPCV was closed during this operation, and reflector temperatures reached as low as 60°R. Pretest predictions indicated that 35 Mw would result in a chamber temperature of 1000°R.

During the run, the chamber temperature had risen to 1400°R when 35 Mw was indicated. The operator attempted to trim chamber temperature to 1000°R, but because of the reactor dynamics, temperature was reduced to 700°R. Power was increased and bootstrap was initiated, with the opening of the TPCV. A power hold of 2000°R was achieved. The characteristics of the startup followed the predicted performance. Restarting the engine in space without an external energy source was shown to be feasible. The major problem with the operation will be perfecting low-flow temperature control of the reactor either manually or automatically.

COMPARISON OF EP-IIB - RUN 1, PRESS.

— TEST DATA
 - - TEST PREDICTIONS

EP-IIB STARTUP TEMPERATURES
 COMPARISON OF PREDICTION AND TEST DATA

Figure 85

Comparison of Predictions and Test Results, EP-IIB

(c) Fixed-Drum Start

To evaluate alternative methods of starting, a start was made with the drums in a fixed position. The reactor was brought critical, and, with 2 lb/sec of gaseous hydrogen flowing through the core, the drum position was fixed. Dewar pressure was 70 psia. The pump was prechilled and the gaseous-hydrogen flow was discontinued. The pump discharge valve and turbine power-control valve were opened, and a chamber pressure of 50 psia was demanded. When the chamber pressure reached 50 psia, the pressure was ramped up at 6 psi/sec to 180 psia. As the flow rate in the reactor increased, the density reactivity feedback was sufficient to increase the reactor power. Temperature reactivity feedback acted to stabilize the power ramp. The predicted chamber temperature of 2000°R was reached. The start closely followed the predictions. This method of startup has potential application for simplifying the controls of future rocket engines and offers a possible means of starting when the initial conditions of the reactor are not well established.

(d) Low-Dewar-Pressure Start

The NRX/EST engine had a suction line several hundred feet long. Therefore, high Dewar pressures were required to meet turbopump requirements for net positive suction pressure. CFDTS data indicated that a 70-psia tank pressure in NRX/EST was equivalent to a 35-psia tank pressure in a flight system. Three attempts were made to start from low Dewar pressures. In the first attempt, the turbopump could not be adequately chilled with a 35-psia Dewar pressure; so it was necessary to raise the pressure to 45 psia. Basically, the same startup procedure as had been used in the first immediate start bootstrap was followed. A turbopump speed of 7200 rpm was achieved, but the system had to be shut down because of high tie-rod temperatures, which resulted from power increasing faster than flow rate. A second bootstrap attempted with a 35-psia pressure was unsuccessful. The power again increased faster than the flow rate and resulted in high tie-rod temperatures. A successful

starting procedure was used on 15 March 1966, with a Dewar pressure of 45 psia. The drums were positioned at the critical position with power at 1 Mw; the TPCV was positioned at 58°. As hydrogen flow increased in the reactor, the hydrogen feedback reactivity caused the power to increase. When chamber pressure reached 50 psia, it was increased at 6 psi/sec until a flow of 20 lb/sec was established. A smooth engine start was achieved by this method.

(e) Full-Power Operation

On 3 March 1966, full-power operation of a NERVA engine was achieved for the first time. The engine operated for over a minute at full power. Calculations and test data are compared in Figure 86. The engine was bootstrapped to 1600°R. After a hold, temperature was increased in steps to the design value, with holds at 2500 and 3400°R. The average rate of temperature increase was scheduled to be 100°R/sec. Previously, rates of temperature increase on NERVA reactors had been scheduled at 50°R/sec. During operation at full power, the diluent valve was adjusted to bring the turbine inlet temperature to 1140°R. The temperature was off 66°R from the prediction before the adjustment was made; an adjustment of 21° was required in diluent-valve position (well within the margin of adjustment allowed from the pretest analysis). Agreement was generally good between anticipated performance and actual performance at design conditions. Because operation was close to several test-parameter limits, good predictions were required.

(2) X-Engine

A report on performance analysis of the X-engine (Report RN-S-0333) was prepared to document the current status of this effort.

(a) Diluent Control System

NERVA digital program 1108 was used in a study to determine the need for the diluent control valve. The hot-bleed port used for this study was the same as that used for NRX/EST except that the bypass holes were assumed to be 0.1385 in. in diameter, as specified in Drawing 706967, rather than 0.078 in.

EP-III OPERATION TO FULL POWER-PRESSURE

EP-III OPERATION TO FULL POWER-TEMPERATURE

Figure 86

Comparison of Calculations and Test Data at Full-Power Operation, EP-III

The first step was to determine the amount of control available with the diluent control valve. A number of runs were made at full power ($T_c = 4090^\circ\text{R}$, $P_c = 563$ psia) with various values used for the diluent loss coefficient to determine its effect on turbine inlet temperature and flow (Figure 87).

An orifice for the diluent line was sized to give a turbine inlet temperature of 1300°R with the diluent control valve closed. With this orifice in place (and assuming a nominal 2.5-in. butterfly valve), the gate position at full power would be 33° . With the diluent valve full open, the minimum turbine inlet temperature that could be reached would be 1100°R . Thus, a range of turbine inlet temperatures from 1300 to 1100°R is allowed.

A second set of runs was made in which pump efficiency at full power was varied (Figure 88). The diluent control valve "K" was held constant at the nominal full-power position, which gave a turbine inlet temperature of 1140°R . With a constant diluent impedance, the 1300°R limit on turbine inlet temperature would be reached if the turbopump efficiency were reduced by 10%. The turbine power-control valve will go full open, and the turbine will no longer be able to supply the required energy if the turbopump efficiency is reduced by more than 16%. If the turbopump efficiency is higher than expected, the engine will operate with a lower turbine inlet temperature. A 40% increase in turbopump efficiency would cause the TPCV to close to 39° and the turbine inlet temperature to decrease to 780°R .

The pump-efficiency factor can be related directly to an increase or decrease in engine impedance from the pump discharge to the diluent extraction point.

Because the pump inlet pressure is constant, pump outlet pressure will change; and this change can be related to the change in pressure drop from the pump discharge to the diluent extraction point. The case where factor L (Figure 88) is 0.9 and the turbine inlet temperature is 1300°R corresponds

Figure 87
 Diluent-Valve Study; T_H , W_C , and W_H vs KDV

Figure 88
Diluent-Valve Study, P_2 , T_{11} , TPCV, and P_c vs Pump Efficiency Factor

to an increase in pressure drop from the pump discharge to the diluent extraction point of 44%, with a residual increase of 0.2% caused by an increase in $\dot{w}_p$ (Figure 89).

A third set of runs was made to determine the effect of core impedance on turbine inlet temperature. Diluent impedance was held constant at the full-power value. A 15% decrease in core pressure drop results in a turbine inlet temperature of 1230°R, and a 25% increase in core pressure drop results in a turbine inlet temperature of 1040°R (Figure 90). The changes in turbine inlet temperature amount to +9 and -7%, respectively.

On the basis of these analyses and a review of the allowable range of turbine inlet temperatures, it was concluded that the engine would operate satisfactorily without a diluent control valve.

(b) Multiple Restarts

The ability to run a number of engine startups in one test profile would result in a more efficient XE-1 series. The transient engine simulation program was studied to determine if a multistart test profile should be included in the X-engine test schedule. Indications of fluid usage, minimum flow rates, timing, and length of time for various segments were obtained.

The multiple-startup concept appears to be feasible. The amount of gaseous hydrogen available for engine warmups will limit the number of ambient engine startups to two, the initial start and one additional. The number of cold-reflector starts that could be made appears to be quite large. The total number of runs is limited by the run-tank hydrogen, the duct coolant water, or the number of thermal cycles that the reactor is able to withstand. By changing the maximum-power point that the engine will reach and the ramp rates, these limits can be extended or decreased.

Figure 89

Diluent-Valve Study; TPCV, P_2 , and T_{11} vs Percent Increase in Impedance between Pump Discharge and Diluent Extraction Point

Figure 90

Diluent-Valve Study; TPCN, P_2 , and T_{II} vs Percent Increase in Core Pressure Drop

The results shown in Figures 91 and 92 were obtained with the transient engine simulation program (IBM jog 12013). The run was made by using the following startup procedure:

The TPCV was opened and held until the turbopump speed exceeded 1000 rpm, at which time (9 sec) nuclear power was added and chamber pressure was demanded at 66 psia. When the chamber temperature reached 1000°R, the engine was switched to closed-loop control of chamber temperature and chamber pressure and was brought to full power at 100°R/sec.

Full power (chamber pressure 561 psia, chamber temperature 4090°R) was held for one min. After 60 sec at full power, the engine was ramped down to 1600°R at -100°R/sec along a normal operating line. At 1600°R, the reactor was scrammed, and the engine control was switched to the pump-tailoff mode. Chamber temperature was ramped down to 650°R at -119°R/sec. At a chamber temperature of 650°R, the flow was switched to 30 lb/sec of ambient hydrogen from the auxiliary flow system. The ambient flow was held until the core inlet temperature reached approximately 535°R. At this point, the engine is ready for another ambient start.

The entire cycle took 187 sec, 146 sec with liquid hydrogen from the run tank and 41 sec with ambient hydrogen from the auxiliary system.

(c) Pulse Cooldown Studies

Pulse cooldown was studied. Pulse cooldown has direct application in a flight engine to minimize propellant usage at low temperature of 1400°R, a tank pressure of 36 psia will drive approximately 5 lb/sec of hydrogen through the system. A flow rate of 5 lb/sec is the minimum flow rate for the reactor flow to remain in the turbulent regime, and chamber temperatures below 1400°R are good for temperature cycling of the reactor.

Figure 91
XE-1 Test Schedule (First Run), Flow Rate vs Time

Figure 92
XE-1 Test Schedule (First Run), Temperature vs Time

The engine system was ramped to 1600°R, the reactor was then scrammed, and the TPCV was scheduled to close in approximately 5 sec. At 5 sec, the TPCV is fully shut. The core exit temperature is 1400°R, and flow is a function of tank pressure. The reactor is allowed to cool off until the core exit temperature reaches 800°R, at which point flow is stopped. The reactor is then permitted to warm up until the Station-26 material reaches the specified temperature, at which point the TSV is opened and the cooldown procedure is repeated.

Reactor scram with pump tailoff was also analyzed. The results showed that rates of 150°R/sec for chamber temperature could be used without exceeding the reactor structural constraints. A system was used in which chamber temperature was controlled with the TPCV after reactor scram.

(d) Engine Performance Analysis

Analytical studies to define the performance characteristics of the XE-engine and test installation have been intensified. A Systems Analysis Design Data Book (Report RN-S-0289) was prepared for use in XE-engine analysis. The report includes descriptions of all components that contribute to engine-system operation, as well as equations agreed upon by Aerojet and WANL for the XE-engine common analog model. The emergency system for the ETS-1 facility has been simulated on the analog computer. The simulation includes the system dynamics of the lines and valves for helium and liquid hydrogen.

The effect of the ETS-1 facility on XE-engine operation has become a major consideration in the analysis of the XE-engine. A report on interaction studies of the XE-engine and ETS-1 (Report RN-S-0328) was prepared to document the current status of these studies. To analyze the system with helium and nitrogen used as propellants, extensive ground work was necessary to prepare property routines for the digital engine model that were sufficiently accurate to permit good definition of those fluids over the temperature and pressure ranges involved. Data on the ETS-1 facility itself have been gathered and compiled into a form that can be used as input for the computer models.

Analyses were performed on the analog computer to determine a method of control for, and the dynamics of, the emergency cooldown system.

Pretest predictions were prepared for XECF runs. Startup runs were calculated for run-tank pressures of 60, 45, 36, and 25 psia. The minimum pressure required for startup is still being investigated. The 36-psia tank pressure resulted in turbopump speeds of over 8000 rpm, and speeds for the run at 25-psia tank pressure oscillated (about 200 rpm); therefore, the minimum tank pressure for bootstrap is between 36 and 25 psia. A study is now being conducted to determine the effect of back pressure on the minimum bootstrap tank pressure.

The XE-engine emergency cooldown is being recalculated with the facility included as part of the digital analytical model to permit the inclusion of blowdown effects, facility pressure drop, and facility heat transfer in the analysis. The past study was made by assuming a 0.5-sec flow interruption at the initiation of the cooldown fluid. Because the new loaded-check-valve emergency system planned for the XE-engine eliminates this type of delay, the initial reactor thermal transient will change significantly. In addition, the maximum tie-rod temperature limit has been raised, and the facility configuration has been modified.

The XE-engine steady-state design point has been modified to reflect the latest information available on the XE-engine. This point is continually modified as more concise component information becomes available. At present, the data from the NRX/EST have been partially included in the XE-engine design-point calculation. A complete XE-engine operating map has been prepared with cross plots of the major engine parameters for different chamber conditions.

Component behavior data and design-aid calculations have been provided to XE-engine project personnel and component design personnel. Flow-control orifices and flow-measuring venturis have been sized for both the XECF and XE-1 engine systems.

The XE-engine data book has been completed and published. The book contains all the information on the XE-engine that has been included in the analytical models, along with the method in which these data are used. Included in the book is a copy of the XE-1 measurements-requirements list. The data requirements for the XE-engine have been reviewed to ensure that all phases of engine operation can be adequately studied.

A year-end report on digital-program development (Report RN-S-0332) was prepared to summarize the development status of the digital-computer programs.

Thirteen major additions have been made to the NERVA transient digital model to improve its operating speed, the number of problems it can analyze, and the accuracy of the calculation techniques. Five improvements have been incorporated in the steady-state program for similar reasons. In addition, many minor improvements have been made in each program.

d. Nonnuclear-Systems Data Analysis (1.8.5)

A final report on CFDTS data analysis (Report RN-S-0294) presenting the analysis of the results of the second and third series of tests with the cold-flow development test system was prepared. The analysis confirmed that all of the following test objectives of the second and third series of tests were achieved:

1. Determination of performance differences resulting from use of the modified turbopump and exhaust manifold.
2. Acquisition of data on performance at NRX/EST conditions of back pressure and tank pressure.
3. Acquisition of performance data under XE-engine and ETS-1 operating conditions.

4. Acquisition of data on the effects of reduced tank pressure with minimum back pressures.

5. Evaluation of performance of the automatic pressure controller during initial engine-startup operation.

6. Demonstration of dry-pump start.

The tests demonstrated that the CFDTs engine will bootstrap with either a wet or dry pump. With a wet pump, the data indicate that peak pump speeds in excess of 5000 rpm can be achieved when run-tank pressures are as low as 45 psia at NRX/EST back-pressure conditions of 12.7 psia, or when run-tank pressures are as low as 30 psia at design back-pressure conditions of 7.5 psia for the ETS-1 facility. Peak speeds of 8000 rpm and greater were obtained in tests performed at higher tank pressures. With back pressures of 0.25 psia, a peak speed of about 8600 rpm was reached with a tank pressure of 30 psia. Tests at this back pressure were attempted with both a wet and dry pump at a tank pressure of 20 psia, but limitations of the facility in maintaining the low back pressure resulted in a deviation from the test conditions before conclusive data could be obtained on the ability of the system to bootstrap at these conditions. The test data indicated that, at back pressures of 12.7 and 7.5 psia, reductions in the tank pressure to below about 45 and 30 psia, respectively, resulted in a sharp reduction in peak pump speed to below 3000 rpm. The peak performance obtained with a dry pump at start was similar to that obtained with a wet pump at the same test conditions. The dry pump run required a considerably longer run time to reach peak performance. At a back pressure of 7.5 psia and a tank pressure of 35 psia, peak performance was achieved with the wet pump after a run time of about 30 sec; with a dry pump, the run time to peak conditions was about 70 sec.

Pump-induced oscillations occurred during an interval just prior to the final pump acceleration to peak performance in the dry-pump starts. These oscillations increased in amplitude and have a period of 1.5 to 5.5 sec.

It is theorized that the oscillations are associated with a two-phase fluid condition in the pump and the pump discharge circuit and that they are triggered by low-speed pump cavitation when the pump is being accelerated against an excessive restriction to flow caused by the two-phase fluid. By delaying the opening of the TPCV valve up to 18 sec from the beginning of the test, the run time and the duration of the period during which the oscillations occurred were decreased without significantly affecting peak performance.

During the CFDTS tests, temperature asymmetries were noted in the nozzle-manifold, reflector-inlet and -outlet, shield-dome-end, and nozzle-chamber plenums during certain phases of the runs. Some of these asymmetries were concluded to be measurement errors caused by instrument lag and inaccuracies, but others appeared to be true asymmetries related to a two-phase flow condition in conjunction with a nozzle manifold design with a single inlet and with the hot-bleed port.

Evaluation of the test data with respect to other objectives of the test program indicated the following results:

1. The improvements made in the turbopump and exhaust manifold prior to the second series of CFDTS tests resulted in an indicated improvement in bootstrap performance of about 40%.

2. The automatic pressure controller operated satisfactorily. When used, it opened the TPCV to the full-open position at the start of the test and controlled the valve position during the run to attempt to maintain the preset chamber-pressure demand.

3. Removal of the orifice in the diluent line reduced the diluent-line loss factor by about 50% and resulted in a system-performance improvement of less than 4%.

e. NRX-Systems Data Analysis

(1) NRX-A3

Data analysis of this test series was essentially completed and reported in the Summary Report for contract year 1965. During CY 1966, the NRX-A3 data-analysis report was used (Report RN-S-0249). In addition, the following was accomplished:

The measured temperatures in the outer-reflector outlet, shield-dome-end, and core-inlet plenums at power holds of the NRX-A3 test series were investigated to determine characteristics of fluid streams discharging into these plenums. The measured temperatures in the outer-reflector outlet plenum indicated variations in the radial direction at a given angular location. Therefore, it is questionable whether a good mixed-fluid mean temperature could be obtained by measuring temperature in this plenum. Because the incoming fluid streams mix well in the shield-dome-end plenum, the mean temperature of the mixed fluid in this plenum can be obtained from temperature measurements. Thermocouples in the central section of the core-inlet plenum gave considerably higher temperature readings than the thermocouples in the peripheral section during the NRX-A3 EP-V power holds, but this condition was not observed during the NRX-A2 EP-IVA power holds. Therefore, the existence of the higher fluid temperatures observed in the central section of the core inlet plenum during the EP-V power holds was not confirmed. Data from future tests will be further analyzed to determine fluid temperature characteristics in the core inlet plenum.

(2) NRX-A5

Data from the NRX-A5 reactor tests were analyzed, and a report (RN-S-0317) was prepared.

The primary purpose of the NRX-A5 test program was to demonstrate the operation of the NRX system for an extended period of time, with the primary objective being an accumulation of 40 min of operation at design conditions. Secondary objectives were: (1) operation with a no-flux-loop temperature controller and (2) a start with the drums in a fixed position. The test program consisted of two experimental plans (EPs) for system checkout and calibration and a series of EPs with operation at full power. The program was terminated after a premature shutdown of the second full-power test when the loss in reactivity became excessive. As a result, only 30.8 min of operation with a nozzle chamber temperature above 3500°R was accumulated on the NRX-A5 system, and the major goal of achieving a 40-min cumulative duration was not achieved. Graphic chronologies of the major reactor-system parameters during EP-III and EP-IV are shown in Figure 93 and 94. The secondary objectives, satisfactory operation of the no-flux-loop temperature controller and demonstration of a fixed-drum start were both achieved.

Data from 15 different times, which were selected from the intermediate power holds and throughout the steady-state full-power holds during the full-power EP's, were utilized in evaluating the steady-state performance of NRX-A5. Best estimates of system pressure schedules, temperatures, flow, and power determined from these data are shown in Figure 95. The data appeared to be normal and uniform throughout both full-power runs except for an indication of small increases in the temperature rise and pressure drop of nozzle-tube coolant during each run. The increase in pressure drop appeared to accumulate with total system run duration, with an increase of approximately 2.5 psi (1.8%) during EP-III and an additional 9 psi (6.5%) during EP-IV. The temperature rise, on the other hand, was the same at the beginning of the EP-IV full-power hold as at the beginning of EP-III, with the increase that had occurred during EP-III, approximately 4.4°R (4.3%), not being retained. The temperature rise then increased approximately 8°R (8%) during EP-IV.

Figure 93
Major Operating Parameters; NRX-A5, EP-III

Figure 95
Summary of NRX-A5 Best-Estimate Steady-State Data

(Confidential figure being submitted under separate cover)

The best-estimate data measured during the intermediate holds of each start transient and near the beginning and end of the full-power holds were compared with pretest and posttest prediction data. In general, agreement between measured and predicted data was good. The computer model predicted slightly higher reflector ΔP and ΔT (6 to 9 psi and 12 to 17°R) and correspondingly lower core ΔP and ΔT . A review of the external temperatures and the internal pressures and temperatures to which the pressure vessel was exposed indicated that the pressure vessel was being subjected to an environment fairly consistent with the NRX-A3 measured and predicted conditions.

A fixed-drum startup to rated flow was successfully demonstrated during NRX-A5. The pretest predicted nozzle-chamber temperature of 3340°R at the full-flow fixed-drum hold condition was missed by about 500°R, indicating a need for improvement in the capability to predict the nuclear reactivity during the transient. Although the start was very smooth, it was characterized by a high-flow, low-chamber-temperature relationship that resulted in a relatively long, low-impulse start transient. A fixed-drum start reduces the control requirements and the system complexity.

As in NRX-A2 and -A3, there was no indication of fluid oscillation during the NRX-A5 tests, such as observed during the NRX/EST transients and low-power operation. The NRX-A5 system incorporated an open-loop propellant feed cycle in contrast to the NRX/EST closed-loop cycle and did not have a closed-loop pressure-control system. In addition, the fluid conditions in the coolant jacket were different from those observed when the oscillations occurred during the NRX/EST tests.

The angular temperature distributions measured in the plenums of the NRX-A5 system were analyzed, after which the data from the NRX-A3 and NRX/EST systems were reviewed. The analysis shown in Figures 96, 97, and 98 disclosed the existence of a well defined temperature asymmetry pattern in the NRX/EST system, in contrast to the pattern in the NRX-A3 and NRX-A5 systems. The NRX/EST test data indicated a general warm region throughout that system, apparently caused by the proximity of the vertical shield on the test car.

Figure 96
Angular Temperature Distributions; NRX-A5, EP-III and EP-IV

Figure 97
Angular Temperature Distributions, NRX/EST

Figure 98
Angular Temperature Distributions, NRX-A3

f. Engine-Systems Data Analysis

(1) NRX/EST Data Analysis

The NRX/EST test series represented the first test of a nuclear-rocket-engine system with major components connected in the flight functional relationship. Prior to the start of testing, the NRX/EST data-analysis plan (Report RN-S-0247) was published to document the report requirements and the data-analysis techniques and computer programs to be used in analyzing the test results.

The major objectives of the NRX/EST series are divided into three phases: (1) initial-criticality and cold-flow experiments, (2) bootstrap to intermediate-power phase, and (3) full-power-duration phase. The results for these phases were as follows:

All the objectives of Phase I, initial criticality and cold flow, were achieved. The test system was thoroughly checked, with a number of operational difficulties being found and corrected. The major objectives for Phase I included initial criticality, cold-flow runs to verify initial startup performance, and determination of engine reactivity characteristics. Also measurements of individual drum worth and low-power dosimetry were made.

Phase II was intended to demonstrate the capability of the engine to bootstrap to a significant power level. This objective was successfully demonstrated by four different modes. With a 70-psia Dewar pressure, bootstrap was achieved by programming chamber temperature and power with an ambient reflector, with a chilled reflector, with fixed drums, and with a no-flux-loop control mode. The objective of a low-Dewar-pressure start was not achieved in Phase II.

The objectives of Phase III, to demonstrate full-power operation of the engine for an extended time and to demonstrate maneuvering capability within the operating envelope, were achieved. The engine operated at power levels of 1000 Mw or greater for 29.5 min. The mapping program was successfully carried out. Bootstrap was achieved at a Dewar pressure of 45 psia. An attempt to start at a 35-psia Dewar pressure was again unsuccessful. The attempts to start at low Dewar pressure were unsuccessful primarily because of inability to adequately chill the test and engine components upstream of the propellant valve when such a low pressure was used to drive the flow. After completion of the NRX/EST testing, the NRX/EST data-analysis report (RN-S-0309) was prepared and published. The report contained a comprehensive review of all significant results of engine testing and subsequent data analysis. Transient conditions, steady-state performance, and transfer-function measurements were analyzed. In addition, two forms of pressure oscillations that occurred during testing were analyzed to determine the contributing factors. Graphical chronologies of each test were prepared to document the relationships of major parameters, such as pump discharge pressure, nozzle chamber pressure, nozzle chamber temperature, and mass flow rate, as well as the control operations that were being tested. A typical example of this type of data presentation is shown in Figure 99.

Significant results of the analysis of NRX/EST test data are summarized in the following paragraphs:

(a) Transient Conditions

The engine-system performance under transient conditions covers cold-flow tests, startup and shutdown transients, and the engine mapping tests. The test program and data analysis indicate the following:

NRX/EST tests demonstrated startup capability with or without stored energy in the system, and without requiring an external source of energy. The tests demonstrated that a nuclear rocket engine could be started at low Dewar pressures as well as high and that the pretest predictions afforded adequate guidance for test operation.

Figure 99
Major Operating Parameters, EP-IIC, Run 2

During shutdown, the system operated as predicted. Besides the normal shutdown at 100°R/sec, shutdown along a high-impulse line was demonstrated to be satisfactory. Also, a fixed-drum shutdown was accomplished; as predicted, this shutdown was very slow.

Engine mapping runs demonstrated the capability of the engine system to operate over a wide area of the engine operating map. Furthermore, these runs proved to be effective means of obtaining large quantities of quasi-steady-state data.

CFDTS and NRX/EST cold-flow performance agreed, as shown in Figure 100. The digital programs were upgraded by using data from the CFDTS analysis, and good agreement is now being obtained in cold-flow analysis.

(b) Transfer-Function Measurements

On the basis of transfer-function analysis, the control system provided good overall control of the system for the planned operational power levels of the NRX/EST. The transfer functions of the pressure loop temperature loop, and power loop were evaluated at lower-power and design-point conditions for gain and phase characteristics. An anomaly in EP-IIB in which the actuator performance deteriorated prompted a re-evaluation of the pressure-control system; however, if the actuator performance had not deteriorated, the pressure controller, as originally designed, would have functioned satisfactorily but with reduced phase margin.

Differences exist between the test data and the dynamics of the common analog model (CAM-II), as shown in Figure 101. The transfer functions from NRX/EST data to observed differences will be taken into consideration to permit a higher degree of confidence in the controller design for the X-engine.

Figure 100
Peak Pump Speed vs Tank Pressure at Constant Back Pressure

Figure 101
Chamber-Pressure Response to Nozzle Inlet Pressure at Design Point,
Test Data (EP-IV and EP-IVA) and CAM-II Data

(c) Steady-State Performance

Steady-state data were obtained for the engine over the full range of operating conditions. Holds were made from 30 to 100% power on the nominal operating line, from 44 to 100% power under structural temperature-limiting conditions, and from 62 to 92% power at the engine flow limit.

In between the operating limits, the engine was mapped by ramping at low rates to have an infinite number of pseudo-steady-state data points available. These ramps were conducted along lines of constant chamber temperature and constant TPCV position. The mapping data were analyzed in detail and found to be representative of engine steady-state operation. Maps of steady-state data were constructed for pertinent engine parameters; a typical example is shown in Figure 102.

The engine performed close to the pretest predictions. At the first nominal full-power hold, the pressure drop was 381.4 psia; The predicted value was 7.8% lower. The pump discharge flow was 76.0 lb/sec, 0.5% above predicted; and the turbine inlet flow was 6.31 lb/sec, 7.9% above predicted.

The maximum flow limit of the engine was expected to be 80.5 lb/sec at a chamber temperature of 3570°R and 76.5 lb/sec at 2880°R. The NRX/EST tests established the maximum flow limit as 81 lb/sec at 3400°R and 75 lb/sec at 2550°R. These results show how close the engine performance was to expectations.

(2) Performance Summary

The following summarizes the performance of the major nonnuclear components in the engine system:

Figure 102
NRX/EST Steady-State Turbopump Operating Map

(a) Nozzle

The nozzle pressure drop and temperature rise were generally close to predictions. A small error in the predicted pressure drop at full power was found to be caused by the effect of the flow-straightening orifice in the aft end of the nozzle. Temperature variations at low power were the result of analytical simplifications that are invalid when hydrogen is near the dome.

(b) Pump Suction and Discharge Lines

Pressure losses in the pump suction and discharge lines were in good agreement with predictions. A new loss coefficient for the pump inlet line was calculated on the basis of measured data. The temperature rise in the suction line was found to be negligible, as predicted.

(c) Pump Performance

The predicted pump operating characteristics were in good agreement with measurements of the values derived from measurements.

Pump efficiencies determined from the test data were in the expected region of 67%. The pump discharge flow determined by test measurement was in excellent agreement with pretest predictions. A comparison of pump inlet and discharge flow also showed good agreement; the difference between these two values provided an estimate of the leakage through the pump bearing. This estimated value, approximately 2 lb/sec, differed from the bearing coolant flow computed from existing equations, which was less than 1.0 lb/sec at the design operating point.

(d) Diluent Line

Excellent consistency of the points within chamber-temperature isotherms was obtained in describing the diluent parameters.

The measured diluent flow rate was slightly greater than predicted at the recommended setting of the diluent control valve. A 20° correction in the setting of the diluent control valve adjusted the diluent flow so that the desired turbine inlet temperature was obtained.

The influence of the diluent control valve on operating parameters at the 20 to 22° and at the 41° positions was determined for the steady-state positions.

A general loss coefficient normalized for the diluent-line pressure drop was established on the basis of test data.

(3) Turbine

The predicted and measured turbine parameters were generally in good agreement. The quality of data was such that small changes from predicted values could be detected to describe the turbine characteristics.

A TPCV loss coefficient was established on the basis of system test data. The observed value was greater than that obtained from component test estimates. This difference may result from a flow disturbance caused by adjacent components in the line or from a discrepancy in the valve-position measurement data. Significantly, the valve did provide adequate control to allow for satisfactory operation of the engine over the full range of desired conditions. Engine operation with the valve at its minimum-resistance point was close to the predicted performance.

The turbine flow parameter was re-estimated. This value differed somewhat from the specified value and was found to be a function of turbine inlet temperature.

(f) Fluid Oscillations

Two types of fluid oscillation were observed during the NRX/EST tests. One type occurred at intermediate pressures during startup and shutdown transients, and the second type occurred immediately after the PDV was opened. These oscillations caused no operational problem but were nonetheless analyzed to determine the possible causes.

1 Intermediate-Pressure Oscillations

The fluid oscillations at intermediate pressure caused chamber-pressure oscillations of ± 10 -psia amplitude at a frequency of 0.6 cps. Oscillations in the nozzle coolant tubes occurred while the flowing fluid was going through the two-phase (critical temperature-pressure) region. The two-phase fluid is the probable cause of the fluid oscillations observed in the system. A detailed discussion of these oscillations has been prepared as Supplement No. 2 to Report RN-S-0309.

2 Oscillations after Opening of Pressure Discharge Valve

Flow oscillations occurred immediately after the pump discharge valve was opened. The amplitude of these oscillations varied from a few psia to as high as 40 psia at a frequency of about 1 cps. The oscillation at the nozzle manifold seemed to disappear about 5 sec after the PDV opened, whereas the oscillations at the pump inlet and pump discharge continued much longer but at diminishing amplitude and frequency. During NRX/EST, no pressure surges of a large magnitude were observed that would indicate any significant problem areas.

(g) Statistical Evaluation of Measurements

The statistical-evaluation program consisted of evaluating representative temperature measurement by means of a special statistical

program to determine its quality. The temperature measurements of the shield-dome-end gas, the reflector inlet, and the nozzle chamber were chosen. Results indicated that the temperature measurements were generally very good. Outliers were properly eliminated from the best-estimate values, areas of inconsistent measurements were detected and eliminated from the analysis, and, when a two-phase flow condition existed at the reflector inlet, the analysis program was able to recognize this condition.

(h) X-Engine Data Analysis

Current data analysis with respect to the X-Engine includes application to the X-engine system of data obtained from the NRX test series, such as vibration analysis and analytical-model improvement. The year-end status of X-engine data analysis (Report RN-S-0329) was prepared to present a data-analysis program plan for the X-engine. A schedule of the data-analysis tasks and report requirements illustrating the time phasing of activities is presented in Figure 103. A diagram that illustrates the relation between data-analysis tasks and shows the principal flow of information between tasks is presented in Figure 104. The activity boxes drawn with solid lines indicate activities in which data-analysis personnel will be directly involved; boxes drawn with dashed lines indicate activities that generate information on which data-analysis is dependent. Multiple arrows between boxes indicate concurrent activities in which a great deal of coordination and free exchange of information is required. The major effort in data analysis prior to the start of testing will be to investigate methods of applying experience gained from previous tests to a computerized data-handling system to greatly improve the quality of data presentation that can be made available within a short time after a test is conducted. In addition, data-analysis personnel will continue to assist in analyzing the results of the ETS-1 data-acquisition-system tests that are currently in progress.

X-ENGINE DATA ANALYSIS SCHEDULE

CALENDAR YEAR	1966			1967												1968		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
A. ETS-1 INSTRUMENTATION ACCURACY TEST SUPPORT																		
B. ETS-1 ACTIVATION EP SUPPORT																		
C. MEASUREMENTS ANALYSIS																		
D. MEASUREMENTS ANALYSIS REPORT																		
E. COMPILE MEASUREMENT DESCRIPTIONS																		
F. ESTABLISH DATA ANALYSIS COMPUTER PROG & PROCEDURES																		
G. COMPUTER PROGRAMS CHECKOUT (COLD FLOW TESTS)																		
H. REACTOR ENGINE TESTING DATA COMPILATION																		
I. DATA REVIEW TEAM SUPPORT																		
J. DATA ANALYSIS																		
K. DATA ANALYSIS REPORT																		

Figure 103
X-Engine Data-Analysis Schedule

Figure 104
Flow Plan for X-Engine Data-Analysis Information

7. Radiation Effects Program (1.9)

a. Integration and Technical Management (1.9.0)

(1) Objectives

The radiation effects program is conducted for the purpose of providing assurance, by testing or analyses, that the NRX, NRX/EST and the XE engine components will perform satisfactorily under operational conditions. This objective is achieved by preparing test plans, test schedules, test specifications, test procedures and preirradiation analyses; performing radiation effects tests; analyzing test data; and preparing test reports.

(2) Test Summary

Forty-nine radiation effects tests have been performed by (or under the cognizance of) REON through September 1966; six were performed during CY 66. The types of materials, components tested, and the number of tests performed are shown below. Detailed discussions of the test results are contained in the sections relating to Sections 1.9.4, 1.9.6, and 2.4.6 in other parts of this report.

RADIATION EFFECTS TEST STATUS (AEROJET ONLY)

<u>Component Description</u>	<u>Test Completed in CY 66</u>	<u>Total Number of Tests Completed Through CY 66</u>
Diagnostic Instrumentation	3	24
TPA Bearings	0	5
Mechanical Components	0	4
Electrical Components	0	5
Materials	2	6
Explosives	1	5

(3) Coordination

Sub-subtask 1.9.0 presents the overall management and coordination of all NERVA radiation-effects activities at Aerojet, Westinghouse, and at the various test facilities.

Numerous meetings were held during this year at WANL, SNPO-C, and GD/FW to finalize the GTR-18 test program, plan the GTR-19 test program, and outline the CY 67 radiation effects program at GD/FW. In addition, the necessary coordination and planning were performed for tests 23/R510 and 23/R511, which were conducted at the Plum Brook Reactor Facility (PBRF).

(4) Subcontracts

Subcontract SNP-000128 was negotiated with General Dynamics, Fort Worth (GD/FW). The scope of the subcontract includes: reworking five thermal conductivity test cells (as required) for performing radiation-effects test 37/R004; and fabricating and checking out a test Dewar vessel for resistance temperature transducer (RTT) test 23/R104. This activation is described in detail in Sub-Subtasks 1.9.6 and 1.9.4.

A subcontract to General Dynamics, Fort Worth, is currently being negotiated to perform postmortem tests on sections from the NRX/EST nozzle, as well as mechanical-property tests of pressure-vessel bolts from NRX/EST. This activity is described in detail in Sub-Subtask 1.9.2.

(5) Reports

The status of all reports associated with the CY 1966 radiation effects program is summarized in Figure 105.

<u>Report No.</u>	<u>Title</u>	<u>Comments</u>
RN-S-0291	Final Test Report for Strain Gage	This report was originally RN-S-0245 and also contained results of earlier strain-gage tests.
RN-S-0273	Final Test Report for Tests 23/R502 (Pressure Transducers GTR-14) and 23/L002 (Accelerometer GT-14)	
RN-S-0251	Final Test Report for Tests 23/L102 (RTT - GTR-14) and 23/L103 (RTT - GTR-14)	
RN-S-0257	Final Test Specification for Test 23/R510 (Pressure Transducers)	
RN-S-0241	Final Test Report for Test 23/R005 (NRX-A3 Side-by-Side Accelerometers)	
RN-2277 Rev.	Radiation-Effects Data Book Inserts through Sept 1965	
---	Preliminary Test Specification for Test 23/R511 (Pressure Transducers)	
---	Final Test Specification for Test 23/R104 (RTT)	
---	Preliminary Test Specification for Test 37/R004 (Thermal Conductivity)	
---	Final Test Report for Phase I-D of the Explosives Irradiation Program	
RN-S-0279	Hazards Analysis for Test 23/R510 (Pressure Transducer)	
RN-S-0282	Final Test Specifications for Test 23/R511 (Pressure Transducers)	
RN-DR-0074	Hazards Analyses for Test 23/R511 (Pressure Transducers)	
RN-S-0280	Final Test Report for Phase I-C Explosive Program	
	Final Test Specifications for GTR-18	

Figure 105
Status of Reports, CY 1966

<u>Report No.</u>	<u>Title</u>	<u>Comments</u>
Informal Report	66-WEV-070 Qualification Test Firing of Phase II Containment Capsules at Aerojet- General Corporation - Downey Plant	
RN-S-0325	Final Test Report for Test 23/R510 (Pressure Transducers)	Rough draft complete; awaiting dosimetry information.
RN-S-0326	Final Test Report for Test 23/R511 (Pressure Transducers)	Rough draft complete; awaiting dosimetry information.
RN-S-0290	Final Report GTR-16 Radiation Effects Test On Structural Materials at -423°F	In publication
RN-S-0327	Final Test Report GTR-17	In publication
RN-S-0300	Thermal and Error Analyses for Thermal Conductivity Test 37/R104	
RN-S-0318	Radiation Effects Summary Report on NRX-A2 and NRX-A3	In publication
---	NERVA Radiation Effects Status Report	In preparation

Figure 105
Status of Reports, CY 1966

b. Countermeasures Radiation Effects Program (1.9.1)

The countermeasures radiation effects program is designed to provide radiation effects information on explosives and propellants as required for the NERVA countermeasures system. Since the United States Army Picatinny Arsenal was developing a NERVA Destruct System, the work of this sub-subtask was continuously coordinated with Picatinny, and that group actively assisted in the program.

(1) Explosive and Propellant Sample Irradiations,
Contract Year 1966

No samples were irradiated during this contract year. Phase II irradiations of 80-gram samples were delayed for completion of the capsule qualification tests, and changes in the General Electric Test Reactor license that will enable these irradiations. Capsules have been loaded and procedures written for Phase I-A irradiations of three prototypes of radiation-stable detonators and three new explosives. These samples will be irradiated early in CY 1967.

(2) Phase II Capsule Qualification Testing

The small-scale tests performed in Phases I, I-B, I-C and I-D evaluated a series of candidate countermeasures system materials to identify the most stable materials and to determine their approximate radiation-tolerance limits. Phase II involves testing large quantities (80 grams) of the best materials to enable heat build-up determination, closed-bomb testing of propellants, and irradiation and testing of a statistically significant sample of detonators.

To irradiate the large samples in the General Electric Test Reactor, a capsule developed by Picatinny Arsenal capable of containing an accidental detonation of 80 grams of high explosive was subjected to an extensive series of development tests, culminating in the final capsule design shown in Figure 106.

Figure 106
Exploded View of Phase II Capsule

General Electric reviewed the results of these tests, and requested a minimum of three successful proof tests of the final design capsule. These proof tests were to be conducted by intentionally detonating 160 grams of high explosive (twice the amount to be irradiated). Capsules were manufactured by Picatinny and Aerojet, and tests were conducted at the Aerojet-Downey facility. The outer glass-to-metal seal and the inner tapered-plug seal failed in the first qualification test. After these components were modified, the last three tests were successfully completed.

The qualification test set-up is shown in Figure 107. The containment capability of the capsule was demonstrated by firing all three capsules in a small water-filled glass aquarium without damaging the aquarium. The control panel shown in the lower right of the figure is used to monitor pressure inside the capsule and to vent excess pressure into an evacuated tank. A section of the capsule after firing is presented in Figure 108, which shows that the inner tube completely contained the blast, while the annular gap between the tubes acted as a shock attenuator.

Shock pressures on the outside of the capsule were measured by the Brewer Engineering Laboratories under subcontract to Picatinny Arsenal. A peak shock pressure of 475 psig occurred at the ends of the capsule, where there is a direct path through aluminum from the inside of the capsule to the outside. Since this pressure is not sustained, only a negligible impulse is transmitted and the reactor would not be damaged.

The Phase II capsules that will be used to irradiate 80-gram samples in the General Electric Test Reactor will be lowered into the reactor pool to a position 1/4 in. from the reactor pressure shell for irradiation exposures. In this location, fluxes will be about 5×10^{10} ergs/gm(C) of gamma radiation, 8×10^{12} n/cm²/sec fast neutrons, and 9×10^{13} n/cm²/sec thermal neutrons.

Figure 107

Phase II Capsule Qualification Test Arrangement

Figure 108
Postfiring View of Capsule Section

(3) Detonator and New Explosive Tests, Phase I-A

Prior to irradiation of large quantities of detonators in Phase II, two or three small capsules will be irradiated with four detonators in each capsule to determine the gross effects of exposure on performance and the approximate damage-threshold dosages. A prototype detonator has been designed (Figure 109), which has an aluminum body and bridge wire, and a glass-to-metal seal to minimize heat generation and decomposition of the nonexplosive components. These detonators were loaded with the three most radiation-stable booster explosives and preirradiation tests were made to establish performance characteristics of the detonators before exposure to radiation.

Three new explosives that are similar to those already tested, which may have superior radiation stability, will also be included in the Phase I-A test. These are all main-charge explosives that could be used in any type of Countermeasures System.

Details of this phase are contained in the Phase I-A final test specifications, REON Report RN-S-0324. The Phase I-C results are summarized in the 1965 status report, and are presented in detail in the Phase I-C Final Report, REON Report RN-S-0280 (CRD).

c. Radiation Effects Analysis and Data Book (1.9.2)

(1) Radiation Effects Data Book

The radiation effects data book (REON Report 2277, September 1965, Revised, CRD) contains a compilation of radiation-effects information applicable to the NERVA program. It was compiled to document the NERVA radiation-effects program and to provide radiation-effects data for design of engine components, indicate the radiation resistance of the engine components, and transmit NERVA radiation-effects information to related projects outside the NERVA program.

Figure 109
Detonator Assembly

The data book has two volumes: Volume I contains detailed radiation effects information and Volume II presents general background information in the main areas of interest.

During the contract year, one set of inserts to Volume I was issued, which updated the NERVA nuclear-environment predictions for each of the engine components that have been tested for radiation effects and included all test data available as of September 1965.

As a result of an engineering survey, it was decided to replace the radiation effects data book with a radiation effects design information file. This activity is as follows:

(2) Radiation-Effects Design Information File

After visiting agencies that included the Battelle Memorial Institute, Columbus, Ohio, and the National Bureau of Standards, Boulder, Colorado, to review existing data files, a format was developed for presenting radiation information relative to materials and instrumentation. Examples of the proposed format were completed for one structural material and one instrumentation transducer, and the files were then reduced to microfilm cards. These data were provided to SNPO-C for review and comments.

Provisions were also made to use the existing REON technical information center's IBM KWIC (Key Work In Context) Index System for cataloging all radiation-effects information under a separate heading. In addition, a radiation effects information library was established in RTIC for storage of selected radiation-effects information. The material in the classified Radiation-Effects Handbook was reviewed and approximately 95 percent was suitable for storage in the radiation-effects library.

(3) Preirradiation Analyses

(a) Pressure-Transducer Tests 23/R510 and 23/R511

During the contract year preirradiation analyses were completed for two Plum Brook Reactor Facility pressure-transducer tests.

The heat-transfer analyses predicted the transducer internal temperatures at various gamma heating rates. The predictions in the analyses closely approximated the actual temperatures that were measured during the irradiation test.

(b) Thermal and Error Analysis for Thermal
Conductivity Test 37/R104

Preirradiation analyses were performed for Thermal Conductivity Test 37/R104. These investigations were concerned primarily with:

1 Predicting the accuracy of data acquisition equipment for measurement of (a) input power, (b) Dewar vessel pressure (c) temperature measurements, and (4) electrical resistance;

2 Calculation of temperature profiles of components during all phases of testing;

3 Evaluation of test design and test objectives;

4 Time required to achieve thermal equilibrium for both LN_2 and LH_2 testing;

5 Extrapolation of experimental and analytical test conditions; and

6 Incorporation of results into test specifications, test procedures, and component design.

(4) NRX, XE, NRX/EST

(a) NRX-A2 and NRX-A3

A report summarizing the radiation effects information obtained from NRX-A2 and NRX-A3 has been completed. Results of component performances and side-by-side radiation effects testing, as well as recommendations

for future tests, are presented. A summary of significant findings from these tests are as follows: (1) transducers on NRX-A2 were also selected for use on NRX-A3. During NRX-A3 the pressure transducers located in high-flux regions had higher signal outputs than anticipated due to gamma heating; (2) during NRX-A2 no radiation effects were detected on the RTT's (resistance temperature transducers); (3) during NRX-A3 the RTT's showed a slight signal increase due to radiation effects; (4) during NRX-A3 radiation effects in the reference junction controller for the immersion thermocouple caused variations in the temperature signal; (5) radiation effects caused signal variation from the thrust chamber thermocouples during NRX-A2 but no such effects were noted during NRX-A3; (6) the strain gages performed satisfactorily during NRX-A2 and A3; (7) an accelerometer malfunction during NRX-A2 was caused by radiation effects within the cable; (8) in-core diagnostics were poor because of radiation effects on the instrumentation selected; (9) the output from electronic multiplexers appeared to follow the power profile; (10) motion picture film quality and television performance were affected by radiation; and (11) tests of NRX-A2 closure bolts show that a change occurs in the mechanical properties of the bolts when they have been subjected to environmental conditions during operation of NRX-A2.

(b) NRX/EST

Postoperative testing of NRX/EST instrumentation is complete. Post-mortem testing of NRX/EST hardware is continuing. A contract for tensile tests of the nozzle and closure bolts and of nozzle specimens has been awarded to General Dynamics, Fort Worth, Texas. A final report relative to these tests is expected by January 1967. A work statement covering tensile tests of nozzle tube specimens has been prepared. These tests, in conjunction with a radio-chemical analysis of fission product plate-out, are designed to provide data about the effect of plate-out on the mechanical properties of the tube material. A radio-chemical analysis of fission product plate-out and impregnation of the nozzle tubes and braze material will be performed at NRDS. In addition to radio-nuclide data relative to activation and fission product plate-out, this analysis will include studies of the depth of impregnation or diffusion of the fission products.

A report summarizing the radiation-effects information obtained from NRX/EST is approximately 50 percent complete. This report will be completed when the results of the test being performed at GD/FW and NRDS have been received.

(c) NRX-A5

Postoperative tests of NRX-A5 components are continuing. Tests have been made of several pressure transducers and accelerometers. A tungsten probe will be shipped to LASL for sectioning and analysis. Tensile tests of the nozzle and closure bolts and nozzle samples will be delayed until after the results from similar tests of NRX/EST parts have been completed. After the NRX/EST results have been analyzed, a decision regarding additional tests of nozzle bolts will be made. The report summarizing the radiation-effects information gained from NRX-A5 is about 10 percent completed.

(d) NERVA Radiation-Effects Support

Numerous analyses relative to potential radiation-effects problem areas were completed. These studies were concerned with instrumentation, cabling, materials, and electrical components.

Analyses were also made to predict the performance errors that would occur in the diagnostic instrumentation of NRX/EST and NRX-A5 during the engine test. The analyses indicated extremely small errors for the instruments, (5°F for RTT's and 20°F for tungsten/tungsten rhenium thermocouples); in general, the actual instrument performance was better than predicted.

d. Technical Services Field Support and Miscellaneous STE (1.9.3)

In addition to the engineering support provided for reduction of GTR-16 and GTR-17 data, coordination was provided for planning GTR-18 and GTR-19 tests at GD/FW.

e. Instrumentation Radiation Effects Program (1.9.4)

(1) Resistance Temperature Transducer Test (23/R104)

Resistance temperature transducer test 23/R104 (GTR-18) was completed at General Dynamics, Fort Worth, in August 1966. Substitution of the large diameter materials Dewar vessel resulted in a lower integrated neutron flux than was desired. However, preliminary study of the data indicated that the objectives of this experiment were accomplished. Apparently the effect of hydrogen-generated, proton-recoil reactions is not as severe as expected, since the performance of the shielded units was not better than that of the unshielded units. Reduction of these data and preparation of the final test report are in progress.

(2) Pressure Transducers (23/R510 and 23/R511)

Both of these pressure-transducer tests were accomplished at the Plum Brook Reactor Facility during CY 1966. Although the value of the tests was affected by the accidental water-immersion of the test items during the pre-irradiation test activities, several design criteria were established. Of the three types of transducers tested (LVDT, bonded strain gage, and vapor-deposited strain gage) the vapor-deposited assemblies performed best.

These units continued to function (although they did show large zero shifts and sensitivity degradation) with less than 0.1 megohm of insulation resistance. Posttesting examination of the transducers showed the insulation resistance of the vapor-deposited strain gages to be in excess of 8 k megohms, whereas the insulation resistance of the transducer-cable assembly was less than 0.1 megohm.

f. Materials Radiation Effects Program (1.9.6)

(1) Program Planning

Activities connected with the planning and design of radiation-effects tests on materials included preparation of preliminary and final

test plans, specifications, schedules, and test reports. Several add-on items to the scheduled GTR-18 radiation test were prepared and incorporated. These additions included investigation of: (1) effects of boron on high-temperature ductility of irradiated material; (2) effects of radiation on the mechanical properties of beryllium, and (3) investigating the properties of candidate bearing-cage materials.

Coordination and liaison were maintained on a continuous basis with General Dynamics, Fort Worth, National Bureau of Standards, Westinghouse, LASL and SNPO-C. Several meetings with representatives of each organizations were held during this time to discuss technical problems.

(2) Radiation Effects Testing

(a) GTR-16 Structural Materials Test

This test was conducted in CY 65; however, additional measurements of area reduction and elongation of the broken specimen with an optical magnification and planimeter were performed during CY 66. These results are incorporated in the final report RN-S-0290.

(b) GTR-17: Organic Materials Test

Five organic materials (three Armalons, one Teflon, and one SP-3 superpolymer) were evaluated to determine the material that will perform best under operational conditions as turbopump bearing components. The radiation run was conducted in CY 65. Analysis of the data and preparation of the report were accomplished in CY 66. REON report RN-S-0337 summarizes the results of this test.

(c) GTR-18

The radiation-effects test at General Dynamics originally designated as a thermal-conductivity test was amended to incorporate

several other materials tests. These included Boron-Containing Materials Test 37/R105; Bearing Cage Materials Test 37/R106; WANL sponsored test of Beryllium Mechanical Properties Test 37/W403; and Inconel 718 Tensile Test 37/R404. Post-irradiation tensile testing is completed for the Aerojet-sponsored portion of the test. To achieve better alignment of the beryllium specimen during pulling, WANL has designed and fabricated new test grips; however, the recommended 5% axiality error (National Science Foundation Committee on Beryllium Testing) was not attained. All beryllium specimens will be instrumented for testing.

(d) GTR-19 Mechanical-Properties Test

This test which is scheduled for November 1966, is being made to obtain comparative data relative to damage caused by fast neutrons on materials submerged in LH_2 and LN_2 during radiation. Seven materials that represent four families are selected for this comparison. Fourteen additional materials in various conditions are scheduled for testing in LN_2 environment with a cold-transfer method or with a warm-up cycle.

Preparations for this test, which is scheduled for early CY 67, are in progress. This test will be made by Aerojet and WANL. Some specimens have already been delivered.

(e) Thermal Conductivity Test 37/R104

General Dynamics, Fort Worth, has a contract with SNPO-C and Aerojet to fabricate two thermal-conductivity test assemblies: one for testing of liquid hydrogen on metallic materials, and the other for testing of liquid nitrogen on beryllium and graphite.

Difficulties occurred in sealing the electrical feed-throughs for both LH_2 and LN_2 test units, which resulted in dropping this test from the GTR-18 radiation run. The thermal and error analysis for this test is described in Sub-Subtask 1.9.2.

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B. ENGINE SUPPORT SYSTEMS AND FUNCTIONS

Task 2

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B. ENGINE SUPPORT SYSTEMS AND FUNCTIONS (TASK 2)

1. Integration and Technical Management

Support equipment management meetings held regularly with representatives of SNPO-C, WANL, ACFI, NTO/E-MAD, and NTO/R-MAD, provided overall program planning, technical guidance, coordination of support-equipment requirements, hardware fabrication and delivery status, and establishment of appropriate action items.

Coordination was maintained with appropriate REON organizations, SNPO-C, SNPO-N, NTO, WANL, ACFI, LASL, and various subcontractors to insure the proper integration of support equipment activities with program objectives.

Numerous WANL functional requirements and design criteria for NRX/EST, NRX-A5, NRX-A6, and XE-1 support equipment were reviewed. Studies of rescheduled test dates for NRX/EST, NRX-A5, NRX-A6, XECF, XE-1, and XE-2 were conducted to determine cost impacts.

2. GSE Handling and Transport System (2.1)

a. NRX Handling and Transport System

(1) Engineering

Continuous document review and coordination with NRDS and WANL personnel assured proper development of NRX handling and transport equipment and their integration with the facilities and equipment at NRDS.

Design criteria were prepared for the following NRX/EST support equipment:

<u>P.L. Item</u>	<u>Nomenclature</u>
19	Radiation Shield Nut Removal Wrench
20	Hot Bleed Port Removal Fixture

Design of the following NRX/EST support equipment was completed:

<u>P.L. Item</u>	<u>Nomenclature</u>
10	Remote Forward Closure/Nozzle Bolt Removal Tool
14	Hot Bleed Port Removal Tool
17	Remote Nozzle Cooldown Cover (modification to existing item)
18	Remote Instrumentation Removal Kit
19	Radiation Shield Nut Removal Tool
20	Hot Bleed Port Removal Tool
135	Pressure Vessel Stand (modification to existing item)
273	Remote Seal Manifold Cutter (modification to existing item)
504	Remote Propellant Line Handling Fixtures
506	Turbine Inlet Line Elbow Holding Fixture
923	Remote Thrust Chamber/Reactor Disassembly Fixture
924	Stand, Thrust Chamber/Reactor Disassembly Fixture

Design was completed on the following NRX-A5 support equipment:

<u>P.L. Item</u>	<u>Nomenclature</u>
21	Tool, Bolt Removal, 0.812-in., Remote
22	Socket, Impact Wrench
137	Fixture, Nozzle Examination, Remote (modification to existing item)

The operational support plan (OSP) for NRX-A6 was issued.

(2) Fabrication

Fabrication was completed on the following NRX/EST support equipment:

<u>P.L. Item</u>	<u>Nomenclature</u>
10	Remote Forward Closure/Nozzle Bolt Removal Tool
14	Hot Bleed Port Removal Tool
17	Remote Nozzle Cooldown Cover (modification to existing item)
18	Remote Instrumentation Removal Tool Kit
19	Radiation Shield Nut Removal Tool
20	Hot Bleed Port Removal Tool
135	Pressure Vessel Stand (modification to existing item)
273	Remote Seal Manifold Cutter (modification to existing item)
504	Remote Propellant Line Handling Fixtures
506	Turbine Inlet Line Elbow Holding Fixture
923	Remote Thrust Chamber/Reactor Disassembly Fixture
924	Stand, Thrust Chamber/Reactor Disassembly Fixture

Fabrication was completed on the following NRX-A5 support equipment:

<u>P.L. Item</u>	<u>Nomenclature</u>
21	Tool, Bolt Removal, 0.812-in. (13/16), Remote
22	Socket, Impact Wrench
137	Fixture, Nozzle Examination, Remote (modification to existing item)
135	Pressure Vessel Stand

b. Engine Handling and Transport Systems

(1) Engineering

Operational support plans for XECF and XE-1 (Volume 1) were issued. Volume II of the XE-1 support plan, Provisioning List and Schedule, was revised.

The design status of the XE support equipment at the end of the contract year was as follows (the symbol "X" denotes completion):

<u>P.L. Item</u>	<u>Nomenclature</u>	<u>Design Criteria</u>	<u>Design</u>
4000	Stand, UTS/TPA Assembly	X	X
4008	Stand, External Shield	X	X
4009	Lifting Fixture, External Shield	X	X
4021	Stand, Engine Assembly	X	X
4027	Stand, UTS/TPA Module Storage	X	X
4049	Covers, Fluid Line, Remote	X	X
4059	Platform, Maintenance, ETS-1	X	5%
4087	Lifting Device, Turbopump Assembly	X	X
4088	Closure, Engine Nozzle	X	X
4094	Stand, PVARA	X	X
4095	Cover, Auxiliary Duct, ETS-1	X	X
4099	Stand, Engine Holding	X	X
4100	Dust Cover, Upper Thrust Structure Assembly	X	X
4101	Lifting Device, Collar, Line Shielding	X	X
4103	Kit, Guides, Flange, Fluid Lines	X	X
4104	Impact Wrench Assembly	X	X
4105	Remote Line Alignment Clamp	X	X
4107	Actuator, Nozzle Closure	X	X
4111	Stand, External Shield Ball Loading	X	X
4112	Tool, UTS/TSA Nut Removal, Remote	X	X
4115	Guides, Control Drum Drive Shaft Housing	X	X
4116	Fixture, Lifting, XE Lower Module	X	X

<u>P.L. Item</u>	<u>Nomenclature</u>	<u>Design Criteria</u>	<u>Design</u>
4117	Coupling Device, 6.50 cc Hex.	X	10%
4118	Coupling Device, 7.62 cc Hex.	X	10%
4119	Coupling Device, 9.00 cc Hex.	X	10%
4120	Coupling Device, 7.75 cc Hex.	X	10%
4121	UTSM/TSA Coupling Device, Remote	X	10%
4122	Stand, Engine Reassembly, Remote	X	25%
4123	UTSM Shield Nut Actuation Device - Remote	X	10%
4408	Fixture, Retention, Central Core Poison Wire	X	X
4701	Adapter, Handling, Thrust Structure (Modified)	-	X
4708	Platform, Maintenance, Engine	X	5%
4746	Sling, Test Stand Adapter	X	X
4749	Fixture, Fluid Line Handling, Remote	X	X

A contract was awarded for the design and fabrication of P.L. items 4117, 4118, 4119, 4120, 4121, and 4123. The estimated delivery date is 2 February 1967.

During development of the remote assembly design aid (RADA), several items of support equipment were provided for development testing. These include:

<u>P.L. Item</u>	<u>Nomenclature</u>
4099	Stand, Engine Holding
4103	Kit, Guides, Flange, Fluid Lines
4104	Impact Wrench Assembly
4027	Stand, UTS/TPA Module Storage

As a result of testing, it was determined that separate wrench assemblies would be preferable to a single remotely adjustable impact wrench assembly (P.L. 4001.) It was also determined that the clamping mechanism on the flange guides (P.L. 4103) should be designed to operate by manipulator

mechanical grip pressure instead of rotary actuation. In this way, a single manipulator could operate the clamping mechanism: thus, an additional tool to support the flange guide would not be necessary during remote removal. P.L. items 4103 and 4104 were redesigned to facilitate remote operations.

The post operative cell material transfer system (POCMTS) drawings, equipment, specification, acceptance test specification, installation specification, spare parts list, factory acceptance test procedure, end-item documentation, final acceptance test procedure, and operation and maintenance instructions were prepared.

Project and design liaison and coordination were accomplished for POCMTS fabrication, factory acceptance testing, shipment, installation, checkout, and final acceptance testing. Drawing changes determined to be required during testing, installation, and checkout were incorporated. Preparation of the final POCMTS end-item report was initiated.

Corrective action was taken on the overhead positioning system (OPS) and floor mounted handling system (FMHS) discrepancies noted during acceptance testing. The final OPS and FMHS end-item reports were issued.

Design was completed of the following E-MAD equipment modifications: (1) incorporation of "harmonic" drive units into the FMHS carriage and dolly-drive trains; (2) increasing the load capacity of the OPS floating head load readout system to 42,000 lb, and (3) incorporation of a gripper actuator into the upper thrust-structure positioning head to interface with the OPS auxiliary manipulator.

The FMHS and OPS spare parts lists were issued, and the FMHS equipment specification was revised to reflect design changes.

A complete stress analysis of the OPS floating head structure was conducted. This resulted in the replacement of standard bolts in the jack struts with high-strength bolts to achieve a 42,000 lb load capacity.

Operation and maintenance instructions and factory acceptance test procedures for the OPS thrust structure positioning head were completed.

Project and design liaison and coordination were accomplished for the final assembly, factory acceptance testing, and shipment of the OPS Thrust Structure positioning head and stand. Required end-item documentation was prepared to accompany these items to NRDS.

(2) Fabrication

The fabrication status of XE support equipment at the end of the contract through the year was as follows (the symbol "X" denotes completion):

<u>P.L. Item</u>	<u>Nomenclature</u>	<u>Fabrication (% Complete)</u>
4000	Stand, UTS/TPA Assembly	X
4008	Stand, External Shield	X
4009	Lifting Fixture, External Shield	X
4021	Stand, Engine Assembly	X
4027	Stand, UTS/TPA Module Storage (2)	X
4049	Covers, Fluid Line, Remote	X
4059	Platform, Maintenance, ETS-1	0
4087	Lifting Device, Turbopump Assembly	X
4088	Closure, Engine Nozzle	X
4090	Spacer, Installation, TSA (Modification)	X
4094	Stand, PVARA (2)	X
4095	Cover, Auxiliary Duct, ETS-1	70%
4099	Stand, Engine Holding (2)	X
4099	Stand, Engine Holding (1)	80%

<u>P.L. Item</u>	<u>Nomenclature</u>	<u>Fabrication (% Complete)</u>
4100	Dust Cover, Upper Thrust Structure Assembly	X
4101	Lifting Device, Collar, Line Shielding	X
4103	Kit, Guides, Flange, Fluid Lines	X
4104	Impact Wrench Assembly	X
4105	Remote Line Alignment Clamp	X
4107	Actuator, Nozzle Closure	X
4111	Stand, External Shield Ball Loading	X
4112	Tool, UTS/TSA Nut Removal, Remote	0
4115	Guides, Control Drum Drive Shaft Housing	X
4116	Fixture, Lifting, XE Lower Module	X
4117	Coupling Device, 6.50 cc Hex.	0
4118	Coupling Device, 7.62 cc Hex.	0
4119	Coupling Device, 9.00 cc Hex.	0
4120	Coupling Device, 7.75 cc Hex.	0
4121	UTSM/TSA Coupling Device, Remote	0
4122	Stand, Engine Reassembly, Remote	0
4123	UTSM Shield Nut Actuation Device, Remote	0
4408	Fixture, Retention, Central Core Poison Wire	X
4701	Adapter, Handling, Thrust Structure (Modification)	X
4708	Platform, Maintenance, Engine	0
4746	Sling, Test Stand Adapter	X
4749	Fixture, Fluid Line Handling, Remote	X

New wheels (with oversize flanges to provide smooth crossings at rail cut-outs) replacement 1/2 hp motors, "harmonic drive" units, and associated drive-train components were procured and installed on the FMHS carriage and dolly. Load distribution pads were fabricated and installed on the FMHS turntables and positioning head stand.

Replacement bolts for the OPS floating head jack struts and a range-change unit for the floating head load readout system were procured and installed.

A contract was awarded to a vendor for fabrication of the remote UTS/TSA nut removal tool (P.L. 4112). The estimated delivery date is 27 December 1966.

c. Engine Installation Vehicle (EIV) Manned Control Car (MCC),
and Locomotive

(1) Engineering

Designs were completed for the lateral and azimuth carriage, TV/manipulator booms, engine dust cover, the engine nozzle closure, and associated controls. The MCC cab door, emergency breathing system, the EIV vertical carriage upward force limiting device, EIV inching drive system, and the EIV tower cut-out were evaluated and modifications made to the equipment. Development testing of the weight and envelope mockup (WEMU) of the X-engine was conducted. MCC/EIV acceptance tests that could be conducted at Sacramento were performed.

The MCC and EIV equipment specifications were revised and published to reflect the proposed equipment changes. The acceptance test procedures for the MCC, EIV, MCC/EIV, and the integrated MCC/EIV/locomotive were issued. The MCC and EIV disassembly plans, receiving and inspection procedures, and the reassembly plans were issued. Preparation of the MCC/EIV operating and maintenance instructions was initiated.

(2) Fabrication

Fabrication, installation, and checkout of the lateral and azimuth carriage, TV/manipulator booms, engine dust cover, engine nozzle closure, and the associated controls were completed.

The MCC was painted, and the EIV partially disassembled and painted: EIV accessories were shipped to NRDS on 29 August 1966. The MCC and EIV were disassembled and shipped to NRDS on 9 September 1966, arriving at the test site on 20 September 1966. The simulated engine test stand-1 (SETS-1) arrived at NRDS on 22 September 1966. Reassembly and checkout of the MCC were completed and integration of the MCC and locomotive begun. Reassembly of the EIV at NRDS was initiated.

3. GSE Checkout and Test System (2.2)

a. NRX Checkout and Test Systems

(1) Engineering

Coordination and document review with NRDS and WANL was provided to assure proper development of NRX checkout and test equipment and its integration with NRDS facilities and equipment.

Design of P.L. 456, modification kit, nozzle throat plug, was completed. The kit provided the capability of performing remote leak checks of the NRX/EST unit at Test Cell "A". To improve NRX-A5 sealing integrity, design of modifications to P.L. 475, reactor/pressure vessel assembly pressure test closure was completed.

(2) Fabrication

The modification kit, nozzle throat plug (P.L. 456) was fabricated and delivered to NRDS. Modifications to the reactor/pressure

vessel assembly pressure test closure (P.L. 475) were completed and the item delivered to WANL.

b. Engine System Checkout and Test

(1) Engineering

Criteria for the X-engine functional valve and leak test set were rewritten to include a pressurization source. Design of the set has been completed and the drawing package approximately 90 percent completed.

Design of the electrical test set, (P.L. 4401) was completed, based on the use of the WANL supplied car wire tester and transducer test set. The drawing package was approximately 90 percent completed at the end of the contract year.

The concept for checkout of a "hot" X-engine after installation of a new UTS assembly was defined and incorporated into the design criteria for the adapter kit, checkout, remote (P.L. 4043). Design of the kit was initiated. The design of the kit, closure, engine pressure testing, (P.L. 4404) was completed.

A helium leak detector has been ordered. Design was processed to include a Remote Interface Adapter and Readout Units (P.L. 4402).

Criteria and a purchase specification were prepared for the electrical simulator (P.L. 4409) and submitted to prospective vendors. Evaluated of proposals was begun.

(2) Fabrication

All components of Items 4400 and 4401 were on order at the end of the contract year and, with the exception of some long-lead items,

were received at Aerojet-General Nucleonics. Fabrication of these items was started. Fabrication of Item 4404, kit, closure, engine pressure testing (P.L. 4404) also was initiated. The closure, turbine exhaust nozzle (P.L. 4108) was fabricated and acceptance tested.

c. ETS-1 Test Stand Control System and Test Simulator System
(2.2.7)

(1) Coordination

Project guidance/direction for the technical coordination of all system and schedule requirements between REON, NTO and WANL was a continuous effort for REON TSCS Projects. Major activities are summarized as follows:

Interface meetings were held at Sacramento to resolve signal interfaces between WANL and REON. Inputs that were agreed on were incorporated into the TSCS wiring list interface package.

The engine signal interface to the top shield was jointly defined by XE/TSCS Projects representatives and pin assignments were completed.

TSCS projects obtained the facility information necessary to define the TSCS interface to the junction box termination level.

REON, NTO and WANL representatives agreed to shift the location of the test stand nuclear instrumentation detectors from Shield 1 to Shield 2, eliminating the need for disconnection of the system after the end-to-end checkout of the TSNI to enable entry of the engine assembly into the test stand.

The conceptual drawing package was updated to incorporate the latest system interface and design concepts since the previous design

review. The conceptual drawing package was then transmitted for review prior to the TSCS design review. The review was held on 17 and 18 November 1965 at Aerojet, Sacramento, with SNPO-C, NASA-WOO, WANL, NTO and REON represented. The agenda consisted primarily of changes to the TSCS/ECS design concepts since the 10-11 June review. Major areas covered were: program plans and problem areas; ECS changes; test stand nuclear instrumentation; signal conditioning system; top assembly and checkout plan; interface controls; process control system; test simulation system; and checkout system and training. All changes presented at this review were approved by SNPO-C, and all design changes reflected the consensus among REON, WANL and NTO representatives.

Meetings were conducted with NTO representatives to resolve training requirements required for the operation of the TSCS/ECS. The training plan was completed and published.

Priorities for the generation of engineering cable termination data for the TSCS were established with NTO. Preliminary information for a portion of the tunnel cable assignments was given to NTO to facilitate initiation of work on cable terminations at the earliest possible date. Final and complete cable termination data were then transmitted to NTO.

Configuration control requirements and procedures for the TSCS were discussed with NTO. It was agreed that configuration control would remain a REON responsibility and that any changes of the TSCS would require approval by REON TSCS projects prior to implementation.

The System Acceptance Test Plan for the TSCS was completed and transmitted to SNPO-C for review and comment. The NRDS portion of the plan was coordinated with NTO and published.

NTO engineers and technicians were integrated into the Sacramento TSCS checkout activities to provide them with on-the-job training, familiarizing them with the equipment at the time of delivery. NTO personnel were actively involved in acceptance test procedures to be used for buyoff of the process system portion of the TSCS.

A detailed listing of all hardware to be shipped to NRDS has been made to assist NTO in their planning for installation of TSCS equipments.

(2) TSCS Design

The detailed design of the TSCS was completed and TSCS projects personnel performed liaison duties in conjunction with fabrication. Aerojet REON fabrication drawings were continuously updated to show the as-built configuration.

(3) TSCS Fabrication

Fabrication of the test stand control system was completed at the Von Karman Center. The major portion of fabrication included 23 panels, 15 chassis, and 11 racks. In addition, six racks for the signal conditioning system and Racks 66 and 67 for the process control system were shipped in advance of the original due dates to assist NTO in performing early installation and cable hookup of this equipment.

Figure 110 shows an overall perspective of the five operator consoles used to operate the test stand control system; Figures 111 through 115 show the individual consoles for the chief test engineer, assistant test engineer, lead reactor engineer, test stand engineer, and assistant stand engineer.

Figure 116 shows the setup panel for the power monitor, override and bypass, SCRAM and bypass, and the simulate panels. Figure 117 shows Racks 63, 64, 65, and 68.

Figure 118 shows the commercial Brush recording equipment that will be delivered with the TSCS.

Figure 110
Test Stand Control System Consoles

Figure 111
TSCS Test Stand Engineer Console

Figure 112

TSCS Assistant Stand Engineer Console

Figure 113

TSCS Chief Test Engineer Console

Figure 114
TSCS Assistant Test Engineer Console

Figure 115
TSCS Lead Reactor Engineer Console

Figure 116
Setup Panel

Figure 117

Racks 63, 64, 65, and 68

Figure 118
Brush Recording Equipment

(4) Test Simulation System (TSS)

The test simulation system procurement specification, AGC-90073, was completed and published. The TSS subcontract was awarded to Electronic Associates Inc. TSCS personnel conducted further technical meetings with EAI to resolve the selection of alternate hardware and to finalize circuit details.

The test simulation system was acceptance-tested and delivered to Aerojet, Sacramento. This system was integrated with the TSCS and integrated system checks of the engine simulation and cool-down simulations with the process control system portion of the TSCS have been completed.

(5) Signal Conditioning Equipment

The signal conditioning system specification, AGC-90075, was completed. The specification was then reviewed with NTO, WANL and EG&G representatives. Joint agreements were reached on the technical adequacy of the specification for joint procurement against the same document; Aerojet/WANL shares of equipment quantities and types; and quality control requirements to be imposed on the procured equipment.

Approval was granted by SNPO-C to procure the signal conditioning equipment directly from the various vendors. Agreements were finalized with WANL on quantities and types of signal conditioning equipment to be procured by WANL. It was agreed that WANL would procure all of the signal conditioning system amplifiers and EG&G power panels with modified raceways.

Additional economies were effected by a joint REON/NTO review of signal conditioning equipment that would be potentially surplus to the spares required, with a recommended reassignment of this surplus equipment for use by the TSCS Project.

All signal conditioning equipment under procurement by REON from B&F, Sanborn, EG&G and Vidar was completed. The equipment was acceptance tested at the vendor plants, delivered to NRDS, installed, and successfully checked out for use at ETS-1.

(6) Cabling

All cabling being procured by REON for installation by NTO in support of TSCS was delivered to NRDS.

(7) Checkout System

The commercial checkout equipment included in the TSCS checkout systems were procured and delivered to Sacramento. This equipment was installed and successfully acceptance-tested as a part of the TSCS buyoff.

(8) System Checkout TSCS/TSS

The preparation of the TSCS laboratory checkout area was completed. This included installation of power, floor supports for the consoles and racks, and installation of checkout cabling between the computers and the checkout room.

A REON Work-Around plan to facilitate checkout of the TSS without the availability of WANL ECS equipment was developed. This required the breadboarding of a computer model of the ECS on a general purpose computer to exercise the engine simulation portion of the TSS for use with the process control system during cooldown.

The process control system portion of the TSCS was successfully acceptance tested and officially bought-off by SNPO-C representatives. The system was then shipped to NTO where TSCS projects personnel assisted in the installation and checkout of the equipment. The equipment is currently being used in facility experimental plan testing.

The integrated checkout of the TSCS and engine control system equipment was delayed due to lack of WANL equipment (including the deliverable power/temperature controller, drum amplifiers and power supplies, temperature average and reject, log channels, linear channels, and pulse channels).

Therefore, partial acceptance testing of a number of the TSCS subsystems was completed in the last month of contract year 1966, including the following items:

- (a) Analyzer and printer system
- (b) Control room recorders
- (c) Checkout equipment
- (d) Isolation amplifiers
- (e) Safety system
- (f) Nuclear instrumentation

The final subsystems, including the engine control system, nuclear instrumentation, and drum control systems were installed, checked out, and scheduled for completion of buyoff in October 1966. These include the following:

- (a) Engine control system
- (b) Drum control
- (c) Temperature average/reject
- (d) Nuclear instrumentation

Equipment that was partially acceptance-tested in September was also scheduled to be retested in the October 1966 final buyoff.

(9) TSCS Mockup

The TSCS mockup panels and breadboard chassis were updated to reflect current design configurations (with the exception of the WANL-provided panels) and were installed into the mockup consoles. The hookup wiring for the system was completed and tied in with the computer programs.

Training of NTO test operations personnel for the TSE and ASE consoles was accomplished.

4. Instrumentation (2.4)

a. Instrumentation and Installation (2.4.2)

(1) Application

(a) System Analyses and Improvements

A measurement system analysis was conducted to provide an estimate of measurement uncertainties. Since it was impractical to perform end-to-end calibrations for all channels after final instrumentation installation, the data-acquisition channels and transducers were evaluated independently. Then, assuming a randomness in the performance of system components, channel and transducer uncertainty values were combined through a root-sum-of-the-squares (RSS) technique to provide a measurement uncertainty value for each parameter. Transducer performance was known from qualification testing, while system channel uncertainty values were based on a Westinghouse Test Cell A accuracy evaluation test, the results of which were reported in WANL-TME-137.2, Test Cell A Narrow-Band Data Acquisition Accuracy Test Evaluation. All total system uncertainty values were related to the transducer, circuit, and multiplexer and the results were presented in two REON reports: RN-TM-0324, Predicted Measurement Uncertainties of AGC Channels, NRX/EST, and RN-TM-0353, Predicted Measurement Uncertainties, NRX-A5.^{*} Techniques for calculating measurement uncertainties for future tests are being programmed for computer solution.

A study was conducted to determine the magnitude of measurement uncertainties induced in copper-constantan thermocouple circuits by the combined effects of cable splices, wire inhomogeneities, inadequate

^{*} All reports made during CY 1966 are listed in Section 2.4, Instrumentation Reports.

shielding, and line unbalance. The study indicates that copper-constantan channel uncertainties can be significantly reduced by placing the thermocouple reference as close to the measurement junction as environmental conditions permit. This study is presented in REON Report RN-TM-0362, Lead Wire Induced Measurement Uncertainty in Copper-Constantan Thermocouple Circuits When Measuring Liquid Hydrogen Temperatures.

A circuit-shaping technique was developed whereby the measurement uncertainty of platinum resistance-thermometer circuits could be reduced (optimized) over selected temperature ranges. Optimization was accomplished by the use of shunt and series resistors to increase the circuit's sensitivity to temperature variations within a selected measurement range. The ability to optimize the measurement uncertainty is important because the temperature-measurement range of greatest interest, relative to engine performance analysis, is usually less than the channel setup range. Circuit-shaping techniques were successfully used during NRX/EST and NRX-A5 testing.

Philosophy, intent, and procedures were established for determining the ETS-1 instrumentation system accuracy with the Facility Engineering Department. The results are outlined in REON Report RN-S-0241, ETS-1 Data Acquisition System Accuracy Test Specification. A preliminary accuracy test was monitored to ensure conformance to the test specification and to provide technical assistance.

Thermocouple temperature-data degradation occurred during NRX-A3, NRX/EST, and NRX-A5 because of a drift in the effective reference temperature of test-car-mounted thermocouple reference junction units. The unit used during NRX-A3 and NRX/EST for tungsten 5% rhenium-tungsten 26% rhenium thermocouples drifted as a result of insufficient cooling capacity, radiation damage to controllers, and mechanical difficulties. The unit employed during NRX-A3 and NRX/EST for base-metal thermocouples (copper-constantan and chromel-alumel) drifted because of the radiation sensitivity of controllers within the unit. However, controlled tests were made of the base-metal thermocouple reference unit

in a remote and shielded location, the additional cable transitions would increase the channel-measurement uncertainty. Thus, one reference unit design will be used for all future tests and remote control will be provided until a radiation-hardened thermocouple reference unit is developed.

(b) Special Measurement Techniques and Studies

1 Cable-Cooling Studies

An analysis of the worst-case installation and environmental conditions to be expected on the XE-Engine was completed. Based on this study, a review of cable size, type, and mounting provisions was conducted and preliminary cable-cooling requirements were established. The review showed that a reduction in cable size combined with suitable heat-sinking of the cable in high radiation regions would meet cooling requirements. Cooling requirements are dictated by data degradation resulting from loss of cable insulation at high temperatures. Samples of metal-filled polyurethane heat-sink materials for radiation testing on the NRX/EST pressure vessel were fabricated. Post-test results indicated that extensive effort will be required to yield satisfactory resin-base formulations. Therefore, a study is being made to determine the feasibility of applying flame-sprayed aluminum, and preliminary results indicate that the flame-spray technique will provide a structurally sound bond. Heat-transfer studies are being conducted to determine the heat-sink capabilities of the flame-sprayed aluminum configuration. This method appears to be acceptable based on existing cooling requirements.

2 Pressure Measurements Using the Infinite-Line Technique

An analysis of NRX-A3 engine nozzle-pressure data indicated that existing flush-mounted pressure transducers will not meet NRX/EST control system accuracy requirements. It became necessary to station available pressure transducers behind radiation shields and couple them to the pressure source with an infinite-line pneumatic tube. The infinite-line technique

provided a method for improving the normally inadequate frequency response of pressure-measurement systems having pneumatic tubing by reducing acoustic resonance effects. Both theoretical and experimental techniques were used to confirm the adequacy of the infinite-line measurement technique. Then, with a computer program written by LASL, infinite-line configurations were selected and successfully used during the NRX/EST and NRX-A5 test series. A report describing the infinite-line measurement technique is being prepared.

3 NRX-A5 Pressure Transducers

Signal-conditioning-module design requirements were defined for interfacing the Test Cell A data system with flush-mounted NRX-A5 evaluation pressure transducers. These transducers have nonstandard excitation voltages and bridge-resistance values. Circuitry was designed, commercially available components specified, and parts were ordered to make such transducers compatible with the Test Cell A data system. Test Cell A zero-balance and calibration circuitry were used to minimize special handling and procedures.

4 Turbopump-Assembly Displacement Measurement

Measurement of TPA displacement during the NRX/EST test was required to cross-correlate the information obtained during TPA testing at Sacramento and NRDS. To fulfill this requirement, two systems were designed and integrated into the Test Cell A data acquisition system. One system displayed double-amplitude TPA displacement information from two selected channels on individual meters in the Test Diagnostic Center (TDC). The displayed information was the complete motion as sensed over the frequency range of 60-2500 Hz as seen by an inertial frame of reference. The second system, also displayed in the TDC, required the manual selection of either of the above-mentioned channels and then presented the g-level output as a function of frequency once a second. The latter system, called the vibration spectrum analyzer, enabled on-line analysis of specific frequencies while monitoring the remaining spectrum for signs of component degradation.

5 Modes-of-Failure Analysis

A modes-of-failure analysis for instrumentation of NRX-A5 was completed and submitted for inclusion with the integrated modes of failure report on this engine.

6 E/STS-2/3 Design

The E/STS-2/3 conceptual design was reviewed and comments were forwarded to the facility engineering department.

(2) Installation

(a) NRX/EST Instrumentation

Delivery of the instrumentation kit to NTO was completed on 21 October 1965. Equipment was also furnished for two modification kits for NRX/EST. Two hundred eleven measurements were made by Aerojet. Six as-built drawings were prepared and released to document modification kits and changes made in the field.

REON Report RN-S-0307, NRX/EST Post-Test Instrumentation is being published.

(b) NRX-A5 Instrumentation

Basic parts lists were prepared and issued for NRX-A5 to document the basic kit and subsequent changes, which included two modification kits. Seventy-nine measurements were made by Aerojet of the NRX-A5 test. Four new instrument drawings, three bracket/assembly drawings, and eight arrangement drawings were generated for NRX-A5 use. All other drawings used were the same as those made for previous engines.

All transducers and supporting equipment for the NRX-A5 instrumentation kit were delivered to NTO in early April.

Engineering support was provided to NTO to handle special mounting and checkout problems. Because of the limited instrumentation on NRX-A5, this support was provided on a part-time rather than full-time basis. Equipment needs were determined, the required equipment obtained, and the procedures were written and distributed for NRX-A5 post-disassembly tests.

Instrumentation specifications were written covering NTO receiving inspection, installation, and checkout procedures and were submitted for incorporation into the engine test specification. Instrumentation procurement status reports covering NRX-A5 were submitted to SNPO-C on a monthly basis through April 1966. NRX-A5 Post-Test Instrumentation Report (RN-S-0330) is being prepared.

(c) NRX-A6 Instrumentation

The basic parts list has been generated, revised, and upgraded, reflecting input through 12 August. Four new instrument drawings, four bracket/assembly drawings, and four arrangement drawings were generated for NRX-A6. All other drawings used were the same as those made for previous engines.

Procurement had been initiated for the complete NRX-A6 instrumentation kit. Approximately half of the kit had been delivered to NTO by the end of CY 66. The balance is expected to be delivered to NTO by November 1966.

Thermal analyses were performed for all applicable instruments, and mounting hardware was designed and provided accordingly.

Instrumentation specifications were written covering NTO receiving inspection, installation, and checkout procedures and were submitted for incorporation into the engine test specification. Instrumentation procurement

status reports covering NRX-A6 have been submitted to SNPO-C on a monthly basis since March 1966.

(d) XECF and XE-1 Instrumentation

Basic parts lists for XECF and XE-1 and one preliminary basic parts list for XE-1 modification kit had been completed by the end of CY 66. Changes will be required because of bracket modifications that are necessitated by a redefinition of the upper thrust structure (UTS). A recent thermal analysis indicated that liquid-nitrogen temperatures will be reached in the UTS. These temperatures are lower than were expected when the bracketry was originally designed.

Instrument selections were completed except for instrumentation to make an additional measurement that was added during the final week of CY 66. This new instrument is an engine compartment microphone that will be used to measure the engine compartment sound-pressure level. A basic microphone has been selected but swaged cable must be added before a model number can be established and procurement initiated.

An improved charge amplifier has been selected for XE-1 accelerometer and microphone measurements and procurement has been started.

Twenty-seven component specification changes were generated. These included new specifications, the addition of new slash sheets (an additional sheet for a basic specification that specifies certain requirements peculiar to a particular instrument and its intended end use) and the updating of other specifications. The additional slash sheets were required because of the switch to a 150°F thermocouple temperature-reference junction at ETS-1 and to satisfy the 10-volt dc excitation and shunt calibration capability required at ETS-1 for strain-gage pressure transducers and accelerometers.

Instrumentation specifications were written covering NTO receiving inspection, installation, and checkout procedures and were submitted for incorporation into the engine test specification.

Brackets were designed for all applicable instruments. However, because of a redefinition of the UTS environment already described, the shield-mounted pressure-transducer brackets are being redesigned.

Thermal analyses of accelerometers, brackets, and other items have been partially completed.

One installation drawing has been started that pertains to installation of the instruments in the test stand adapter (TSA).

Orders have been placed for 90% of the instrumentation kit for XECF and XE-1. It is estimated that 40% of the kit will have been delivered to NTO by 30 September, and the balance by the middle of December. Instruments for XECF that are being borrowed from Liquid Rocket Operations are available in stores.

Instrumentation procurement status reports covering XE-1 and XECF have been submitted to SNPO-C on a monthly basis since June and July, respectively.

(e) XE-General

The requirement for an engine (shield)-mounted temperature reference junction was generated and coordinated with the Pace Company. The order was placed and delivery was scheduled for the end of September.

(f) XECF and XE-1 Electrical

Electrical cable installation drawings for the TSA and UTS were initiated. The electrical checkout procedures were reviewed and approved.

The electrical cable drawings for XECF and XE-1, which included 76 individual component drawings and one process specification, were completed.

Purchase orders for the XE electrical hardware have been placed. Fabrication of the XECF hardware was 20% complete at the close of CY 66.

(g) NES Duct Instrumentation

The NES duct instrumentation task was near completion, with the shipment of the balance of the permanent instrumentation kit to NTO during the third quarter of CY 66. All that remains is the coordination and checkout of the installation, which should be completed during the first quarter of CY 67.

(h) Inventories

A total of 564 instrumentation components and various quantities of 384 different items of mounting hardware were reviewed. Parts were allocated to: future assigned engine kits; potential future engine kits; existing or potential development tasks; assigned LRO/NT0/WANL NERVA tasks; and to salvage.

This action reduced inventories by removing obsolete parts from stores, correspondingly reducing storage costs. Items peculiar to the instrumentation-development effort were moved to a low-cost storage area for ready accessibility when needed.

b. Qualification Testing (2.4.5)

(1) Engine-Mounted Control Pressure Transducer

A test plan was written for the NRX-A5 pressure transducer qualification test of four candidate control pressure transducers having cable connectors. A schematic block diagram was generated for the design of the pressure-stimulus system and pressure-reference system of this test.

NRX-A5 Qualification Test Specification for Engine-Mounted Pressure Transducers was written to be incorporated in or used as an addendum to the NERVA Program WANL-TNR-204 NRX-A5 test specification.

Four Statham transducers, Model No. PA812-750-1500-16647 (750 psia units), were used on the qualification test. This transducer has a connector intended for use with an associated right-angle connector for swaged cable attachment. Since high-temperature, right-angle connectors and associated swaged MgO insulated cables were not available for this test, six conductor, shielded-cable assemblies (AGC SCD 299767), manufactured by Physical Sciences Corporation (PSC), were used to connect each transducer to the test - car terminal box.

The qualification test was conducted in June 1966, during the NRX-A5 tests. Test records indicate more $\pm 100\%$ full-scale deviations from the reference pressure transducer's output signal during EP-III and EP-IV. Temperature measurements of the transducers indicate cable connector temperatures of 900°F and more. A Statham transducer of exactly the same design used on NRX-A5 was connected to approximately ten feet of PSC 39038-2 cable (the same cable type used on the NRX-A5 test) in the REON Research Laboratory. Approximately 16 in. of cable loop was placed in an oven, and the remaining cable and transducer were kept at room temperature. As the 16-in. loop of cable was heated, the insulation resistance and transducer output were recorded at 0 psig. At 900 to 1000°F an apparent transducer zero shift occurred, changing from 1.9 mv to 500 mv and then

to -20 mv, at which point the circuit output began to change in a positive direction again. The insulation resistance from conductor to shield dropped as low as 0.1 megohm during this test. The transducers have a nominal full-scale output voltage of 100 mv at 25-vdc excitation. Another Statham transducer of exactly the same type, with its associated connector and cabling, was connected in parallel with approximately 10 feet of PSC 39038-2 cable in the REON Research Laboratory. The PSC cable connector and approximately 1 foot of cable were heated in an oven, while the remaining cable with the Statham transducer and its connecting cable were at room temperature. Again the circuit output was monitored at 0 psig. At 900 to 1000°F the circuit output changed from 3.3 mv to greater than 200 mv and then to -125 mv, at which point the output began to change in a positive direction again. These tests were conducted to simulate suspected cable-connector conditions that occurred on the NRX-A5 test. The transducer remained at room temperature and constant pressure throughout these tests. The apparent transducer zero shifts observed were caused by the variation in cable insulation resistance with temperature shunting the transducer bridge circuit. This condition is not expected with qualified integral lead-MgO insulated cable planned for use in future engine tests.

A NRX-A5 qualification test report is being written. When two of the NRX-A5 qualification test transducers are delivered for post-testing, the NRX-A5 qualification test report will be completed.

(2) Metallic-Sheathed Cable

Qualification evaluation test plans and procedures were generated to qualify additional metal-sheathed instrumentation cables. These plans and procedures will be issued in the form of a qualification evaluation test specification during the first quarter of CY '67. Thermocouple cables and signal cables were procured from three suppliers that meet the Aerojet specifications and the equivalent supplier specifications. Cable qualification evaluation tests and a report are expected to be completed by mid CY '67.

c. Instrumentation Development (2.4.6)

Development progress reports were submitted to SNPO-C on a monthly basis. A preliminary program plan was submitted to SNPO-C in July. A complete list of all reports made during CY 66 is presented at the end of this section.

(1) Thrust-Chamber Temperature Probes

Major accomplishments in the CY 66 thrust-chamber thermocouple development program were:

(a) Verification that carbon contamination was a significant contributor to erratic thermocouple output.

(b) The development of a tantalum-carbide-coating technique to overcome the problem of carbon contamination.

(c) The design and fabrication of a thrust-chamber thermocouple having better accuracy and repeatability and less lead transition bend stresses than the probes now in use.

(d) Performance of simulated rocket condition tests in a plasma-arc facility, called the hyperthermal environmental simulator (HES), that partially verified calculated correction factors, for probe heat radiation and the probe time constant, at operating conditions.

(e) Improvement of the laboratory high-temperature capabilities by setting up a 5500°R clean-atmosphere, tungsten-resistance furnace and an automatic optical pyrometer that has four times the accuracy of the previously used pyrometer.

(f) Development of a simple, reliable reference-junction termination for use with sheathed thermocouples.

(a) Carbon Contamination

By the end of CY 65, carbon (in the calibration furnace as vapor from the heater element and in the engine as hydrocarbon) was believed to cause approximately a 1% loss of signal in a tungsten-rhenium thermocouple operating above 4000°R for 1 hour or more. This loss appeared to stop after about an hour, so that drift during an engine test could conceivably be eliminated by preseasoning the probes for an hour in a furnace having a carbon atmosphere. Subsequent furnace tests in a methane-helium atmosphere have shown, however, that what appeared to be a stoppage in drift was the onset of erratic operation. Output changed up to 400°R after repeated cycling to 4500°R.

Two techniques were considered to overcome this carbon-contamination problem. One was to investigate the mechanisms by which signal loss and erratic operation may occur, so that the design might be altered to eliminate the effect. The second approach was to find a coating that would prevent carbon from penetrating the probe.

Attempts to identify the contamination mechanism produced no conclusive results. The most plausible hypothesis is that the thermocouple alloys change from specific binary alloys of tungsten and rhenium to tungsten-rhenium-carbon mixtures of unknown electrical characteristics.

A protective coating consisting of a flame-sprayed layer of tantalum 10% tungsten (Ta 10%W), 4 mils thick, produces an impervious carbide layer when exposed to carbon. After carburization has occurred the layer prevents further carbon penetration, at least up to 4500°R. Probes coated with Ta 10%W and furnace tested in a methane-helium environment showed little or no drift or erratic behavior.

To test for hydrogen compatibility, a coated probe was heated to 4500°R in pure hydrogen, held at this temperature for 30 minutes, then cooled to room temperature in a total elapsed time of 3 hours. This probe showed no visible or electrical change.

Based upon the success of these tests, the four probes used on NRX-A5 were coated with Ta 10%W to eliminate possible carbon contamination effects. Readings obtained from these probes agreed within $\pm 75^{\circ}\text{R}$ of their average temperature throughout the NRX-A5 test series. This agreement is the closest achieved in any of the reactor tests.

(b) REON-Built Development Probe

Figure 119 shows the REON-built development probe. The main external change from the standard vendor-built probe (AGC SCD 1010306) is the curved housing for bringing the lead out at a 90-degree angle to the probe stem rather than the square-cornered transition of the standard probe. This curved transition eliminates the high stresses produced on the brittle W 5%Re thermocouple lead by the sharp right-angle bend. In the NRX/EST, two of the three tungsten-rhenium thermocouples, AGC SCD 1010306, used in the turbine inlet line open-circuited in this region. Failure of the leads in the sharp-corner transition occurred because of overstressing, which resulted from vibration levels that were significantly greater than had been predicted. The curved transition eliminates most of this prior stressing.

The major internal improvements result from insulator cleanliness, insulator arrangement, and the formation of the hot sensory junction. In furnace calibration tests this thermocouple showed a 2% higher emf output than the vendor-built probes at all temperatures and measurement repeatability within 20°R at 4500°R, compared with 40°R for the vendor probes at the same temperature.

Figure 119
Thermocouple Developed by REON Program

To achieve a 5000°R operational probe, this development probe was heated from 4834 to 4904°R for 1 hour in the carbon resistance furnace. The emf output signal sensitivity varied from 7.77 microvolts/°R at the starting 4834°R to 7.71 microvolts/°R 1 hour later at 4904°R. This 0.06 microvolt/°R difference is an inherent decrease in sensitivity that occurs at the higher temperature and does not indicate thermocouple degradation.

Having successfully attained 4904°R, the next test involved heating the probe to destruction to determine the upper limit and the mode of its failure. Failure occurred by melting at 5030°R, about 1000°R below the 6108°R melting temperature reported by the Hoskins Mfg. Co. for the tungsten-26% rhenium probe sheath material. Metallurgical tests that were made to determine the cause of the lower melting temperature indicated extensive intergranular melting, similar to that caused by aluminum. Beryllium, from the beryllia insulation (which is similar to aluminum in many respects), could have lowered the melting temperature. A photospectrometer showed that beryllium was present, but the amount exceeded the range of the instrument for beryllium so that a quantitative analysis could not be made. Another possibility is carbon, which was found to be present at about 24 atomic percent. This probe had not been coated with Ta 10%W. Further controlled condition tests are planned to investigate this anomaly.

(c) Simulated Rocket Tests

The hyperthermal environment simulator (HES) was used to test two features of the thrust-chamber thermocouple under conditions that partially simulated those existing in the engine. The first test involved the degree to which the probe is below gas temperature because of heat radiation from the probe to a cooled surrounding wall. In the rocket engine the probe is in hot, virtually transparent hydrogen and radiates on about 80% of the solid-view angle to walls that are cooled by liquid hydrogen. This heat loss has been calculated to lower the temperature of the probe below that of the gas about 60° at 4500°R. In the HES, this correction was measured by operating the probe in hot gas surrounded by cooled walls and then with a hot reflective shield, which

prevented radiated heat loss. When corrected to actual engine conditions, this measured radiation correction agreed within 10° of the calculated correction.

The second test involved measuring the response of the thermocouple for various step changes in the power to the HES and noting the time required to reach 63% of the final change. When corrected to actual engine conditions, the measured time constant was 0.5 second. This value agrees with the 0.5 second time constant obtained earlier by plunging the probe into molten lead. Improvements are now being made in the HES to more accurately duplicate engine conditions so that no corrections will be required.

(d) Improved Laboratory Capabilities

Two new pieces of laboratory equipment were installed and put into use. Most important is an Astro Industries tungsten-resistance furnace, Model 2570 WM, that will eventually enable testing to 5500°R in vacuum, hydrogen, nitrogen, and carbon-free inert atmospheres. As yet, 5500°R has been achieved only in the vacuum condition because of excessive heat losses when gases are present. With gases present, 5000°R is about the current upper limit.

The second piece of laboratory equipment is a Leeds and Northrup automatic optical pyrometer, Model 8641. This instrument enables temperature readings within $\pm 5^\circ\text{R}$ from 2500 to 500°R , compared with about $\pm 20^\circ\text{R}$ for the micro-optical pyrometer formerly used.

(e) Cold Junction for Swaged Thermocouples

A schematic drawing of the swaged thermocouple cold junction is shown in Figure 120. The essential parts are three injection-molded polycarbonate pieces. Two of the pieces are a split cylinder that properly spaces the thermocouple wires relative to the swaged cable and the copper

Figure 120
Schematic of Swaged Thermocouple Cold Junction

extension wires. The third piece is a thimble that encloses and protects the wire-separation assembly. The entire unit is sealed by dipping it in a polycarbonate solvent such as methylene chloride. Further details are presented in REON Report RN-TU-084, Inexpensive Thermocouple Wire Lead Insulator Design is Highly Reliable.

(2) Vibration Transducers

Analytical studies were conducted to determine methods of improving the performance of piezoelectric accelerometers in an environment with varying temperatures. One approach was the relation between change of charge sensitivity and varying element capacitance as a function of temperature changes. If such a correlation could be established and accurately measured, then it would be possible to correct for a change in the charge sensitivity by measuring the change in sensing-element capacitance. The study concluded that this approach was feasible but would involve additional on-line equipment and laborious manual data reduction methods to correct data for temperature effects. The results of the study are presented in RN-TM-0300, Feasibility Report for a Method of Piezoelectric Accelerometer Temperature Compensation.

Another approach was a method of incorporating a temperature-sensitive ceramic capacitor in the sensing element of the transducer. This method, if feasible, would provide instantaneous temperature compensation during a run and would not involve the use of additional equipment. The results of the study will be presented in RN-TM-0349, Feasibility Report for an Alternate Method of Piezoelectric Accelerometer Temperature Compensation. It was concluded that this approach is feasible and more advantageous than the previous method described.

In January, a redesign of the piezoelectric accelerometer was started. The new accelerometer, like the previous piezoelectric unit, has a lead-zirconate, lead-titanate element operating in the shear mode. The redesign incorporates an integral cable and improved electrical isolation of the sensing element.

Five experimental evaluation accelerometers were built and irradiated around the forward flange of the NRX-A5 vehicle. The data correlated well with data from strain-gage accelerometers located around the same flange. Posttest examinations are being made.

Extensive thermal and design analyses were conducted to determine the best methods of reducing internal thermal gradients. The analyses indicated that a single design could be used at any currently required location on the engine without external cooling during full-power operation. Based on the indications of the analyses, the accelerometer base and mounting-post material was changed to "A" nickel, base height was decreased, post thickness was increased, the temperature compensation range was increased, and the upper limit was decreased. A drawing, a specification, and a calibration sheet were released, and five transducers were procured for laboratory evaluation. To verify the temperatures predicted by thermal analyses, measurements of accelerometer-mount temperatures on NRX-A6 were requested.

REON Report RN-S-0241, NRX-A3 Side-by-Side Radiation Effects Test, describes the results of a radiation-effects test that was conducted concurrently with the NRX-A3 test series, to determine the suitability of various accelerometer designs for nuclear rocket test applications.

(3) Engine-Mounted Control Pressure Transducers

The following work was accomplished during CY 66 to achieve a control pressure transducer that would be accurate to within $\pm 1\%$ of full-scale and that has a frequency response to 16 Hz within ± 3 db of static for all phases of engine runs.

(a) Calibration and Evaluation Testing

Evaluation pressure-calibration tests, as a function of temperature, were made of Statham Model PA812-750-1500 (750-psia units) over the temperature range of -200 to 400°F. During temperature evaluation testing

it was noticed that temperature compensating resistors had been used in all but two of the transducers. Over this 600°F band the best results obtained with the transducers having temperature-compensating resistors were $\pm 2.6\%$ F. S. and $\pm 3.0\%$ F. S., the two transducers without temperature-compensating resistors produced results of $\pm 2.1\%$ F. S. and $\pm 3.8\%$ F. S.

On the basis of these tests, Statham Model PA812-750-1500-16647 transducers (without temperature-compensating resistors) were ordered for evaluation tests and the NRX-A5 qualification test. The best results obtained over the temperature range of -200 to 400°F were $\pm 2.3\%$ F. S. Over the 600°F band the results were encouraging. One transducer was then subjected to acceleration of 5- to 30-g (in 5-g steps) sine vibration over the frequency range of 25 to 2000 Hz at 0 psig and room temperature. There was negligible effect on the transducer output for all three axial positions. This model, with a minor redesign, uses a hub at the outer-center diaphragm surface to improve nonlinearity.

Standard Controls transducers, Model No. 470-2, were calibrated over the temperature range of -200 to 400°F and the best result obtained was $\pm 6.1\%$ F. S. over this 600°F band. This transducer was used on the NRX-A5 test to sense nozzle-chamber pressure. The NRX-A5 data are being reviewed. Misranging problems and possible shunting effects may have occurred because of the low insulation resistance values of the PSC cable (the same type that was used on the NRX-A5 qualification test).

(b) NRX-A6 Designs

As a result of the NRX-A5 engine-mounted pressure transducer qualification test data (Section 2.4.5), the Statham design has been changed to eliminate the problems encountered on NRX-A5. Sixteen Statham Model P812-1-750 pressure transducers, with 30 feet of integral cable, have been ordered for NRX-A6 and for evaluation testing. This transducer design eliminates the connector temperature problems that limit successful transducer performance in high gamma-heating radiation fields and shortens the length of the transducers to 0.80 in. (the previous design was 1.97 in. long). The weight of the transducer has been reduced to approximately 40 gm (weight of the previous design was 70 gm).

Six Standard Controls transducers, Model 470-3, have been ordered with 30 feet of integral cable for NRX-A6. This transducer design eliminates the connector temperature problem, shortens the transducer length to 1.02 in. (the previous design was 1.90 in. long), and reduces the mass of the transducer substantially.

(c) Plum Brook Testing

Test fixtures for Plum Brook test numbers 23R/510 and 23R/511 were calibrated and checked out in the REON research laboratory prior to shipment to WANL, Large, Pa. The tests were completed in June 1966 and the data are being reviewed.

(4) Resistance Temperature Transducers

The objective of the GTR-18 test was to determine the effect of nuclear radiation on platinum resistance transducers at very low temperatures. The effects of different types of radiation on resistivity were investigated. Eleven Rosemount Model 134EB probes were used in that phase of the test. Nine of these probes were modified and contained the following types of shields: two with 0.030-in. cadmium; two with 0.030-in. hafnium; three with 0.015-in. hafnium and 0.015-in. cadmium; and two with 0.015-in. steel. The units with neutron shields also had 0.015-in. steel covers.

The test also included two Rosemount Model 137CJ units, one Temtech Model 1881-2 (furnished by LASL), and six previously irradiated Rosemount units (two 134EB1X, two 134EB2X, one 110AA, and one 134EB).

The reactor was activated 23 June and was shut down 2 July. The elapsed time was 234 hours, with irradiation at full power for 200 hours.

A computer program was developed to reduce the data. A separate table of resistance versus temperature was generated for each transducer and was used to determine temperature degradation. A subroutine for computer plots was obtained. Results show that the shields had no effect on reducing resistivity increase in the transducers. The eleven units in the mechanism-of-damage study phase all had essentially the same temperature degradation. A formal report is being prepared.

NRX/EST data were reviewed and input was prepared for the post-test report. Of the sixteen RTT channels, seven showed intermittent output during various EP's. Several of the units were sectioned, and the failure appeared to occur in the base area where the connecting wires were unsupported.

Nine Rosemount 134JA RTT's were ordered, six of which will be installed on NRX-A6 for development purposes. The sensing elements are identical to those in Model 134EB. The new models contain integral MgO cable, and the cavity in the connector units will be filled with Norton 1055 potting compound. The filling is to provide support to the wires and prevent intermittent behavior at very low temperatures.

(5) Strain Gage Transducers

The GTR-15 data analysis was completed and REON Test Report RN-S-0291 was written and published.

The NRX-A3 data analysis was completed. Measurement uncertainties associated with the NRX-A3 strain measurements were reduced by removing the portion of the uncertainty due to temperature-associated bias errors.

Development of a 0.25-in.-long gage for use in the combined environments at the external surfaces of the vehicle was discontinued because existing measurement requests can be satisfied with the 9/16-in. gage. Work was continued only as required to satisfy unique design and installation requirements for the NRX-A5, A6, and XE-1 engines.

The installation of integral-lead gages in the vicinity of the NRX/EST hot-bleed port proved to be difficult and resulted in the destruction of one gage, because the 1/8-in. cable lacked the flexibility required for routing in the available space. For subsequent engines, the four-conductor, 1/8-in. integral cable was replaced with two 1/16-in. two-conductor integral cables.

The XE measurement requirements include measurement of outer surface strain on the pump-inlet line. Therefore, strain-gage specifications and drawings were revised to enable strain measurements on the outer surfaces of lines containing liquid hydrogen.

NRX/EST test results showed that use of the integral cable had prevented failure due to degradation of insulation resistance. No elements opened during full-power operation, but four elements opened during EP's prior to full-power operation when the outer surfaces reached their coldest temperatures. The design was modified to prevent failure of the elements because of differential expansion of the instrument and the surface of attachment. The strain gage was provided with smaller, more flexible element tubes with built-in strain relief, and the vertical cylindrical bridge completion piece was replaced with a 0.156-in.-OD horizontal-transition piece that contains the bridge connections.

(6) Nozzle-Temperature-Profile Probe

Report RN-S-0297, Concepts of a Thrust-Chamber Temperature Profile Measurement, was completed during the third quarter of CY 66 and is being prepared for publication. Issuance of this document will complete the contractual requirement for this item.

(7) List of Instrumentation Report

Instrumentation reports prepared during the calendar year are listed in Figure 121.

<u>REPORT</u>	<u>TITLE</u>	<u>STATUS</u>
RN-S-0238	Instrumentation Evaluation, NRX-A3 Tests	Released
RN-S-0241	Final Test Report for NRX-A3 Side-by-Side Radiation Effects Test	Released
RN-S-0273	Evaluation of Test Results for Pressure Transducers and Accelerometers, Ground Test Reactor (GTR) Irradiation Test No. 14	Released
RN-S-0291	Evaluation of Test Results for Strain Gages and Pressure Transducers, GTR-15	Released
RN-S-0292	Minutes of First Contract Year Instrumentation Review Meeting	Released
RN-TM-0300	Feasibility Report for a Method of Piezoelectric Accelerometer Temperature Compensation	Released
RN-TM-0324	Predicted Measurement Uncertainties, NRX/EST	Released
RN-TM-0325	Carbon-Resistant Coating for Tungsten- Rhenium Thermocouples	Released
RN-TM-0329	Evaluation and Testing of Engine- Mounted Metal-Sheathed Cable Assemblies	Released
RN-TM-0353	Predicted Measurement Uncertainties, NRX-A5	Released
RN-TM-0362	Lead-Wire-Induced Measurement Uncertainty in Copper-Constantan Thermocouple Circuits When Measuring Liquid Hydrogen Temperatures	Released
RN-S-0297	Concepts for a Thrust-Chamber Temperature-Profile Measurement	In Publication
RN-DR-0078	NRX/EST Leak Measurement System Performance Analysis	In Publication
RN-S-0307	NRX/EST Post-Test Instrumentation Report	In Publication

Figure 121
List of CY '66 Instrumentation Reports

<u>REPORT</u>	<u>TITLE</u>	<u>STATUS</u>
RN-TM-0349	Feasibility Report for An Alternate Method of Piezoelectric Accelerometer Temperature Compensation	Completed and being revised
RN-TM-0355	Experimental REON-Built Thrust-Chamber Thermocouple	Awaiting New Data
RN-S-0330	NRX-A5 Post-Test Instrumentation Report	Being Written

Figure 121
List of CY '66 Instrumentation Reports

5. Ground-Operations Safety (2.5)

a. Safety Analysis and Review

The safety of ETS-1 facility systems was evaluated to assure that system activation could be undertaken without compromising the safety of personnel or equipment. As a result, a number of facility modifications were made and procedural requirements established for XE test operations. An ETS-1 personnel safety control plan was prepared that describes requirements for the control of personnel during all phases of test-stand operation. Modifications were recommended for the safety system (which includes the area surveillance and warning system, criticality monitoring system, radiation monitoring system, and combustible gas and oxygen detection systems).

E-MAD installation and checkout and acceptance testing of systems and components were reviewed to assure safety of operations. An E-MAD facility safety report was initiated that incorporated information obtained from the reviews.

Safety of the as-built EIV-MCC was evaluated, and results were then documented in report RN-TM-0344. Safety recommendations led to design modifications and to the verification of system integrity through operational checkout and testing. Ground-support-equipment designs also were reviewed to assure their conformance to established safety standards and their incorporation of fail-safe features.

NRX/EST testing and disassembly were reviewed and evaluated, and SNPO-C approval was obtained for conduct of the operations. The safety evaluation report, test specifications, and control room operating procedures for the NRX-A5 reactor were reviewed, and SNPO-C approvals were obtained for the assembly, testing, and disassembly of NRX-A5. The instrumentation and safety-circuit backup requirements were established for testing of the integrated nuclear instrumentation system (INIS) during the NRX-A5 series.

Safety of the X-engine system was evaluated, and safety requirements for the design, assembly, checkout, and operation of the system were identified. In addition to the design and operation of the test article itself, the evaluation included engine control, emergency cooldown procedures, and ground support equipment required for XE assembly and handling at NRDS. The resulting recommendations improved the safety aspects of the XE design and test program.

Safety documentation pertaining to WANEF operations, facility modifications, and procedural and limit changes were reviewed. This review, and the modifications to WANEF facilities and operations made as a result of review recommendations, supported the request for SNPO-C approval of WANEF operations. SNPO-C approval for limited FCX reactor operations, extension of the WANEF test-cell fuel-storage rack, and activation of an auxiliary shutdown system for the PAX reactor was obtained during the contract year.

The program for safety auditing of operational facilities became fully functional, and procedures were established for periodic audits of all phases of NERVA safety operations. Six scheduled safety audits of NERVA operations at NRDS and WANL were conducted. A formal, monthly, safety-inspection program was implemented at the Sacramento facilities of REON.

NTO was assisted in the preparation of NTO-A-0027, Documentation and Control for Engineering Operations Conducted at NTO Facilities. This document categorizes all NTO engineering operations and specifies documentation, reviews, and the approvals required for the conduct of each category of operations; it has already demonstrated its effectiveness during ETS-1 activation testing. NTO also was assisted in the preparation of NTO-A-0022, NTO Health and Safety Manual, which establishes both general safety requirements and those applicable to fire protection, industrial hygiene, cryogenic safety, pressurized-system safety, radiation safety, and criticality control. REON addenda and supplements to the Sacramento Plant safety manual also were issued.

The NERVA safety program (including NTO, AGC, and WANL) maintained a safety record during CY '66 (e.g., accident frequency and severity rates, radiation exposure, and fire and other accident losses) that was substantially better than those of comparable industrial enterprises and the AEC average. Both REON and WANL were presented AEC awards for outstanding safety achievements during CY '66.

b. NRDS Ground Operations Safety (2.5.2)

(1) Administration

During CY 66 there were no lost-time accidents at NTO. The highest whole body exposure to radiation was 4.5 Re REM. The highest individual exposure to radioisotopes taken into the body was 15% of the guide levels established by the Federal Radiation Council, and there were no Type A or B accidents or radiation exposures as defined in the USAEC Manual, Chapter 0502.

Approximately 150 personnel received 12 hours of instruction in the fundamentals of radiological safety; about 100 NTO personnel received instructions in the use of respiratory protective equipment and were fitted with respirators. Recommendations made as the result of semiannual reviews of NTO Health and Safety by SNPO-C were put into effect. SNPO-C conducted an audit and approved SS Materials Management at NTO. Monthly safety inspections were made at Test Cell A, E-MAD, R-MAD, and ETS-1 and recommendations for corrective action were made.

The NTO Health and Safety manual, NTO-A-0022, was prepared and distributed; NTO Criticality Control Manual, NTO-A-0029 was updated, revised, and reissued. A master document (NTO-A-0027) was prepared, approved, and distributed that indicates the necessary review and approved actions required for all engineering actions conducted by NTO.

(2) Activities

NTO Health and Safety personnel supported the following activities:

(a) Test Cell A

- 1 NRX/EST
- 2 NRX-A5
- 3 Emptying and purging all liquid and gas systems
- 4 "Moth-balling" the cell

(b) ETS-1

- 1 Steam generator procedures and tests
- 2 Water flow tests at ETS-1
- 3 Initial LH₂ filling of large storage Dewar
- 4 Successful pressure testing of the 250,000 gallon LH₂ storage Dewar
- 5 First Facility Experimental Plan
- 6 Coordination of ETS-1 instructions with the NRDS Safety Patrol

(c) E-MAD

- 1 Rechecking of two areas in the post-mortem cells with the 1800°C Co⁶⁰ source in the shielding integrity check program
- 2 RADA Program
- 3 Installation of radiation detection and criticality alarm systems
- 4 Operating guides for the OPS, V-1 Crane, and VMHS
- 5 Checkout procedures for the POCMTS
- 6 Assisted REON Safety with the second phase of its evaluation of E-MAD readiness for XECF

(d) R-MAD

- 1 Assembly, disassembly, and postoperative examination of NRX/EST and NRX-A5
- 2 Assembly of Phoebus 1B
- 3 Off-site shipment of radioactive and contaminated NRX hardware

6. Product Assurance (2.6)

a. Product Assurance, Contractors' Plants

The feasibility of an ultrasonic test method for evaluating the nozzle braze joints was demonstrated. Development of the technique has already resulted in a 40% improvement in the accuracy of measuring an unbonded condition. Continued parametric studies, better calibration references, and better tooling will result in further improvements in accuracy. The calibration references, the attenuation blocks and the 24-inch test section, have been received and are being evaluated. The nozzle rotating fixture is being reworked to accommodate the nozzle with the inlet torus attached. A self-aligning, squirter type transducer mounting has been designed and is in fabrication. The procedure for the evaluation of the nozzle braze joint has been drafted. It provides for 82 circumferential scans, with half of these located in the high stress portion of the convergent cone. A strip chart recorder will record the degree of unbonding for each of the 82 scan paths.

Thirty-nine turbopump forgings and 45 rotors have been evaluated. Fifteen rotors were machined from ultrasonically selected forgings, with 13 being accepted and two failing to meet the criteria for a finished rotor. Sixteen rotors were retested in a group and the results compared with the prior tests; good reproducibility was demonstrated. No physical discontinuities were found in this population, and the ultrasonic results correlated with the grain size and the inclusion size and distribution. A random-noise analysis test that has been used for rotors from ultracentrifuges was tried on rotor S/N 042 without success. No characteristic resonance peaks were observed.

An investigation was made of all factors involved in the failure of tubes of the gaseous hydrogen heater during a TPA test run. After determination that zinc contamination was the causative agent, a colorimetric test was used to determine that other stained tubes were not contaminated with zinc. All tubes in the heater were then ultrasonically inspected to a height of 9 feet above the headers. Only one indication of a defect was found and the defective portion was removed and sectioned. The defect was a tight subsurface crack 1/8-in. long by 0.015-in. in a radial direction in the 0.058-in.-thick tube wall. Subsequent successful operation of the heater has confirmed the effectiveness of these inspections.

Six bleed ports were radiographed for weld quality and the liner thickness was measured with a Vidigage. The weld quality was marginally acceptable on five of the six ports. The Vidigage indicated excessive thinning of the liner in three of the ports.

Data are being compiled to use an eddy-current test to identify A-286, Hastelloy X, Hastelloy N, Inconel 718 and Rene' 41. The data have a high degree of reproducibility and discrimination, and indicate that eddy currents may also be used to monitor the heat-treated condition of these alloys.

An improved system for processing Aerojet shop orders, similar to that used for processing purchase requisitions, was initiated. This will result in considering quality requirements, specified by NERVA Quality Engineering on the master requirements record, at the time of shop order review and approval.

Aerojet has selected the Sacramento plant supplier Quality Control Department to perform supplier evaluations for all Aerojet plants. This department will apply the coordinated aerospace supplier evaluation (CASE) system, which has been used successfully at the Sacramento plant.

Due to a soldering problem discovered at NTO, an extensive review of standards applicable to special processes was initiated. AGC Standard 9012 has been prepared, and a preliminary review has been made by REON, NTO and SNPO-C. Surveillance of special processes, such as soldering, is under more stringent surveillance by Product Assurance, and this surveillance has been extended to the REON control laboratory and the component development laboratory.

Removal of the 1-in. nozzles in the first two 1300 cu ft 5000-psi, gaseous-hydrogen pressure vessels and their replacement with gasket-sealed, internal steel plugs was determined to be the most feasible method of dealing with repeated nozzle failures. All plans and procedures for installation of manways and replacement of the nozzles were reviewed and amended where necessary for improvement of nondestructive-test requirements. The actual work, scheduled for completion in CY '66, has repeatedly been delayed by requirements for extra machining and rewelding to eliminate flaws found in the original supplier's welds. All nondestructive tests are being critically reviewed. The quality engineering control in the modification of these two vessels is emphasized by the fact that these methods are also to be applied to eight other vessels in the Sacramento plant and possibly to NASA vessels at other locations.

In-plant acceptance testing of the cryostat for calibration of cryogenic resistance temperature transducers in the Aerojet transducer laboratory has revealed design-concept deficiencies. Cryogenic Engineering Company proposed to control the temperature by conversion to an isothermal compartment. The cryostat is designed for simultaneous calibration of twelve RTT's in comparison with two NBS-calibrated platinum resistance thermometers in cryogenic temperature ranges with a system accuracy of $\pm 0.028^{\circ}\text{F}$.

During CY '66 two documents were released as part of the cleanliness control program. AGC Standard 9007, "Cleanliness Levels, Components and Assemblies," establishes five general levels of cleanliness for REON hardware; Specification AGC-90082, "Cleaning of Propellant Lines," establishes an ultrasonic cleaning method for achieving the required levels of cleanliness in lines per AGC-STD 9007.

To improve the control of engineering and manufacturing processes of suppliers of commercial products, the use of specification and source control drawings was expanded. Qualified products lists (QPL's) have been established for listing manufacturers of parts requiring qualification.

Environmental conditions that occurred during the NRX-EST test resulted in re-evaluation of qualification and acceptance-test requirements for transducers. New parameters have been established that will provide better conformity with system design demands and improved functional reliability.

NERVA Quality Engineering maintained close surveillance during fabrication of the ETS-1 control system and the associated STE components. The functional acceptance and check-out of the test stand control system (TSCS) were successfully accomplished under surveillance of SNPO-C and PAD. Final acceptance will be performed after installation at NTO.

The functional acceptance test plans and procedures for the TSCS and engine control systems were approved as conforming with the product assurance plan for the test stand control system (Subtask 2.2.8). Functional checkout of the process control system and other support subsystems has been successfully accomplished under the surveillance of SNPO-C and REON Product Assurance Division (PAD) representatives to the requirements of the applicable acceptance test procedures.

Reliability and quality assurance program plan Report No. 2469B reinitiated a reliability effort after a lapse of more than 2 years.

Procedures for reliability assurance, test area control, modes of failure and design review were issued to supplement this plan. In addition, two basic plans for documentation and data were developed and implemented to provide the base necessary for a reliability activity. A projected 10-year program was completed for the reliability effort applicable to a PFRT NERVA engine program.

A failure-mode analysis of NRX-EST was issued in preparation for testing. Catastrophic and critical failure modes were examined prior to the test to determine that all actions had been taken to minimize the effects of these conditions.

The replacement of the turbine power control valve actuator with the later configuration (NT-D1) was supported by a failure-mode analysis of the new system.

The failure-mode analysis of NRX-A5, an updated NRX-EST version, was made but was limited only to those major modifications that could seriously affect reliability. WANL, REON, and NTO participated in determining that failure-prevention features were established prior to test.

Failure-mode analyses of NTO's ETS-1 steam generator and EIV/MCC were evaluated for adequacy.

The unreliability of tungsten-rhenium thermocouples caused by a lack of concentricity was eliminated by modifying the engine interface to allow 0.010-in. nonconcentricity.

A comparative failure mode analysis provided the reliability basis for recommending one of five NERVA turbopump designs. Comparison of the five designs showed that the least reliable design would have 2.4 times the failure rate of the best design. This evaluation was part of a trade-off study in selecting a design concept for development.

Five competitive propellant feed systems were evaluated to determine their relative reliability. Existing failure-rate data applied to the elements of each system showed that the most reliable system is 48% less likely to fail than the least reliable one.

Failure mode analyses were prepared, coordinated, issued, and responded to as appropriate for the NRX-A5, Test Cell A, XE-1, and ETS-1.

The REON PAD technical support to SNPO-C on Contract SNPC-30 for the ETS-1 engine compartment radiation shield was continued during final fabrication of articles at WEC, Sunnyvale, and installation of the shield at NRDS.

The NTO product assurance program plan for Test Cell C has been reviewed by the REON NRX-A6 project manager and by REON PAD.

Significant improvements have been achieved in the quality, timely issuance, and effective processing of NTO-generated QRDR's. The AGC-issued QRDR status report has been established as an effective document, useful to NTO, WANL, AGC and SNPO-C.

REON Product Assurance has participated in REON support systems engine handling and transport systems surveillance. This effort provided added assurance that major subcontractors have discharged their responsibilities for completion of required components. The drawings, equipment specification, acceptance test specifications, installation specification, factory acceptance test procedure, end-item documentation and final acceptance test procedure were reviewed and approved by REON PAD for the post-operative cell material transfer system (POCMTS), the floor-mounted handling system (FMHS), overhead positioning system (OPS) and the manned control car and engine installation vehicle (MCC/EIV).

The POCMTS installation data package was prepared, coordinated, and approved relative to final acceptance testing at NRDS. Preparation of the POCMTS end-item report has been started.

The FMHS and OPS were acceptance-tested at NRDS and the end-item report initiated, transmitted to (and approved by) REON PAD and SNPO-C. The FMHS and OPS equipment specifications were revised to reflect approved design changes. The OPS thrust structures positioning head and stand was fabricated, factory acceptance tested, and delivered to NRDS.

The MCC/EIV was shipped by rail and truck to NRDS after acceptance tests and inspection were completed at Sacramento. A documentation report was prepared and delivered with the shipment. It included certificates of compliance, a configuration summary, acceptance test procedures, a list of tests not completed, a list of discrepancies, an inspection report, a list of troubles encountered during testing and corrective action taken or pending. The EIV will be assembled and tested along with the MCC prior to final acceptance at NRDS.

Product Assurance supported the Systems Division during the steam generator EP-II test series. All components of the steam generator system were examined after steam generator disassembly and repair. Proper control of the component quality through Project and Quality Engineering evaluation resulted in a successful 1100-sec full-steam run.

b. Product Assurance (2.6.3)

(1) General Operations

During this report period NTO Product Assurance updated and expanded the Workmanship Standard, NTO-SOP-0044. The standards specified in this document are currently being used by all NTO subcontractors.

Welding standards and welding procedures for use on NERVA hardware were developed by Product Assurance and coordinated with NRDS organizations.

A reliability program plan was prepared to define the reliability tasks that will be performed at NTO. This plan has been transmitted to the REON/WANL organizations for review and approval.

A survey of propellant sampling procedures at NTO and at the various vendor facilities was performed by NTO Product Assurance. The results of this survey were defined in NTO-M-11727.

The requirements for an EG&G Quality Control Program were defined, and a plan conforming to these requirements was submitted by EG&G. This plan has been reviewed by cognizant organizations and is currently being revised.

(2) R-MAD Operations

During CY 66 Product Assurance was involved in four main areas of operation at R-MAD: NRX/EST instrumentation assembly; NRX/EST mechanical assembly; NRX-A5 assembly and disassembly; and NRX/EST disassembly.

The responsibility for Quality Control of the actuators for NRX-A5 was transferred from WANL to NTO Product Assurance. Procedures were established and implemented for the accomplishment of this task.

Support activities continued relative to gage calibration, tool inspection, and nondestructive testing.

(3) Test Cell A and Control Point A Operations

Product Assurance activities at Test Cell A and Control Point A were primarily concerned with the preparation of the NRX/EST mate to Test Cell A, and the subsequent facility checks, inspections, and engineering surveillance during prerun and run activities for all experimental engine test plans.

Product Assurance provided support at Test Cell A during prerun and run activities for NRX-A5.

A discrepancy log procedure was prepared and implemented at Test Cell A during all facility checks and experimental engine test plans. Discrepancy logs were prepared in accordance with this procedure and were submitted for review and the identification of final corrective action.

Quality Engineering surveillance of Pan Am and EG&G Quality Control operations was performed in accordance with applicable quality reliability instructions for the NRX/EST experimental test plans.

(4) Test Cell C Operations

A Product Assurance program was defined for Test Cell C, and was approved by LASL management. To implement this program, an NTO product assurance engineer was assigned to the LASL organization.

(5) ETS-1 Operations

NTO Product Assurance at ETS-1 was primarily concerned with the steam generator testing program, interface system installation, duct installation, radiation shield installation, specification and drawing review, review of ETS-1 standard operating procedures, facility checkout procedures, and the preparation of quality standards applicable to ETS-1 operations.

Shields S-1 and S-2 were received and installed on the transfer cars. The intermediate shields for S-1 and S-2 were installed, and water-load deflection tests were satisfactorily conducted.

NTO Product Assurance, together with ETS-1 operations, AETRON and subcontractor personnel, conducted audits of the mechanical and electrical activities. All discrepancies and deviations were logged, and corrective actions were proposed or implemented.

(6) E-MAD Operations

Product Assurance personnel participated in the following activities in the E-MAD area: proof-load testing of slings, hoists, and cranes; acceptance inspection covering receipt and installation of the manned control car; completion of the post-operative cell material transfer system acceptance test plan; receiving inspection of hardware and components scheduled for the NRX-A6/T7 test car.

7. Materials Development (2.8)

a. Planning and Coordination (2.8.0)

Planning efforts were completed for a turbopump of advanced design and for pressure-vessel fabrication. The key problems were expected to involve melting practice, forging, and joining. Transmutation of $B^{10} (n, \alpha) Li^7$, which occurs in high-strength superalloys (such as Inconel 718), would be detrimental to components operating at 1000°F or higher, including turbine rotors and the inlet manifold. To resolve this problem, action was initiated for obtaining extra-low boron content in Inconel 718 and for investigating the substitution of Boron 11 (low-capture cross section) for Boron 10 (high-capture cross section). The establishment of specifications for Inconel 718 raw material and weldability was basic to both efforts, and preliminary documents were completed. Detailed plans were also prepared for developing welding-processing schedules for pressure-vessel and turbopump configurations fabricated of Inconel 718 and for testing of weldments to establish design properties. The turbopump planning also includes evaluating the mechanical properties of titanium alloy 5Al-2.5Sn(ELI) inducer forgings at liquid-hydrogen temperature.

Support for NRX and XE engine development included: lines and valve; components for Mark III, Mod 4 turbopump; thrust-chamber components; and instrumentation. The most significant contribution was development of antigalling material combinations for use on the gate and lipseal of the 5-in. butterfly valve. The optimum combination consisted of 0.0005-in.-thick electroplated chromium on the gate or moving element, and 0.00025-in.-thick Dalic gold on the lip seal or stationary element. This combination was successfully demonstrated in an Argon atmosphere on a lathe, the tool post of which was instrumented to measure forces normal and tangential to a rotating shaft. A plot of the dynamic-friction coefficient vs cycles to gall, shown in Figure 122, demonstrates the low-friction values of the gold vs chromium electroplated combination. The success of this combination was confirmed by tests of full-scale valves under operating conditions.

Figure 122
Friction Coefficient vs Wear-Test Cycles for Seal-Surface
Candidate Materials

Review of subcontractor activities included WANL, as well as several fabricators involved in construction or repair of test facilities. Significant effort was directed toward review, approval, and surveillance of repairs of the large pressure bottles for hydrogen storage, which are required for turbopump testing. The recommended mechanical-plug-type repair procedure was approved by both SNPO-C and the State of California. Continuous surveillance of current repair operations is being maintained. Relative to the NERVA exhaust system, weld problems encountered by the fabricators of the exhaust duct and the steam generator have been resolved.

Documents issued by REON Materials and Process Department during CY 1966 include five topical reports and two papers presented at technical-society conferences.

b. Material and Processes (2.8.1)

The two most significant contributions of the year were determination of material properties as affected by irradiation and evaluation of self-lubricating wear-resistant materials for bearing retainers.

Studies were made of the effects of radiation on three self-lubricating organic materials. Armalon (FEP), Teflon (EFP), and SP-3 polyimide were irradiated to three dose levels, 10^9 , 5×10^9 , and 3×10^{10} ergs/gm (C), at room temperature (reactor ambient) and -423°F . The effects of these doses on ultimate tensile strength and elongation are presented in Figures 123, 124, and 125. These data demonstrate the stability of strength and ductility for SP-3 polyimide over the full ranges of dose and temperature. Although Armalon (FEP) retained constant elongation over all ranges, it lost tensile strength rapidly above 10^9 ergs/gm (C). However, during this degradation severe delamination occurred as shown in Figure 126, which would limit Armalon to service at doses below 10^9 ergs/gm (C). Relative to strength vs dose, Teflon (FEP) reacted similarly to Armalon (FEP), but unlike Armalon its elongation property degraded rapidly at doses beyond 10^9 ergs/gm (c). This condition was attributed to the fact that Armalon is a glass-cloth laminate with Teflon as the impregnating resin. All three of the organic materials

Figure 123
Strength vs Gamma Dose of Organic Materials at -423°F

Figure 124

Strength vs Gamma Dose of Organic Materials at 80°F

Figure 125

Figure 126

Degradation of Armalloy 510-128 (FEP) after Irradiation

tested can withstand less than 0.5% permanent deformation at -423°F , and should be designated as brittle materials. However, because their elastic moduli (ranging from 1 to 3×10^6 psi) are much lower than those of common metals (ranging from 10 to 30×10^6 psi), applications are possible where elastic strains may be 1 to 3%, which is not possible with brittle metals.

Inconel 625, Inconel 718, Hastelloy X, and Type-347 stainless steel were irradiated at ambient temperature to dose levels of 10^{17} nvt, 10^{18} nvt, and 10^{19} nvt of thermal neutrons. After irradiation, these materials were subjected to tensile tests at temperatures ranging from 1240 to 2000°R . Data are currently being reduced and analyzed to determine the effects on tensile properties of boron-10 transmutation to lithium-7, which results in formation of helium.

The modification of a NERVA bearing tester was a significant contribution toward measuring the wear resistance of materials in liquid hydrogen. With this unit, six test coupons can be loaded against an AISI 440-C stainless-steel cylinder, which rotates with a surface velocity of 8500 ft/min. This is the only known equipment that has been developed to measure wear resistance in liquid hydrogen at a sliding velocity of this magnitude. Concurrently with the preceding effort, a literature and field survey was completed, and the first series of candidate materials was procured for testing. These candidate materials were: Dupont Vespel polyimide (SP-series) filled with molybdenum disulfide and/or bronze; Midwest Research Institute powder-metallurgy-produced molybdenum disulfide and nickel; and a Boeing Co. proprietary wear-resistant compact. Three composition variations of each material were procured, and samples were tested for reference mechanical properties. Armalon specimens were procured as the reference standard for wear-resistance tests, and the first shake-down build-up of the wear-test apparatus was completed during the final week of CY 66.

c. Design, Drawing, and Specification Review (2.8.2)

During the contract year, 1887 drawings were reviewed, in addition to change notices. This review prevented the incorrect selection of materials or processing methods and precluded incorrect specification callouts on

415 drawings that required revision before ultimate acceptance by the REON Materials and Processes Department.

The NERVA Engine Materials Parts List (U) was published as Report No. RN-S-0316, classified C-RD. This includes the current materials and procurement specifications used throughout the engine as compiled from Aerojet drawings of nonfuel components and WANL data on reactor components.

d. Materials Properties Data Book (2.8.3)

The NERVA Materials Properties Data Book was revised and expanded during CY 1966. The new edition will be published in two volumes of about 300 pages each during October. This publication is intended to provide reliable minimum allowable material properties for design calculations. The document also provides reference data common to both reactor and engine components, so that design decisions can be reached using standardized materials properties. During the contract year, 461 pages of new graphical data were prepared, as well as 75 new descriptive pages containing general information for each material.

8. Assistance to LASL (2.9)

Aerojet continued to supply technical assistance to the Los Alamos Scientific Laboratory on an as-required basis.

C. NRDS SUPPORT

Task 3

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C. NRDS SUPPORT (TASK 3)

1. NRDS and Advanced Facilities Support (3.0)

a. Engineering Support for Existing NRDS Facilities

(1) Design Modifications

Test facilities and associated requirements for the experimental-engine series were coordinated with NRDS on a continuing basis. The requirements documents, design criteria, and design and procurement packages for facility equipment and facilities changes were initiated, completed, and transmitted to NTO for implementation at NRDS.

(a) Filter Requirements

The design specification was established for additional filters in the ETS-1 systems supplying fluids to the engine and was transmitted to NTO for implementation at NRDS. Filters were provided in the run-tank fill line, the cooldown systems, and the engine valve-actuation supply lines.

(b) Gas-Sampling-and-Analysis System

The design and test specification was completed for the engine-test-compartment (ETC) gas-sampling and analyzing system. This document defined the design criteria for the system and the tests required to verify the adequacy of the detector systems and the ETC purge.

(c) Fill-and-Drain System for Engine External Shield

The design and procurement package for the fill-and-drain system of the engine external shield was completed. The system was designed for a 1200-sec run and, thus, provided a recirculating capability as

well as satisfying the fill-and-drain function. Included in the design are the necessary valves and a pressure source for leak-checking all engine connectors prior to filling the system. The configuration of the borated-water mixing tank, pump, and heater was selected to permit use of a commercially available chemical mixing tank and obviate design effort for a special application (Figure 127).

(d) Engine Valve-Actuation Supplies

The design criteria for providing a supply of gaseous helium in lieu of nitrogen for engine valve actuation were completed and transmitted to NTO for implementation. This modification was required to avoid freezing of nitrogen in the engine valve actuators due to the close proximity of the actuators to the valves that will handle LH_2 . In addition, modification requirements were provided to NTO to establish a double-block-and-bleed system in the hydrogen supply line to the control-drum actuators. This safety-dictated modification provides the means to lock out the actuation supply to the control drums mechanically when it is impossible to lock the control drums because of radiation levels. As part of this effort, the facility-supplied actuation source for the control-drum actuators was evaluated to ensure that the operating requirements for the control drums were satisfied as defined in WANL E & FE-FR-237, "Pneumatic Supply and Exhaust System for the Control Drum Actuator for ETS-1 Application - Functional Requirements." In conjunction with the modification requirements for the double-block-and-bleed system, a separate hydrogen supply had to be provided for the engine turbine power-control valve (TPCV) to enable TPCV checkout when the control-drum actuation supply has to be blocked out (Figure 128).

(e) ETC Purge and Purge-Checkout Device

To ensure an adequate purge flow pattern within the engine test compartment and the upper thrust structure (UTS) of the engine, a design package was developed whereby purge gases would be directed equally to the UTS and the ETC. The portion directed to the ETC is distributed throughout

Figure 127
Engine External Shield Fill-and-Drain System

Figure 128
Supply System Engine Valve Actuation

the compartment by means of a purge ring that is mounted directly below the top shield. To check out and verify this purge system, a design and procurement package was completed for a simulated engine UTS and a test-stand adapter. This purge-checkout device will be installed as part of the NES checkout device to ensure that the flow pattern within the ETC simulates patterns expected when an XECF is installed at ETS-1 (Figure 129).

(f) Engine Vent System

A design package was completed that identified the modification required to the ETS-1 vent system as the result of vent requirements for the new common 5-in. vent for the engine cooldown and pump discharge. This new line will run from Engine Station zero to intersect, at a point behind the shadow wall, with the existing 6-in. vent line to the flare stack. As part of this design package, a 3-in. propellant-feed-line vent was provided to tee into the main engine vent above the top shield. This increase in vent size was required to provide a faster prerun chilldown of the propellant feed line (Figure 130).

(g) Installation Specification for Test-Stand Adapter

The installation specification for the test-stand adapter was completed during this reporting period and transmitted to NTO and REON personnel. The specification defines the equipment needed to handle and install the test-stand adapter, as well as procedures for alignment, cleanliness, attachment, and testing. The general sequence of tasks associated with installing the test-stand adapter is followed step by step in the sections of the specification. The detailed procedures for each part of the installation process can be derived from this document.

(h) Checkout Device for Interface Systems

The preliminary design package for the engine primary-flow simulation device was completed and transmitted to NTO. This device

Figure 129
Purge Checkout Device and ETC Purge Ring

Figure 130

Main Engine Vent, 5-In.; Propellant Feed Line Vent, 3-In.

was necessary in the overall ETS-1 activation program to verify the dynamic response, integrated control, and thermodynamic characteristics of the ETS-1 propellant-feed and cooldown systems, as well as for operational verification of the associated test-stand control system. The design of this device includes the equipment necessary to verify that the fluids delivered at the interface by three systems meet the cleanliness levels specified for the X engine. Also included as part of the design are the devices required for flow checkout of fluid lines for the actuation and purge interface system. A separate temporary disposal system included in the design package allows burning of the fluids coming out of the engine primary-flow simulation device without using the NERVA exhaust system. This bypass system will carry the fluids away to a flare stack located a safe distance from the test stand and other ETS-1 facilities (Figure 131).

(i) Cooldown System

The design package for the modification required in the LN_2 portion of the engine cooldown system was completed and transmitted to NTO for procurement, fabrication, and installation. This modification enables introduction of LN_2 into the common cooldown line at a point downstream of all other fluids to avoid any possibility of LN_2 solidification in the line from contact with entrapped LH_2 (Figure 132). Additional studies and analyses were completed to identify other modifications required to the cooldown system to provide pulse cooling and an alternative cooldown path. The design package for this modification is currently being reviewed by SNPO-C, WANL, and REON. In anticipation of the acceptance of this design package, special spool pieces have been provided for the common cooldown line and the main propellant line. The spool piece for the common cooldown manifold allows for the flanged connection of the new LN_2 line, the alternative-path pulse cooling line, and the filter for the common cooldown fluids. The other spool piece, designed to replace the flow element in the main propellant line, allows for later flanged connection of the alternative-path cooldown line.

Figure 131
Bypass System and Flare Stack

Figure 132

LN₂ Cool-Down Piping Modifications

(j) Water Strainer

The design package for an in-line strainer in the NERVA-exhaust-system (NES) water-supply system was transmitted to NTO. This strainer will be installed in the 30-in. line just downstream of the presently installed flow venturi and will protect the NES against the damaging effects of contaminants that otherwise could be carried through the system.

(2) Evaluation and Analysis

REON participated in the analysis of facility capabilities required to support various concepts of engine cooldown and multiple runs. In the process, a series of charts and curves were developed that showed estimates of fluid use at ETS-1 for these concepts and the anticipated recharge times for different run durations. These analyses and charts indicate that both the capability for extended engine runs and the facility turn-around time are limited by the water-storage capability and the water-refill time.

The adequacy of the buffer-gas system for the ETC seal was evaluated and analyzed in detail. This study identified the need for increased pressures in some lines and for several valve changes to provide flow rates that are commensurate with the ETC seal leakage criteria. During checkout and activation of the ETC, this analysis will be verified, and the recommended corrective actions will be taken.

In accordance with a verbal request from SNPO-C, studies were conducted to determine the modifications required at ETS-1 to provide for continuous LH_2 topping. The fill-and-drain system as designed for the engine external shield was found to be adequate for an extended-duration run, and it was determined that topping of the run tank would be satisfactory without any major modification to the existing LH_2 storage vessel or the 6-in. transfer line. However, a high-pressure LN_2 Dewar is required to provide adequate cooldown capability. The preliminary design and the cost estimate for this Dewar and necessary

system modifications were reviewed by SNPO-C, and the decision was made that continuous LH_2 topping would not be provided for the initial XE tests.

An evaluation to determine if the shielding-integrity checks scheduled at ETS-1 were mandatory for personnel safety resulted in the tests being eliminated from the crowded activation schedule.

On the basis of design criteria issued by AGC, WANL developed a preliminary design concept for the source drive system utilizing a 1-curie source. Analysis of the shielding requirements, heating levels, and source size verification confirmed that the design concept was acceptable; and the system is currently in the final phases of design and fabrication.

The coordination of WANL, NTO, and REON safety efforts has been continued to develop the final design criteria for the ETS-1 criticality monitoring system. Contributions to the ETS-1 safety-analysis report have resulted from the evaluations of facility systems. These evaluations have included the ETC purge system, intermediate-shield fill-and-drain system, and the NES exhaust plume.

A procedure is being developed for maintaining configuration control of the NRDS facilities. This procedure will define the responsibilities of participating organizations and the techniques to be used to maintain configuration control and ensure dissemination of information as appropriate. It will also define review and approval requirements for designs and modifications of NRDS facilities. Meetings have been held with NTO, WANL, and SNPO-C to coordinate inputs to the procedure and review preliminary drafts of the procedure document.

Test specifications were reviewed and facility capabilities were evaluated to ensure consistency with engine test requirements. As part of this effort, the following final documents were reviewed: ETS-1 Activation Specifications, NTO-I-0094, and Clean Assembly Requirements, E-MAD, NTO-R-0073. The facility experimental plans and associated control room procedures were also reviewed as received.

b. Advanced-Facilities Engineering Support (3.0.2)

Engineering support has been provided to SNPO-C in activities related to advanced NRDS facilities for the NERVA engine. This support has included provision of data on fluid requirements for various engine operating and shutdown regimes and on future use of ETS-1.

Report RN-TM-0284, NERVA II Fast Shutdown Fluid Requirements, dated 24 November 1965, defines the fluid requirements for fast shutdown and subsequent cooldown of an engine after a 30-min run at 50,000 Mw. The investigation utilized the latest definition of the engine system and reflected both experimental data and experience gained in NRX-A tests. NERVA-engine end-point conditions to be expected after a run were calculated to determine the decay power level at which the engine cooling could be terminated.

Report RN-PA-0005, The Future Utilization of ETS-1, explored the possibilities of additional use of ETS-1 during 1968, 1969, and 1970 and verified Aerojet's initial planning with regard to engine testing. The use of ETS-1 for engine testing was evaluated in terms of cost, effect on schedules, and program goals. Facility uses other than engine testing were also studied and evaluated. Cost, schedule, and program-goal factors and the engine-system, component, subsystem, and radiation-effects tests were all considered. Future use was recommended on the basis of three distinct time periods. During the first period, NERVA engine cold-flow tests were recommended. Modifications to the facility during the second period would permit engine operation at up to 3000 Mw over a portion of the engine operating map. During the third period, ETS-1 would be used as a backup for E/STS-2/3 in case of excessive testing-frequency requirements to meet tight schedules or excessive downtimes for repairs because of unanticipated malfunctions.

Estimates of NERVA engine fluid requirements during engine startup, steady-state operation, shutdown, and cooldown regimes were provided and updated for use in E/STS-2/3 design. The latest estimates are given in Figure 133

<u>Name of Function</u>	<u>Conn. Dia (in.)</u>	<u>Fluid</u>	<u>Max Press. (psia)</u>	<u>Max/Min Temp (°R)</u>	<u>Max Flow Rate (lb/sec)</u>	<u>Max Flow Time</u>	<u>Fluid (lb) Max Quantity</u>
Propellant Inlet Line	22	LH ₂	35	50/38	350	60 min	643,000
Flight Simulation Cooldown	(same)	LH ₂	35	50/38	350	11.5 days	55,000
Ground Test Cooldown	(same)	LH ₂	35	50/38	305	600 sec	17,000
Thrust Structure Purge	(no connector)	GHe	65	≤530	0.3	30 min	150
Module Tank Press. Line	(to be specified)	GH ₂	715	≤270	(to be specified)	60 min	(to be specified)
Special Purpose Purge	2	GHe	65	≤530	0.1	10 min	60
Turbine Inlet and Exhaust Purge	2	GHe	65	≤530	0.1	10 min	60
Turbopump Assy Hot Purge	2	GHe	65	590+25	0.002	30 days	5,200
Pneumatic System Purge	2	GHe	65	≤530	0.1	10 min	60
Pneumatic Tank Purge	2	GHe	65	≤530	0.1	10 min	60
Pneumatic Tank Fill	(same)	GH ₂	715	≤270	1.0	1 min	60
Ground Test Cooldown	12	GHe	1250	≤530	165	2.5 min	20,000
Ground Test Cooldown	(same)	GH ₂	250	≤530	20	10 sec	200
Ground Test Cooldown	(same)	LN ₂	500	530/140	230	440 sec	70,000
Ground Test Cooldown	(same)	LN ₂	250	530/140	105	2 days	450,000
Ground Test Cooldown	(same)	LH ₂	250	50/38	90	584 sec	10,000
Ground Test Cooldown	(same)	LN ₂	100	530/140	15 (pulse)	7.6 days	100,000
O ₂ Detector Line	2	To Be Supplied					
H ₂ Detector Line	2	To Be Supplied					

Figure 133
NERVA Engine/GTM Interface Fluid Properties

as they influence the test-facility design. Also shown are the fluid-line sizes at the engine-facility and engine-GTM interfaces. The ground test shutdown and cooldown fluid requirements are based on criteria similar to those used for XE-1 modified only by the differences in reactor-decay heat generation and engine configuration. Preliminary estimates of the normal cooldown fluid requirements were also made and are presented in Figure 134. Assistance was provided in developing a sequence plan and schedule for testing the NERVA engine and stage in the E/STS-2/3 complex. Two alternative ETC concepts were submitted for consideration, and an estimated design and construction schedule for E/STS-2/3 was prepared for planning purposes.

REON representatives provided assistance to the Government Design Review Committee directing the E/STS-2/3 architect-engineering work of Kaiser Engineers in Oakland, California. Volumes I, II, III, and IV of the "Final Project Report, Budgetary Study for the Engine/Stage Test Stand 2-3" were received from Kaiser Engineers the latter part of May. These documents were reviewed at Aerojet in great detail by personnel knowledgeable in each area and their comments presented at a series of meetings at Kaiser Engineers in Oakland the last week of June. Preliminary portions of these documents were received periodically during contract year 1966, and review comments were returned for inclusion in the final documents. The umbilical requirements submitted by LMSC were reviewed and comments were submitted; also, the instrumentation and control accuracies specified by Kaiser Engineers were evaluated. The Kaiser Engineers preliminary report "Hazards Separation vs Site Costs," was reviewed, and comments were submitted to the Government Design Review Committee for E/STS-2/3. This study was performed to investigate separation distances between major facilities and liquid-hydrogen storage locations; the possible accidents governing design; and the validity of applying DOD Instruction 4145.21 regarding separation distances.

Nuclear analysis and design support was provided for E/STS-2/3. Studies were initiated to determine the expected radiation dose rates on and around the test stands. Preliminary studies were made of the possibility of inadvertent criticality caused by ejection of fuel elements into the exhaust duct. The effect

Fluid	Source	Fluid Weight (lb)			Interface Press (psig) at Max $\dot{w}$	Max $\dot{w}$		
		For Test Durations of:				For Test Durations of:		
		<u>5 Min</u>	<u>15 Min</u>	<u>30 Min</u>		<u>5 Min</u>	<u>15 Min</u>	<u>30 Min</u>
LH ₂	GTM	16,000	30,000	55,000	60	114	131	140

Flow Duration, Sec

500,000 for 15 Min Test

750,000 for 15 Min Test

1,000,000 for 30 Min Test

Figure 134
NERVA Engine Normal Cooldown Requirements

of scattered radiation through an empty run tank was evaluated for full-power and shutdown radiation levels (Figures 135 and 136). The reactivity worth of the side shields was determined for three different shield combinations. A summary of the analysis results is given in Figure 137. Nuclear heating rates in the various shields were determined and the results are summarized in Figure 138. Dose rates in the duct vault from neutron activation of the concrete were determined for preliminary configurations. Results are given in Figures 139 and 140. In mid-year, a program was developed for the nuclear support to the design phase of E/STS-2/3, including both nuclear and thermal radiation analysis.

A study was initiated to identify costs and prepare cost estimates for assembly and acceptance-test facilities for NERVA flight and flight-support engines. This study identified several alternative approaches to the assembly requirements at different geographical locations.

Six methods of closing the space between the nozzle exit and duct entrance planes in E/STS-2/3 were studied and evaluated. A preliminary design of one of these methods, that of a one-piece duct extension, was presented to SNPO-C for consideration. Also, as part of the design evaluation of the wet-elbow duct, a cost estimate was prepared for facilities engineering to study water-jet penetration during the NES design-demonstration tests.

c. Engineering Support for NRDS Instrumentation Systems (3.03)

Information on the capabilities and limitation of the ETS-1 instrumentation systems has been provided on a continuing basis as required for support of the X-engine program and development of the test-stand control system. The evaluation of several types of LH_2 level probes that could be used in the three Dewars at ETS-1 and which would be compatible with the radiation environment was continued during this reporting period. Carbon-resistor-type probes were selected for immediate installation, but reflectometer and magnetic-reed-switch types are still being tested and evaluated with the hope of ultimately selecting a more accurate and reliable system. Evaluations have been started to

Figure 135
Air-Scattered Gamma Dose Rates during Full-Power Operation

Figure 136
Air-Scattered Gamma Dose Rates 24-Hours after 30 Minutes at Full Power
349

<u>Shield Configuration</u>	<u>LASL</u> <u>(Phoebus-I)</u>	<u>AGC</u> <u>(ETS-1)</u>	<u>AGC</u> <u>(E/STS 2-3)</u>
Plain Water in Side Shields	\$1.60	\$2.56	\$.10
1% Boronated Water	.85	.85	--
2% Boronated Water	.75	--	--
1/4-in. Boral Liner	.75	.80	.10

Figure 137

Summary of Analytical Results

<u>Source</u>	<u>Intermediate</u> <u>Shield</u>	<u>Lower</u> <u>Shield</u>	<u>Duce</u> <u>Plenum</u>
Neutron Absorption	18×10^3	12×10^3	45×10^3
Neutron Kinetic Energy	1.8×10^3	2.8×10^3	2.8×10^3
Gamma Rays	3.8×10^3	3.6×10^3	1.8×10^3
TOTAL	24×10^3	18×10^3	49×10^3

Figure 138

Nuclear Heat Loads in the Various Shields of E/STS 2-3,
Reactor Power = 10,000 MW

(Multiply dose rate of Figure to obtain
dose rate at appropriate location)

<u>Z, ft</u>	<u>R=0 ft</u>	<u>R=12 ft</u>	<u>R=14 ft</u>
10	.48	.65	.69
20	.60	.87	1
30	.59	.77	.88
40	.51	.94	.70
50	.43	.53	.57
60	.36	.43	.47
70	.3	.36	.39
80	.25	.30	.32

Z = distance from top of concrete wall
R = distance from axis of vault
Radius of vault - 15 ft

Figure 139

Activation Dose Rate Scale Factors for Points within Duct Vault

Figure 140

Dose Rate in E/STS 2-3 Vault, Activation of the Concrete Vault Well

develop design criteria for the installation of a TV camera in the engine upper thrust structure and sound pressure level measurements during XE testing at ETS-1. Pin and wire assignments needed for the measurement-requirements list have been coordinated with WANL/REON and NTO on a continuing basis.

As part of the effort of the ETS-1 Instrumentation Committee, the NTO-produced ETS-1 data-handling plan was reviewed, and significant review comments were transmitted to NTO for incorporation in the final draft of the plan.

The approved version of the "ETS-1 Data Acquisition Accuracy Test Specification" (RN-S-0308) was issued in July and is being used by NTO as the basis for producing the detailed procedures to perform the data-acquisition-systems accuracy tests. The procedures for the first phase of testing have been reviewed, and comments have been incorporated in the final procedures.

2. NERVA Exhaust System (NES) (3.1)

a. ETS-1 Nucelar Exhaust System, NASA

(1) Technical Assistance to SNPO-C

(a) Coordination with Duct Fabricators

REON personnel have attended NES duct-fabrication meetings at the Air Preheater Company, Wellsville, New York, to discuss fabrication progress. The agenda has included fabrication schedules, weld procedures, fabrication techniques, assembly procedures, and shipping operations.

During welding operations, shrinkages of 3-in. occurred in the duct elbow, and shrinkages of 2-3/4 in. occurred in the primary duct. The duct truss structure and the trunnion supports were modified to compensate for these shrinkages. As a result, however, the level of the secondary duct, as installed in the ETS-1 vault, is raised by a total of 5-3/4 in.

The upper and lower sections of the duct truss were assembled at Air Preheater, and proof and leak tests were satisfactorily completed. The assembly is shown in Figures 141 and 142. After the proof and leak tests, the duct was disassembled at the duct-truss severance plane and was prepared for shipment. The primary duct and unassembled components were shipped overland to NRDS. Size and weight limitations imposed by various Midwestern states made it necessary to ship the secondary duct by water to Texas City, Texas, and then overland to NRDS.

Field erection and assembly of the duct were initiated at ETS-1 on 29 July 1966, and installation was completed by 27 September 1966. Assembly operations at ETS-1 are shown in Figure 143 and the duct is shown being installed in ETS-1 in Figure 144.

During proof and leak testing, the inner wall of the drain tube on the secondary duct failed; a new drain tube is being fabricated. When installation of the new drain is completed, proof and leak tests will again be conducted.

(b) Seal Development Program

The duct-to-facility Marman clamp was completed by the Marman Division of the Aeroquip Corporation. The lower-flange-and-clamp assembly was shipped to Air Preheater for assembly to the primary duct. The upper-flange-and-bellows assembly, with gaskets and conoseals, was shipped to NRDS for installation in the ETS-1 vault. This installation was completed by 11 August 1966. The report on the full-scale seal development program was completed 15 August 1966.

Figure 141
Primary Assembly of Duct Truss Section Being Placed in Upright Position

Figure 142

Primary Assembly Being Placed on Elbow

Figure 143
Duct Assembly Operations at ETS-1

Figure 144
Duct Being Installed in ETS-1

(c) Duct Instrumentation

Instrumentation brackets were shipped to Air Preheater for installation on the duct prior to its shipment. The instrumentation will be installed at ETS-1 after proof and leak tests are completed. Installation will be in accordance with the NES Duct Instrumentation Installation Procedure, Report No. RN-S-0225.

(d) Design-Demonstration Test Program

Because of schedule delays in the installation of the permanent engine compartment at ETS-1, the design-demonstration test program will be conducted in accordance with the alternative design-demonstration test plan, RN-S-0286. All hardware for this program has been fabricated and delivered to NRDS. The temporary engine compartment has been assembled and aligned with the test stand in preparation for installation.

b. Steam Generator System (SGS) (3.1)

Early in the contract year, a steam-generator recovery test plan (addendum to Steam Generator Development Program, RN-S-0303) was transmitted to SNPO-C for approval. The objectives of this test plan were to verify that crack-type failures in the SGS injector weld were caused by boiling or flashing of the propane in the regeneratively cooled injector face and that problems with water-hammer had been resolved. The test specification covering these tests was issued after SNPO-C approved the test plan. To further implement the SGS test program, a REON task force was formed and assigned the tasks of (1) coordinating the injector development tests, (2) completing the SGS development program (as modified by ETS-1 schedule restraints), and (3) providing continuous engineering and logistics support.

As part of the SGS hardware repair program, the steam-generator subcontractor performed the following:

(1) Repair of three injectors (SN 017, 018, and 019) and instrumentation of two for use in the injector-evaluation program.

(2) Redesign and rework of the upper torus on three combustion chambers.

(3) Residence of a technical representative at NRDS during the injector-evaluation program.

A study of the SGS water system resulted in a recommendation for minimizing pipe bends and installing a two-way control valve with a linear plug. During the modifications, poor-quality welds were discovered in the manifolds and the piping system. These pipes and manifolds were proof-tested and verified to be adequate for a short-duration test.

Rework on combustion chambers SN 0016 and 0018 was completed by the subcontractor. Chambers SN 001 and 0019 were returned to Aerojet-Sacramento for incorporation of the new torus design. During the modifications, chamber SN 0019 was discovered to require replacement of the chamber inner liner.

The injector-evaluation test series (EP-IV) was initiated on 14 December 1965. A total of five 60-sec-duration, full-steam tests were subsequently conducted with propane propellant temperatures controlled between 40 and 68°F. Because of facility limitations for propellant conditioning, the proposed 80°F tests had to be deleted. The tests indicated that limiting of propane temperature to a maximum of 60°F resulted in safe and reliable steam-generator operation.

During the EP-IV tests, the upper torus of combustion chamber SN 001 failed after approximately 250 sec of full-steam operation. The chamber was replaced with chamber SN 0017, which incorporated the new torus design, and testing was successfully completed.

Prior to the start of EP-V tests, the piping welds were repaired and modified. In Test Series EP-V, which started on 22 March 1966 and was successfully concluded on 1 April 1966, development testing of single generators was continued, with each generator performing satisfactorily.

A committee was convened to determine procurement action with regard to major components for steam-generator spares. As a result, three combustion chambers were fabricated by Aerojet and three injector-igniter assemblies were procured.

On 9 May 1966, the EP-VI test series, which called for simultaneous operation of two generators, was initiated. The operation of two modules, each generating half of the required steam output, was satisfactorily demonstrated. Also, the switching of generators was successfully demonstrated by Test No. 7 on 23 May 1966.

Posttest inspections of the system revealed bowing of the steam discharge line. Analysis revealed that the bowing was caused by the thermal expansion of the line being restrained by the hanger suspension system.

On 25 May 1966, Test No. 8 was conducted by using the temporary discharge stack. In accordance with the test plan, Generator No. 1 was manually shut down and, 4 sec later, Generator No. 3 was automatically commanded to full steam. After Module No. 3 had operated at full steam for approximately 4 to 5 sec, the second-stage LO_2 propellant valve on Unit No. 1 (the shut-down unit) was destroyed by a localized LO_2 detonation. All test operations were terminated, and the remaining two tests were suspended.

A subsequent analysis of the LO_2 valve and circuitry indicated that this malfunction was typical of LO_2 contamination explosions. To correct the design deficiency that permitted the contamination, the purge system was modified to provide a continuous N_2 purge after shutdown. This modification provided a secondary pneumatic "check valve" to prevent the entry of contaminants into the propellant circuit and ensured more reliable purging of residual LO_2 .

Posttest inspection of the SGS also revealed excessive porosity in the weld areas of the injector face. The only exception was the repair weld made on a small fissure. When samples from both areas were analyzed, Hastelloy weld-rod material was found in the repaired fissure, and N61 rod material was found in the other sample. Further investigation into the causes of weld-area porosity indicated that intergranular corrosion was being caused by galvanic action between the N61 rod and the nickel face of the injector, which may be aggravated by the sulfur content in the propane. Corrective action consisted of removing the N61 welded areas and rewelding with Hastelloy-type rod material. Also, investigations into the cost and availability of sulfur-free propane were initiated.

On 8 August 1966, the test series to evaluate steam-generator switching was resumed with the newly repaired, 20-in.-dia, steam discharge pipe. Shutdown of a generator and startup of a standby unit was successfully demonstrated while the third unit continuously generated steam. The next day, a full-duration 1000-sec test was performed at full steam output. Switching to the standby module was successful, but full-steam operation of the standby module was not achieved. This long-duration test brought the steam-generator development program to completion.

During the steam-generator development program, it became apparent that minor modifications to the system could result in major improvements in performance. Discussions between NTO and Sacramento personnel resulted in the following recommendations:

- (1) Utilization of combustion-chamber-coolant waste water for plenum cooling. This modification would reduce the total system water flow rate approximately 20% and would increase dynamic head.

- (2) Change from an 80- to a 20-mesh strainer element. This simple replacement of cylindrical strainer elements would also increase the dynamic head.

(3) Incorporation of a timer to automatically extend the GN_2 purge cycle after the sequential shutdown of three generators during termination of operations. This change would automate a safety procedure performed manually by the SGS operator.

(4) Operation of the SGS with higher propellant tank pressures and changing of third-stage propellant venturis. The increased flow rate in the igniter-injector assembly would increase the respective chamber differential pressure and result in more reliable operation of the control-system pressure switches. New venturis would be designed to maintain the current third-stage propellant flows and operate well beyond the marginal cavitating point.

(5) Incorporation of a means of shutting off the third-stage only; i.e., returning to idle. The advantage is that a continuous bleed of the third-stage lines would be provided thus allowing instant restart capability. After a routine start, the current shutdown mode affects all three stages and necessitates a short propellant-bleed period prior to restart.

(6) LO_2 lead-time reduction. Studies of EP-VI data confirmed that reduction of the LO_2 lead period from 1 to $3/4$ sec produced no chamber-pressure surges. Further investigations of LO_2 lead may eliminate control-system elements and thereby improve the system reliability.

(7) Third-stage ignition from second stage only. Demonstrate that full steam operation of a module can be safely obtained despite a first-stage propellant-valve failure.

On 26 September 1966, the above recommended improvements were included in a test plan (Report RN-DR-0087) and submitted to SNPO-C for approval.

c. E/STS-2/3 NES Support (3.1.1)

(1) E/STS-2/3 NES Analytical and Experimental Studies

Analytical and experimental effort for Sub-Subtask 3.1.1 during CY 1966 was directed toward determining the shortest, most reliable, and most functional altitude-simulation system for testing the NERVA engine in the E/STS-2/3 facility. This effort was concentrated in the following study areas:

(a) Dry-Elbow Diffuser Evaluation Study

A trade-off study was conducted to define the best diffuser entrance contraction angle and contraction ratio consistent with efficient diffuser operation for the NERVA nozzle contour, area ratio, and gimbal requirements. The effects of reduction in length for the constant-area minimum-diameter section and of downstream-diffuser contraction ratio were evaluated.

Experimental test results indicated that satisfactory environmental cell pressures could be attained only by reduction of the contraction half-angle from the initial test value of 8 degrees. It was demonstrated that use of a 4-degree half angle and a reduced minimum-area section length provided satisfactory operation within the original envelope. Reduction of the initial contraction ratio from 1.9 to 1.67 failed to improve the performance of the 8-degree configuration and served only to raise the starting-pressure ratio requirement slightly. The effect of the downstream constriction on the diffuser operating characteristics was negligible, although subsonic flow parameters in the turning elbow were subject to the influence of the downstream area change and the starting pressure requirement was increased.

(b) Wet-Elbow Experiments

The cooling effects of water injected into the subsonic region of the diffuser were evaluated in a series of tests conducted for

both peripheral and centerline injection-port orientation. For these experiments, the diffuser environment upstream of the turning elbow was simulated using heated hydrogen gas; water was injected for a range of mass-flow ratios, and the stream temperature drop was measured with thermocouples.

The results showed that the injected water did not cool the bulk of the gas flow within the elbow region but provided enough spray-cooling to keep objects in this area below 220°F. The best results were obtained when the cooling water was injected perpendicular to the gas flow, causing maximum water breakup and a uniform cooling effect in the critically heated areas.

(c) Film Cooling Experiments

The effectiveness of water injection through the diffuser boundaries for wall cooling was investigated in a test series in which a flat plate was inserted into gas streams consisting of cool and heated N_2 and H_2 . Environmental conditions around the plate were similar to those at the turning elbow in the subscale diffuser. Water at selected mass-flow rates was injected through a hole in the flat plate and the extent of cooling was determined using temperature-sensitive paint. The plate was oriented at various angles of attack to evaluate the effect of impingement angle.

The results of this test series, which were not completely evaluated by the end of CY 1966, are expected to indicate the local injection-port density and water mass-flow rates required for maintaining sufficiently low elbow-wall temperatures for diffuser operation. Preliminary analysis indicates well-defined geometric cooling patterns that will be used to establish temperature-profile data.

(d) Water-Penetration Tests

An experimental series was initiated late in CY 1966 to establish the depth of water-jet penetration into a gas stream that simulated the environment of the entrance to the turning elbow. Water was injected through nozzles of selected areas at various driving pressures, into streams of cool and heated N_2 and H_2 . The penetration characteristics were measured by recording injection patterns through a transparent boundary.

Preliminary data indicated that definition of the injection phases (penetration, jet breakup, and vaporization) are clearly defined using this technique. It is expected that the experimental data can be correlated with the existing theoretical analysis to enable a method of prediction of the jet-penetration characteristics for the actual NERVA diffuser system.

(e) Large-Radius-Elbow Evaluation

Tests to determine the effect of various elbow radii on the heat-transfer rates through the elbow sidewalls are in progress. Test results will be used to compare heating-rate profiles for elbows with turning radii ranging between 1.4 to 2.5 times the internal elbow diameter. The objective is to determine an optimum elbow radius that has a minimum area and a limited magnitude of heat flux.

(f) Secondary-Ejector Preparation

A secondary ejector has been designed and fabricated to pump down the diffuser system to a pressure that will enable the diffuser to start operating at low nozzle-chamber pressures. The scale model ejector is designed to operate with nitrogen at about 650°R, with the actual ejector using steam at 1650°R.

(2) Test Description and Operation

(a) Dry-Elbow Study

A diffuser system having a scale of approximately 1/20 was fabricated and installed in Test Bay 87 of the Aerojet-Azusa test facilities. The system was sized for use with a subscale NERVA nozzle of 40:1 expansion ratio using a weight flow of 5.3 lb/sec N_2 at approximately 1500°R and a chamber pressure of 700 psia. The test bay installation is shown in Figure 145. The basic diffuser configuration, shown schematically in Figure 146, consisted of an initial convergent section of 1.90 area ratio and a wall half-angle of 8 degrees. Downstream of the contraction section was a constant-area duct with a length-to-diameter ratio of 4, a conical divergent section expanding the flow area by a ratio of 2.80, and a 90-degree turn elbow of constant diameter. Flow-constriction sections at the downstream end of the elbow were fabricated for reduction of the flow exit area.

The diffuser was instrumented along its entire length with static pressure orifices and with thermocouples tack-welded to the wall on the outside. The entire system was insulation-wrapped. During operation, nitrogen gas was preheated and exhausted through the system at constant temperature at pressures controlled by a manual bypass (bleed valve) and burst diaphragm system. Pressure and thermal transients were measured as a function of operational time.

Test results indicated that the initial contraction angle of 8 degrees was too large to obtain the desired nozzle environmental pressure during diffuser operation. The diffuser was modified for a reduced contraction ratio of 1.67, and subsequently for a reduced contraction angle of 4 degrees at the original contraction ratio. The effects of these changes are shown in Figures 147 and 148. Figure 147 shows the environmental pressure transient for each of these conditions and indicates the marked improvement in operational pressure for the 4-degree configuration. Figure 148 shows the effect of downstream

Figure 145

Test Bay Installation Showing Dry-Elbow Heat-Transfer Test Setup

Figure 146
Schematic of Diffuser-Ejector Test Setup

Starting Transients Defining Performance of Diffuser Systems

Figure 147

▽ L/D = 2.2 (ALL OTHER = 4.0)

constriction on the diffuser starting total pressure. Because use of the reduced contraction angle resulted in longer over-all diffuser length, the length of the constant-area section was reduced to a length-to-diameter ratio of 2.2 to maintain the original diffuser envelope. Data for this configuration are also presented in Figures 147 and 148 and indicate that the improved operational characteristics of the reduced contraction angle could be maintained adequately for the shorter minimum-area section.

Figure 148 shows that decrease in the diffuser contraction ratio resulted in a significant increase in diffuser starting pressure. The increase was substantially greater than that caused by reduction in contraction angle. These data definitely indicate reduced starting efficiency for both this reduction in contraction ratio and for excessive constriction downstream of the turning elbow.

Additional testing was conducted to determine the effects of ambient air bleed into the environmental cell and of nozzle-gimbal deflection on nozzle immersion into the diffuser entrance. Auxiliary air bleeding effectively reduced transient pressure spikes at and near the starting condition. Nozzle deflection angle or minor changes in immersion had no significant effect.

A primary objective of the dry-elbow diffuser test series was to determine local heat-transfer coefficients at the diffuser boundaries, particularly in the 90-degree-elbow section. Typical coefficient distributions at the diffuser walls shown in Figure 149 are characteristic of subsonic flow conditions in the elbow. These and similar data obtained at the diffuser system walls may be extrapolated for full-scale application through consideration of gas-transport properties.

Figure 149
Heat-Transfer Coefficient Distribution

(b) Wet-Elbow Experiments

The subscale-diffuser system was modified as shown in Figure 150 to provide a straight-through diffuser flow, with which the effects of water injection for stream saturation could be evaluated. The dry-elbow system was simulated to the water injection station, and the conic and elbow sections were replaced by an instrumented quasicylindrical section. System instrumentation consisted of transverse rakes containing discrete total-pressure probes and double-faced-disc thermocouples. The thermocouples were designed so that each unit would record the temperature of a copper disc directly exposed to the stream and the temperature of a back-side submerged disk.

Water was injected into heated hydrogen through either a single centerline injector or through eight discrete radially-oriented ports. All injectors were located at the exit of the diffuser minimum section and the rake, at selected distances downstream of the injection station. Sample test data are presented in Figure 151 and show the effectiveness of saturation cooling relative to the theoretically obtainable temperature drop for the subscale system.

(c) Film-Cooling Experiments

The technique of temperature measurement based on color change of temperature-sensitive paint was used to obtain thermal profiles defining cooling-port orientation and mass-flow rates. Prior to testing, the surface of a 3 by 5 in. thin flat plate was coated with paint, inserted into the cylindrical section used for the wet-elbow tests, and oriented at a preselected angle of attack. Water was injected through a single port in the plate at a prescribed flow rate and gas flow through the diffuser was initiated. After thermal equilibrium was achieved, the system was shut down and the plates were removed and photographed. Typical results are shown in Figure 152, illustrating data for three plates at 30° angle-of-attack at water-flow rates of .025, .050, and .100

Figure 150
Test Bay Installation of the Wet-Elbow Test Setup

Figure 151

Wet-Elbow Temperature Profile

Figure 152
Film-Cooled Plates

(reading left to right) and for nitrogen gas flow at 1700°R and 700 psia initial-stagnation conditions. For these tests, one-half of the plate was coated with a 200°-rated paint and the other, with a 500°-rated paint. The photographic results indicated clearly the zones for temperatures above 500 degrees and between 200 and 500 degrees.

(d) Water-Penetration Tests

A special test fixture was fabricated for evaluation of the depth of penetration and of the break-up characteristics of a water jet injected into the diffuser environment that exists in the subscale system just upstream of the turn elbow. A two-dimensional test section 3-in. wide and 20-in. high was enclosed on one side by a transparent window and was instrumented with static pressure orifices and thermocouples on the opposite side. Transverse total pressure rakes were located at selected stations downstream of the injection station. The downstream end of the test section was open to ambient atmospheric conditions, and cool and heated nitrogen and hydrogen gas were selectively introduced through a multiorifice plate at a mass-flow rate resulting in simulation of diffuser-flow Mach number.

Typical penetration photographic data are shown in Figure 153. The picture shows the results of injection at the lower left boundary, the subsequent penetration depth, and the breakup of the jet into droplets. This test was made with a 1/4-in. injection-orifice diameter for a flow of cold N_2 at a water pressure of 150 psi. Tests for this program phase are being continued.

(e) Large-Radius-Elbow Evaluation

Two large radius elbows were fabricated to be attached to a diffuser system with an initial convergent half-angle of 6 degrees, a convergent ratio (A_{D1}/A_{D2}) of 1.92, and a primary duct L/D of 4. These elbows, together with the small elbow used for previous tests, will be tested to provide heat-transfer data for elbows with turning radii of 1.4, 2.2 and 2.5 that of the internal diameter.

Figure 153
Stream Penetration

Extensive instrumentation is available to furnish detailed heat-transfer-rate profiles and pressure profiles along the inside and outside walls of each elbow. These tests will be conducted by using a diffuser test setup.

(f) Secondary Ejector

A secondary ejector has been designed and fabricated to be attached to the 1/20 scale-model diffuser. It was designed with an annular throat and a capacity to provide environmental pressure that will enable the diffuser system to start operating at a primary chamber pressure of 10 atmospheres. The ejector will then continue to operate until stabilized primary chamber pressures are obtained. The performance characteristics of the secondary ejector are currently being determined. Conditions under which the ejector is being evaluated are: hot nitrogen with secondary-ejector chamber pressure ranging up to 200 psi, and a primary flow simulated by bleeding air into the system upstream of the annular ejector. Water will also be flowed into the upstream portion of the ejector to simulate the effect of coolant water on operational characteristics prior to start-up of the primary system.

(3) E/STS-2/3 NES Supporting Studies

The development plan for the E/STS-2/3 Nuclear Exhaust System has been completed and includes a recommended diffuser-ejector configuration and a recommended bid package, shipping, installation, calibration and testing procedures. Thermodynamic and aerodynamic support to SNPO, Marquardt, and Kaiser on the E/STS-2/3 budgetary study effort and the follow-on study effort was provided as follows:

(a) Information was supplied to Marquardt for their follow-on study program plan and SNPO was supported during negotiations with Kaiser.

(b) Water-injection analytical and experimental study efforts by WANL, Marquardt, and REON, were coordinated.

(c) Film cooling concepts were evaluated for possible use in the E/STS-2/3 diffuser.

(d) SNPO was supported in reviewing and evaluating Kaiser's budgetary study report and the SNPO-formulated work statements for the follow-on work.

(e) REON's review of Marquardt's diffuser heat-transfer calculations resulted in a diffuser height reduction of 22 feet.

(f) The initial diffuser coolant-flow rate calculated by Marquardt and REON was 430,000 and 180,000 gpm, respectively. The difference was found to be in the larger diffuser and in the large coolant-tube diameters recommended by Marquardt. Marquardt felt that the increased cost of supplying the water would be balanced by the lower diffuser fabrication costs. Marquardt's recommended coolant-flow rate is now approximately 200,000 gpm.

(g) The ejector fluid (steam) requirements specified initially by Marquardt for the E/STS-2/3 diffuser-ejector system were 40 to 80% higher than those calculated by REON. This difference has been resolved and Marquardt's calculated flow rates are now in agreement with REON's.

(h) REON supplied to Marquardt an analysis showing the effect of scale buildup in the cooling passages on diffuser heating rates. Marquardt revised the coolant requirements from untreated to treated water based on the preceding results.

(i) REON supplied analyses to Kaiser Engineers for determining the hydrogen exhaust plume shape and thermal radiation.

(j) Estimated ejector fluid requirements and the estimated diffuser-ejector coolant flow rates were determined.

(k) Preliminary studies were conducted to determine the feasibility of film cooling. Film-cooling design techniques are not sufficiently advanced to analytically design or scale experimental results with the degree of confidence required for designing a nuclear exhaust system. The effect of film cooling on the aerodynamics of a diffuser cannot be determined analytically, but a prior ETS-1 duct scale-model test program indicated that the shock structure upstream of the single row of film-coolant injection holes increased in strength. A preliminary analysis indicated that the required film-coolant flow rate would be in the order of 600 to 1000 lb/sec for water and 160 to 270 lb/sec for liquid hydrogen, providing the injection pattern and injection velocity can be determined. The hole spacing would have to be approximately 3 in. or closer at shock attachment locations. The estimated duct cost (installed) is \$2,000,000. Other costs include \$500,000 to design and fabricate a LOX-LH₂ NERVA II engine (required for testing the duct during its development); \$500,000 to test and modify the duct; and \$1,700,000 for the secondary gas generators (which includes the fluid storage), if a pumping system is needed.

(l) Preliminary studies were made to determine the feasibility of the water-cooled elbow. Water can be introduced in the elbow section to reduce the hydrogen gas temperature to the saturation temperature of the water. This will eliminate the high-heating rate in the elbow. An energy balance shows that approximately 5000 lb/sec of water would be required. The major disadvantages of this system are that the secondary-ejector flow rate would increase significantly and the fallout problem would be more severe.

(m) Two basic scrubber concepts were evaluated. One consists of a convectively-cooled diffuser, (5000 lb/sec) water film cooled 90° elbow, a (45,000 lb/sec) horizontal centrifugal water scrubber, and an ejector.

The other consists of a convectively cooled diffuser exhausting into a large pool of water, a large vacuum tank for altitude start-up, and a burn stack with a flapper door.

The aerodynamics of the first concept should not be affected by the mass addition in the elbow, providing it and the secondary ejector are large enough to preclude a high diffuser back pressure. The hydrogen velocity will decrease in the elbow when the water is mixed with it. The final velocities of the hydrogen (at 200°F) and the water will be nearly equal at the end of the mixing section. For an assumed maximum diffuser back pressure of 23 psia and a water-hydrogen velocity of 20 ft/sec, the mixing section diameter would be approximately 58 feet. The mixing section diameter could be reduced to 26 feet, if an extremely high water velocity of 100 ft/sec were practicable. The steam flow rate required for a secondary ejector to pump the hydrogen and water is approximately 20,000 gpm to obtain an 8 psia back pressure, and 35,000 gpm to obtain 4 psia back pressure. The secondary chamber pressure would be between 150 and 200 psia. This concept does not appear to warrant further study.

The second scrubber concept evaluated was based on the assumption that bubbling the 200°F hydrogen and saturated steam through water will decontaminate the hydrogen and condense the steam. A vacuum tank start is practical, economically competitive, and more reliable than a gas generator-supplied ejector that has the hydrogen at a low (200°F) temperature. Various problems associated with this concept, such as inadvertent criticality caused by core particles in water, leakproofing the system, and flapper-door sealing require further investigation.

(4) NERVA Testing in ETS-1 Studies

The practicality of testing a larger engine with a large area ratio nozzle in the ETS-1 facility at gas temperatures below 1500°F was investigated. This test would use a new uncooled diffuser-ejector and was discussed in report AGC-RN-TM0287, ETS-1 Modifications for NERVA II Follow-on Study.

Use of a new uncooled duct in the ETS-1 facility would enable the testing of nozzles with a larger area ratio than is currently possible. The present duct is large enough to test a 7:1 area ratio NERVA nozzle at up to approximately 40% power.

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D. PROGRAM MANAGEMENT

Task 4

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D. PROGRAM MANAGEMENT (TASK 4)

1. Program Planning and Control (4.1)

Program planning and control activities associated with the contract year 1966 work program and evaluations of program status were conducted for management on a continuing basis.

The routine biweekly updating, evaluation, and reporting of the active PERT networks were also continued. These included the REON portion of the NRX-EST, NRX-A5, NRX-A6, WEMU, MCC/EIV, RADA, XECF, XE-1, XE-2, E-MAD, and ETS-1 networks.

The activities of program planning and control personnel at the test site and at subcontractor facilities were monitored and coordinated.

A major effort during this period involved the detail planning, direction, coordination, and preparation of long-range plans.

2. Fiscal Control (4.2)

At the beginning of CY 1966, a new cost report format was developed in cooperation with SNPO-C and was implemented. This format displays budget, actual, and variance cost data as well as actual man-hours.

Throughout the report period, monthly fiscal reports and monthly cost estimates were prepared and submitted in accordance with the work statement.

The annual 2-year budget study and a special 12-year study were made. A 9-year proposal was prepared and submitted.

3. Technical Reports (4.3)

Reports published during the first three quarters of contract year 1966 are listed in Quarterly Reports No. 37, 38, and 39. During the fourth quarter of contract year 1966, the following reports were published:

<u>Report No.</u>	<u>Title</u>	<u>Pub. Date</u>	<u>Class</u>	<u>No. PP</u>	<u>No. Figs.</u>
2578	Program Requirements Document	6-27-66	Uncl	-	178
RN-66014 (Vol. II)	Program Plan for Contract Year 1967	8-24-66	Uncl	56	225
RN-DR-0075	SNPO XE Review (U)	7-15-66	C/RD	23	254
RN-DR-0083	Repairs of Discrepant Steam Generating System Liquid Lines	9-30-66	Uncl.	7	30
RN-DR-0084	Electro-Pneumatic Servo Actuator Evaluation Procedure	9-2-66	Uncl.	25	10
RN-S-0123 (Vol. VI)	MK Mod 2 Turbopump	9-20-66	Uncl.	---	84
RN-S-0190 (Vol. I Rev. 1)	Operational Support Plan XE-1	7-15-66	Uncl.	---	205
RN-S-0190 (Vol. II Rev. 1)	Operational Support Plan XE-1	7-22-66	Uncl.	302	---
RN-S-0241	Final Test Report NRX-A3 Side-by-Side Radiation Effects Test	8-2-66	Uncl.	31	71
RN-S-0274	Design Equation Analysis for Heat Transfer to Cryogenic Hydrogen at Pressure from 600 to 1500 psia and Wall-to-Bulk Temperature Ratios to 20	7-20-66	Uncl.	36	24
RN-S-0277	Development of a Multi-Color Infrared Radiometer to Measure NERVA Nozzle Wall Temperatures	6-29-66	Uncl.	54	18
RN-S-0283	Common Analog Model for NRX/EST(U)	8-5-66	C/RD	64	45
RN-S-0288	NRX/EST Malfunction Analysis (U)	7-14-66	C/RD	57	35
RN-S-0289	XE-Engine Systems Analysis Design Data Book (U)	9-15-66	C/RD	117	187
RN-S-0291	Evaluation of Test Results for Strain Gages and Pressure Transducers GTR-15	8-5-66	Uncl.	26	42
RN-S-0294	CFDTS Data Analysis Final Report	7-18-66	Uncl.	40	48
RN-S-0298	Final Report CFDTS Series I, II, and III Tests	8-3-66	Uncl.	102	82
RN-S-0300	Thermal and Error Analysis for Thermal Conductivity Test 37/R004	9-7-66	Uncl.	42	16
RN-S-0303	Evaluation of NRX-A5 Pressure Vessel	7-11-66	Uncl.	18	14

<u>Report No.</u>	<u>Title</u>	<u>Pub. Date</u>	<u>Class</u>	<u>No. PP</u>	<u>No. Figs.</u>
RN-S-0304	Evaluation of Alternate Controls for the 7-27-66 Technology Engine	7-27-66	Uncl.	16	17
RN-S-0306	NERVA Support Equipment Operative and Maintenance Instructions for Post/Operative Cell Materials Transfer System	7-7-66	Uncl.	33	17
RN-S-0308	ETS-1 Data Acquisition System Accuracy Test Specification	7-20-66	Uncl.	45	15
RN-S-0309	NRX/EST Data Analysis (U)	7-27-66	C/RD	133	258
RN-S-0309 (Supplement)	NRX/EST Data Analysis Report	9-8-66	Uncl.	10	200
RN-S-0310	XE-1 Test Plan	9-22-66	Uncl.	28	8
RN-S-0311	NERVA Materials Developments 2nd Quarter	8-26-66	Uncl.	62	15
RN-S-0314	XECF Test Specification	9-28-66	Uncl.	65	2
RN-S-0315	WEMU Test Plan	8-23-66	Uncl.	15	---
RN-S-0316	NERVA Engine Materials Parts List (U)	9-38-66	C/RD	29	43
RN-S-0324 (Vol's I & II)	Final Test Specification for Phase I-A of the Countermeasures Radiation Effects Program (U)	9-12-66	C/RD	39	7
RN-TM-0332	Stress Analysis of the XE-1 Lower Thrust Structure	7-27-66	Uncl.	18	---
RN-TM-0356	An Evaluation and Comparison of Thrust Deflection Methods for NERVA Engines	9-28-66	Uncl.	31	21
RN-TM-0358	Survey of Bearing Retainer Materials	8-23-66	Uncl.	25	8
RN-TM-0359	NRX-A5 Aluminum Pressure Vessel S/N 0000010 Structural Evaluation of Redesigned Cylinder/Closure Joint	7-26-66	Uncl.	20	12
RN-FR-0032	Monthly Fiscal Report Covering Period of August 1966	9-22-66	Uncl.	242	1
RN-FR-0031	Monthly Fiscal Report	8-22-66	Uncl.	243	1
RN-Q-0038 (Tech. Section)	Informal Quarterly Progress Letter No. 38 (U)	6-29-66	C/RD	275	101
RN-Q-0039 (Tech. Section)	Informal Quarterly Progress Letter No. 39 (U)	7-30-66	C/RD	203	87

<u>Report No.</u>	<u>Title</u>	<u>Pub. Date</u>	<u>Class</u>	<u>No. PP</u>	<u>No. Figs.</u>
RN-Q-0039 (R&QA Section)	Reliability and Quality Assurance Supplement Progress Letter No. 39	8-22-66	Uncl.	48	---
RN-TDI-0007	NRX/EST Nozzle and Bleed Port Qualification Final Test Report (U)	6-27-66	Conf.	25	48
	Stress Analysis of the XE-1 5 Inch Butterfly Valve Assembly P/N 1114342	7-6-55	Uncl.	28	---

4. Central Data System (4.4)

The central-data-control development plan was completed and transmitted to SNPO-C. This plan outlines the long-range objectives of data and documentation control systems that will be used for collection, storage, retrieval, and dissemination of technical data developed in the nuclear rocket program.

Four-hundred technical documents have been filmed and mounted in 4- by 6-in. microfiche jackets by using the 16-mm Recordak microfilm planetary camera. A duplicate Kalvar negative was made from the original silver negatives for transmittal to SNPO-C. Reports in alpha-numerical sequence, report numbers, and the key word in context (KWIC) of technical documents were generated to provide information for search and retrieval of documents.

Indexes of drawings, specifications, and standards of all NERVA drawings were updated and forwarded to SNPO-C on 16-mm film and 35-mm aperture cards.

Parts lists of engine reactors, facilities, and ground support equipment were transmitted to SNPO-C monthly on 16-mm microfilm.

Test data were distributed in the following forms for the indicated tests:

	<u>NRX-A1, A2, A3</u>	<u>NRX/EST</u>	<u>NRX-A5</u>
Channel listings		X	X
Hard copy and 16-mm microfilm of Cal-Comp plots	X	X	X
Steady-state averages		X	X
Multiple plots		X	X
Oscillograph and oscillograph microfilm at 0.1 and 4 in./sec		X	X
Narrow-band and wide-band time-data listings		X	X
Wide-band digital plots		X	
Digital power-spectral-density listings			X
Expanded time plots		X	
Calculated-leakage-rate plots		X	
Event Sanborn and Sanborn microfilm		X	
Amplitude-vs-frequency plots		X	

Communication among the various agencies and contractors in the nuclear rocket program is being maintained through the documentation and distribution of technical data in the form of (1) drawing lists, (2) specification indexes, (3) 16- and 35-mm microfilm, (4) microfiche, and (5) reports as required for specific retrieval of data.

5. New Technology Reporting (4.6)

Increased participation in the basic NASA technology utilization program resulted in these achievements during the contract year: (1) inputs submitted to the new technology program increased by 75%; (2) eleven reportable items were published as Technical Briefs; (3) three new technology articles were prepared and released to trade journals; (4) several backup packages were prepared; (5) three items reported were identified as potential transfers to other industries; (6) one item was transferred to industry through the Baldwin-Lima-Hamilton Corporation.

At the beginning of the contract year, an attempt was made to achieve renewed interest in the program by sending letters of commendation from the vice-president of REON to regular contributors. However, a marked increase in submissions was not noted. Better results were achieved when REON-produced Technical Briefs were displayed on a special bulletin board in a heavily trafficked location.

In addition to promotional activities, new technology briefings were given at various REON division staff meetings, NTO, and at REON program review meetings. In addition, continuing liaison with engineering personnel was maintained, as were regular meetings with the several divisional new technology coordinators.

As a result of these promotional and liaison activities, 172 new technology inputs were recorded during CY 1966, as opposed to 102 inputs during the previous year. Because of a CY 1967 reduction in program hardware development (the activity from which most reportable items are derived) a new awards program is currently under study for the next contract year.

At the request of SNPO, preparation of trade-journal articles was encouraged. Three were released during the year. Eighteen backup packages also were prepared and forwarded to SNPO-C during CY 1966. These packages included reports, drawings, pictures, and instructions.

Three reportable items were identified as potential technology transfers. These were:

- (1) The Rokide bonding process (RN TU-018) which was transferred to other industries through the Baldwin-Lima-Hamilton Corporation. This technique has been used to apply strain gages in a number of applications.

- (2) The high-temperature thermocouple (RN TU-065) which is now being marketed by Aerojet's Aerometrics Division. Inquiries have been received, but a new source for the tungsten-rhenium tubing material must be established before the commercial potential can be realized.

(3) A working model of the high-speed brazing furnace (RN TU-036) was built at the request of SNPO-C. Operating and maintenance instructions were prepared and transmitted to SNPO with descriptive Vugraphs and photographs.

More than 75% of the reportable items submitted during CY 1966 were approved by SNPO-C as potential Technical Briefs and Shop Notes. During the previous contract year, only 45% of these items submitted were thus approved. The increased quality of CY 1966 reportable items is attributed to both an increase of inputs and the closer working relationship established with SNPO-C personnel.

Other activities during CY 1966 included monthly or bi-monthly program status meetings with SNPO personnel and the start of a compilation of computer programs for distribution to other contractors through NASA.

Assistance was also provided SNPO in the collection and documentation of technological advancements achieved at REON for incorporation in a SNPO ROVER program reference document. Some 26 reportable items submitted during CY 1965 were reworked, in whole or in part, during CY 1966. Six patent disclosures were submitted to NASA/AEC during the contract year.

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E. CAPITAL EQUIPMENT

Task 5

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E. CAPITAL EQUIPMENT (TASK 5)

L. AGC-NASA Plant Equipment (5.0.2)

a. Fabrication

Several items of plant equipment necessary to support the NERVA nonnuclear test program at the Sacramento Plant were procured and installed during the contract year. For Plant Test Operations a digital tape handler was procured from the Ampex Corporation. This equipment, which records on-line digital test data, was received and installed in early May. Also, a gaseous-hydrogen flowmeter calibrator was procured from the Brooks Instrument Division of the Emerson Electrical Company in February. The system was installed in the Transducer Laboratory and successfully acceptance tested.

A new Dewar vessel was to be installed in an existing cryostat, that would enable the cryostat to be used for calibrating pressure transducers. Subsequently, the addition of a small fixture within the existing Dewar was determined to be adequate for adapting the existing cryostat for pressure transducer calibration. Installation of the modified test fixture has been completed, and the cryostat can now be utilized for pressure transducer calibration using an immersion type of fixed-point temperature control.

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F. SACRAMENTO PLANT SPECIAL TEST EQUIPMENT

Task 6

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F. SACRAMENTO PLANT SPECIAL TEST EQUIPMENT (TASK 6)

1. Test Zone A (6.2)

Development testing of NERVA components continued throughout the contract year in the Cryogenics Laboratory. Test Bay A-5 was utilized exclusively to meet testing requirements for the TPA Bearing Development Program. Test Bays A-7, A-9 and A-11 were used extensively for conducting tests of the 5-in. check valve, PSV, 5-in. butterfly valve, 5-in. PDSV, and simulated cooldown line.

A plan to provide a test setup for the XE upper thrust structure was eliminated because the test hardware would not be available. Subsequently, a new plan was established to conduct a series of environmental tests on the XE upper thrust-structure module. These tests are scheduled for the early part of CY 1967.

2. Test Zone H (6.3)

The NERVA/PHOEBUS test complex in Test Zone H is shown in Figure 154. The test stand designations are indicated on the front of the test complex, with the exception of Test Stand H-4A and H-4B. The sign indicating Test Stand H-4 should indicate Test Stand H-4A. Test Stand H-4 extends from the superstructure at the rear of the complex. Test Stand H-4B extends from the rear of the complex adjacent to the right side of H-4 and directly behind the spherical vessel on the right of the test complex. The large spherical vessel in the left center of the photo is the LH_2 catch vessel, V-H 10. The cylindrical tank in the left foreground provides a 5,000-gallon supply of propane for the burners of the GH_2 heater. The vent stack to the heater is seen directly behind the propane tank.

Figure 154
Test Zone H NERVA/PHOEBUS Test Complex

Test Stand H-5, shown in Figure 155 was activated during the latter part of contract year 1965 and continued in use during the first quarter of contract year 1966. A block of 21 CFDTs tests was conducted during CY 1966, which successfully demonstrated the bootstrap concept. During this block of tests the two-stage nozzle and turbine-exhaust ejector systems provided a controlled range of backpressure conditions, including a simulation of expected ETS duct pressure.

Backpressure conditions were achieved by injecting a variable flow of GH_2 spoiler gas into the ejector systems to combine with hardware effluent flows. Satisfactory performance of the ejectors and the spoiler gas system was demonstrated during the tests that were concluded on 12 November.

Test Stand H-6 continued to serve the turbopump assembly development program throughout contract year 1966. The gaseous hydrogen heater provided heated hydrogen as the turbine drive fluid for 53 of the tests, and five tests were conducted using ambient hydrogen as the turbine drive fluid. Figure 156 shows a typical hot-gas drive TPA installation in Test Stand H-6.

It was expected that heated hydrogen would be used as the turbine drive fluid during all TPA tests, but failure of the hydrogen heater on 1 November 1965 interrupted the hot-gas testing. Subsequently, approval was obtained to demonstrate some of the TPA performance characteristics using ambient-temperature hydrogen as the turbine drive fluid. Therefore, the Test Stand H-6 turbine drive system was modified and the five cold-gas drive tests conducted.

The failure of the hydrogen heater was attributed to the cracking and rupture of two of the heater tubes, which contributed to the failure of other nearby tubes. As part of the repair effort, the two unaffected sections or tube bundles of the heater were modified by removing 10% of the tubes in each section. The tubes were thinned out to increase the velocity of the gas

Figure 155
Test Zone H-5

Figure 156
Typical Hot-Gas Drive TPA/Installation in Test Stand H-6

flow in order to achieve a lower average operating temperature across the wall of the tubes. Repair, modification and reactivation of the heater was completed and hot-hydrogen TPA testing was resumed in mid-January.

Concurrent with the other activities relating to Test Stand H-6, an auxiliary TPA discharge and turbine exhaust duct was installed by a sub-contractor, PMI Corporation. The system provides an alternative means of hydrogen disposal in the event that the catch vessel, V-H 10, or the V-H 10 flare stack do not perform satisfactorily. The 45-day subcontracted effort was completed on 28 February.

The hot-gas system of Test Stand H-6 was also used to provide heated hydrogen to Test Stand H-4A for turbine power-control-valve testing. Figure 157 shows a typical test setup for TPCV testing. Eight TPCV tests were conducted during the year. In conjunction with four of these tests, performance of a Bendix actuator was also evaluated.

NERVA nozzle tests on Test Stand H-4 (Figure 158) were conducted throughout the last quarter of contract year 1966. Ten tests were conducted during the period.

At the beginning of the contract year, the low-pressure auxiliary system vents (bleeds, fill lines, GH_2 actuation, purge panel, etc.) were manifolded together and vented through the V-H 12-vent stack. Under certain conditions (the V-H 12 overpressurization incident, for example) the venting of V-H 12 caused the burst diaphragms in the low-pressure systems to fail in reverse due to shock loading. Also, the vent systems serving both LH_2 run vessels (V-H 11 and V-H 12) were not equipped with ignition systems, which could enable the formation of hazardous hydrogen clouds during periods of high-pressure venting. To provide more desirable venting systems, a flame-front ignition panel and three pilot nozzle assemblies installed on Test Stand C-9 were procured from the M-1 Program during the first quarter. Subsequently, a modification to the existing vent system was made that included separation of the low- and high-

Figure 157
Typical Test Setup for TPCV Testing

Figure 158
NERVA Nozzle Test on Test Stand H-4

pressure vents and the installation of the vent-ignition system. The vent system modification and installation of the ignition system was completed on 26 August under a subcontracted effort by the PMI Corporation.

The hydraulic-supply capability of the NERVA/PHOEBUS test complex was augmented with a Rucker hydraulic pumping unit from the M-1 Program. The additional unit became necessary when test-complex demands were increased. A subcontract was awarded to PMI Corporation for the relocation and reinstallation of both the C-Zone unit and the existing unit located high in the superstructure of the test complex. Installation of the augmented system on a concrete pad adjacent to Test Stand H-4A was completed on 5 August.

Leakage in the Test Zone H high-pressure gaseous hydrogen receivers during the previous two contract years resulted in downgrading the maximum operating pressure of the A. O. Smith receivers from a 5000 psig rating to 3500 psig. Representatives of A. O. Smith, SNPO-C, NASA, and AGC participated in a discussion of methods of repair or modification of the receivers that would ensure design performance. The most feasible modification appears to be a mechanical-plug. Modification includes removal of the 1 in. vent nozzles in each of the receivers and replacing the nozzle with a mechanical plug.

Daco Metal Products was awarded a subcontract to modify and repair seven receivers. Subsequently, cycle and hold testing of the first vessel repaired was added to the subcontract. Under a two-phase plan two receivers are being modified in Test Zone E during CY 1966 and five receivers will be modified in Test Zone H during CY 1967, following successful repair of the two receivers. Modification of the GH_2 receivers V-H 74 and V-E 6 started after award of the subcontract on 26 May.

Modification of the two preceding receivers was initially scheduled for completion by September 1966. However, defects in the original welds were detected during removal of the receiver vent nozzles. These defects, which generally appear as voids, cracks, porosity, and lack of fusion between

the weld and parent material, have delayed the receiver modifications beyond the original date. Repair of these defects is expected to delay completion of the two-vessel modification effort until January, 1967.

In conjunction with the Daco receiver-modification effort, PMI, Inc. was awarded a subcontract to repair the vent nozzle on the LH_2 storage vessel, V-E 34. This vessel, obtained as part of E Zone equipment transferred to the NERVA Program from the M-1 Program, has been repaired prior to use as a source of LH_2 or LN_2 for the liquid-to-gas converters. The gas from the converters will be used for testing of the repaired receivers.

3. Other Test Zones (6.8)

Delivery by Cryenco of a high-sensitivity cryostat for the calibration of platinum-resistance temperature transducers was made on 7 March. The cryostat and the associated data acquisition system were installed in the Transducer Laboratory for final checkout and acceptance testing. These tests indicated deficiencies in performance and operation of the cryostat, and some internal wiring modifications and procedural changes were made. However, lack of agreement in the readings from the two temperature standards could not be corrected without modification of the cryostat inner assembly. These modifications will be made by Cryenco.

Four Potter flowmeters have been calibrated by the National Bureau of Standards. The meters will serve as standards for calibrating other meters used to measuring liquid flow.

Three gaseous-hydrogen flowmeters have been calibrated by the University of Colorado. Fabrication of the calibration system in which these flowmeters will be used has been deferred until contract year 1968.

4. LRO Laboratories (6.9)

A bell-type prover was procured from the American Meter Company. This low-pressure flow standard is being installed in the measurement standards laboratory and will be used primarily for the calibration of bellows-type flowmeters. The prover was calibrated at the National Bureau of Standards prior to shipment to Aerojet.

Development testing of NERVA components continued during the year in the R&D Engineering Laboratories. To meet these testing requirements a load cell, relief valves, Fisher-Porter flowmeters, and LN_2 Dewar vessels were procured.

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G. NRDS OPERATIONS

Task 7

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G. NRDS OPERATIONS (TASK 7)

1. NRDS General Support (7.0)

a. Management of NERVA Test Operations (NTO)

Overall program management for NTO at NRDS was provided together with close liaison among NTO, ACFI, SNPO-N, SNPO-C, LASL and other NRDS contractors; coordinated with the activities of government agencies and participating contractors to resolve problems; and informed off-site management of program status.

During the second quarter of CY 1966 two new groups were formed that report to the Manager, NTO. The first is a site engineering group incorporating the nuclear analysis and engineering support group previously shown under Sub-task 7.1 and some of the engineering effort from ETS-1 and E-MAD. The main effort of the group was in support of the NRX/EST and NRX-A5 Test Series at Test Cell A, and the activation programs at E-MAD and ETS-1. The second is a central documentation and reporting group. The NRX documentation and reporting group under Sub-task 7.1 was expanded to include all NTO operations. Efforts included the preparation and processing of NRX-A5 pretest and posttest procedures, NRX/EST and NRX-A5 reports, and E-MAD and ETS-1 activation procedures and reports. Efforts were also expended in the preparation or revision of administrative procedures and standard operating procedures in support of NTO operations.

Specific activities of the site engineering group and the documentation and reporting group are covered under other sub-tasks.

b. Program Planning

Detailed test site schedules for NRX/EST, NRX-A5 and NRX-A6, reactor testing, assembly, disassembly, post-operative inspection,

hardware delivery dates, required document preparation dates and Test Cell A and Test Cell C activities were prepared and maintained.

Projection and procurement of propellants and pressurants required for hardware testing and facility testing at NRDS were performed.

The fourth annual edition of the Program Requirements Document (Report 2578) was submitted to REON, Sacramento for publication. The second revision to the fourth annual edition is being prepared and will be issued 1 November 1966.

Viewgraphs were prepared depicting monthly NTO expenditures of government PRD funds, AEC and NASA, for operational and capital equipment dollars against the established budget banks of monies obligated to PanAm, and cost data were provided. Requirements were prepared for development by EG&G of a cost versus bank report to be submitted monthly to NTO. A current NTO activation and operations status presentation was prepared for NERVA program management at Sacramento.

Other activities included preparation of: working bar charts for ETS-1, which were correlated with the ETS-1 Master Network (work is in process to bar chart the NTO tasks reflected on the E-MAD master network).

2. Test-Cell-A Operations (7.1)

Two major test series were performed at Test Cell A during contract year 1966. The first, performed during the period December 1965 to March 1966, was the NRX/EST test series, which involved a test assembly simulating the engine configuration. The second was the test series performed on the NRX-A5 test assembly.

a. NRX/EST

(1) Experimental Plans

The experimental plans for the NRX/EST test series were:

a. EP-IA: Experimental Plan IA was performed on 8 December 1965, and the following operations were performed successfully: (1) the central poison wires were removed, (2) the reactor was brought to initial criticality at a drum position of 99 degrees and (3) differential and integral drum-bank worth measurements were made. Cold-flow tests scheduled for EP-IA were not performed because of bad weather and lack of control-room time.

b. EP-IA': Experimental Plan IA' was performed on 15 December 1965, and the operations included (1) checkout of the PCV-41 pressure-control loop by performing an ambient hydrogen-gas-flow test and (2) four cold-flow tests on the EST system. In the cold-flow tests, the turbine did not rotate as predicted. Posttest inspection revealed discoloration of the turbine exhaust ducts, and test data indicated that hydrogen had burned in the stacks during the run. Investigation revealed no damage to the turbine.

c. EP-IA'': Experimental Plan IA'' was performed on 6 January 1966, and significant operations included: (1) response measurements on the power-control loop, (2) turbopump rotation, and (3) test-assembly bootstrap.

d. EP-IA⁴: Experimental Plan IA-4 was performed on 19 January 1966, and the operations included five cold-flow tests that (1) confirmed predictions of cold-flow startups and (2) established an acceptable Dewar pressure for a successful bootstrap test to intermediate power.

e. EP-IIA: Experimental Plan IIA was performed on 2 February 1966, and significant operations included: (1) Phase-II neutronic calibration and (2) a scaled-down bootstrap test to intermediate power.

f. EP-IIB: Experimental Plan IIB was performed on 3 February 1966 and consisted of two bootstrap startups to intermediate power that (1) demonstrated a bootstrap startup on a 50°R/sec chamber-temperature ramp, (2) provided some system-response measurements at a 2000°R chamber temperature, (3) provided thermal calibration data at a 2500°R chamber temperature, and (4) demonstrated capability to bootstrap when stored energy in the outer reflector was depleted. The TPCV was not functioning properly during this test, and Control Drum No. 1 failed to respond immediately to a Scram signal. Both anomalies were investigated, and fixes were made on the TPCV by replacing the actuator and, on the drum by insulating the hydraulic piping.

g. EP-IIC: Experimental Plan IIC was performed on 11 February 1966. Significant operations included (1) bootstrap startup to intermediate power with constant drum position, (2) system-response measurements, (3) limiter checkout, (4) checkout of the no-flux-loop temperature controller, and (5) mapping of a constant-chamber-temperature line of the operating map.

h. EP-III: Experimental Plan III was performed on 3 March 1966, and the successful operations included (1) bootstrap to full power and (2) establishment of the engine operating map.

i. EP-IV: Experimental Plan IV was performed on 16 March 1966. The operations included (1) bootstrap startup to full power with fixed drums, (2) operation at rated temperature for 14.8 min, and (3) cross-correlation measurements.

j. EP-IVA: Experimental Plan IVA, performed on 25 March 1966, included operation of the test assembly at nominal rated conditions for approximately 13.5 min. The reactor was shut down when outward movement of the control drum reached a nominal 160°.

(2) Significant Accomplishments

The most significant operations and accomplishments in the NRX/EST test series were as follows:

- a. A nuclear-rocket-engine system was operated for the first time with the major engine components connected in the flight functional relationship.
- b. System stability under a number of different control modes was demonstrated while operating the engine over a broad area of its performance map.
- c. The multiple-restart capabilities of the engine system were demonstrated.
- d. The endurance capability of the reactor and other engine components was demonstrated by operating at nominal rated conditions for approximately 30 min and at or above a 1700°R chamber temperature for approximately 100 min.

In general, the performance of the reactor and engine system was in accordance with pretest predictions. Reactor parameters, such as temperatures, temperature distribution, pressures, pressure drops, and engine system performance, were reproducible from one test to another. The planned test series called for use of the facility turbopump and associated systems for one or more of the full-power tests in order to meet the reactor objective of 30 min of full-power operation. Because the engine system performed satisfactorily, it was not necessary to change over to the reactor-only configuration (use of facility turbopump). All experimental plans of the NRX/EST test series were performed by using the engine system.

The integrated power for the test series, as determined from the nuclear instrumentation, was approximately 3.7×10^6 Mw-sec, which compares with an integrated power of 1.6×10^6 Mw-sec for the NRX-A3 reactor and 3.4×10^5 Mw-sec for the NRX-A2 reactor.

b. NRX-A5

(1) Experimental Plans

The experimental plans associated with the NRX-A5 test series were:

a. EP-I: Experimental Plan I was performed on 26 May 1966. Significant accomplishments were (1) initial criticality, (2) Phase-I neutronics calibration, (3) control-drum worth measurements, (4) response measurements on the PCV-41 pressure controller and the power controller, and (5) ambient GH_2 and cold GN_2 flow tests and Scram LH_2 flow-decay tests.

b. EP-II: Experimental Plan II was performed on 6 June 1966. Significant accomplishments were (1) Phase-II neutronic calibration (RAM set), (2) cross-correlation of power controller and limiter checkout, (3) low-power dosimeter irradiation, and (4) valve and system operation with the reactor at 50 w for an interference check.

c. EP-III: Experimental Plan III, also performed on 6 June 1966, was the first full-power run of the NRX-A5 series. Significant accomplishments were (1) full-power operation over the maximum period compatible with Test-Cell-A fluid capacity and (2) checkout of the no-flux temperature controller, the power and temperature limiters, and the fixed-drum controller.

d. EP-IV: Experimental Plan IV was performed on 23 June 1966. Major objectives were (1) startup from low power to rated conditions with LH_2 flow control, (2) operation at steady-state conditions in no-flux temperature control, and (3) operation at rated conditions for the maximum period compatible with Test-Cell-A capacity. The first two objectives were achieved, but the outward movement of the control drum to the test-parameter limit of 140° terminated the test after approximately 14.3 min at full power.

(2) Significant Accomplishments

The most significant operations and accomplishments of the test series were as follows:

a. The test assembly operated for 30.4 min at close-to-rated conditions and for 35.3 min above a 1900°R chamber temperature.

b. Operation of a new eight-decade neutronic system was demonstrated. For EP-I and EP-IV, the neutronic detectors were located on the test car under the test article and were used as the neutronic-system feedback.

c. The reactor was checked out and operated at rated conditions by using a temperature-control system without the neutronics power control as an inner loop.

d. The acceptability of a startup from low power to near-rated conditions was demonstrated by using hydrogen reactivity with the drums in a fixed position.

e. Initial-criticality tests of the reactor were performed after all poison wires had been removed.

In general, performance of the reactor and engine system was in accordance with pretest predictions. Reactor parameters, such as temperatures, temperature distribution, pressures, pressure drops, and engine system performance, were reproducible from one test to another. The integrated power for the NRX-A5 test series, as determined from the nuclear instrumentation, was approximately 2.2×10^6 Mw-sec.

(3) Facility Preparations for NRX-A5

After the NRX/EST test series, a considerable effort was required to decontaminate Test Cell A and reduce the radiation environment. As soon as the radiation levels were reduced, work was initiated to prepare the facilities for the NRX-A5 test series. The major facility modifications made prior to NRX-A5 were as follows:

- a. Changeover of the facility system and control-room system from the NRX/EST to the NRX configuration.
- b. Installation of the integrated nuclear instrumentation system (INIS).
- c. New power and temperature limiters.
- d. Fixed-drum mode of control.
- e. No-flux temperature control.
- f. A new LH_2 level-measuring device in Dewar C (LASL-supplied reflectometer).
- g. Modifications to the emergency shutdown system.
- h. New scram flow-decay circuit.

To check out the facilities and obtain operational data for the NRX-A5 test series, one facility-checkout experimental plan was performed on 12 May 1966, the significant accomplishments of which were:

- a. Checkout of the facility turbopump and cryogenic piping.
- b. Checkout of the LH_2 flow-control system.
- c. Checkout of the fixed-drum-startup flow profile.
- d. Operator training.
- e. Acquisition of data for the scram flow-decay system.

In preparing for the NRX-A5 test series, a new subsystem-checkout program was formally initiated to ensure that all systems and subsystems were ready for the test series. The program was very successful, and only minor abnormalities occurred during the test series.

c. Posttest Operations

Because no further testing was scheduled for Test Cell A after NRX-A5, the facility was decontaminated and shut down. The gas propellant banks were depressurized and purged, and the LH_2 Dewars were emptied, warmed up, and purged. All other systems were put in a state to permit reactivation within ninety days, if required. A complete inventory was taken, and the cell was turned over to LASL custody on 15 August 1966.

NRX test-operations personnel have been integrated into the LASL organization to support the Phoebus tests and future NERVA-program tests at Test Cell C. NTO efforts to date have been primarily concerned with system familiarization and assistance in checking out the new Dewars, pumps, and vaporizer systems.

3. R-MAD and Post-Mortem Operations (7.3)

a. NRX/EST

(1) Assembly Operations

The NRX/EST assembly operations started the first week of June 1965 with the receipt and inspection of NRX/EST components. Assembly of the components on the NRX/EST test car was performed in two phases. The first phase included the direct component shield (DCS), turbopump assembly (TPA), and the associated piping beneath the DCS. The majority of this work was performed prior to receipt of the reactor pressure vessel assembly. The second phase involved installation of the reactor/pressure vessel assembly and the propellant feed system on the test car.

Subsequent installation effort included the control drum actuators, removal of the peripheral poison wires prior to installation of the nozzle, and the privy roof mounted shield (PRMS).

The NRX/EST test assembly was moved to Test Cell A on 18 October 1965, for mating to the test cell. Final test cell mating was accomplished with completion of the high-level-plug breakaway tests.

After the mating, an instrumentation resistance check was made. This was followed by a complete leak check of the car-cooling water system and leak checks of the propellant feed system, hydraulic lines, and the pneumatic lines.

In preparation for testing, an end-to-end instrumentation checkout was performed, the control drum system was checked out, a 50-psig helium leak check of the test assembly was conducted, test car valves were checked out, and the DCS enclosure was leak checked. The test assembly was completed and ready for testing on 4 December 1965.

The NRX/EST test series included 11 experimental plans. At the completion of the test series, the NRX/EST was disconnected from Test Cell A and the test article was transferred to R-MAD for disassembly.

(2) Disassembly and Postmortem Operations

Decontamination of the disassembly tooling was accomplished and tooling modifications were completed on a schedule that met the requirements of the disassembly operation.

Disassembly of the NRX/EST test article was completed, and the NRX/EST parts were shipped to WANL, AGC, and LASL for analysis. The disassembly tooling and equipment was then decontaminated and reworked in preparation for the A5 reactor disassembly. Those parts not shipped were removed from disassembly area and placed in the post-operative-examination hot cells for storage.

The follower card system and procedure for hot-cell control of radioactive hardware and fuel elements were prepared and the procedures for the post-operative examination work on the NRX/EST were completed. Storage areas were geographically designated and marked for storage of radioactive parts, and the procedures for placement of all parts in the dump area were completed.

The following list shows the types and quantities of operations performed as a part of the post-operative examination of the NRX/EST test assembly. Also shown is a comparison of the number of operations scheduled per test specification and the actual number of operations performed as a result of posttest selection.

<u>Operation</u>	<u>Per Test Specification</u>	<u>Actually Performed</u>
Fuel Elements:		
Detailed visual examination	72 elements	307 elements
Dimensional measurements	135 elements	140 elements
Depth of corrosion	166 elements	171 elements
Electrical resistivity	100% of core	80% of core
Airflow impedance	Posttest select	20 elements
Axial sectioning (bore exam)	13 elements	53 elements
Incremental weight (sectioning and exam)	16 + posttest select	53 elements
Flexure tests	12 + posttest select	68 elements
Fatigue tests	24 samples (min)	63 samples - (8 elements)
Orifice (detailed) exam	Posttest select	5 elements
Replication	100 elements	12 elements
Center element radiography	Posttest select	63 elements
Preparation of metallograph specimens	63 + posttest select	58 elements
Support block visual examination	100% of core	100% of core
Support block detailed visual exam	Posttest select	100% of core

In addition, hardware and instrumentation were examined in accordance with the test specification. Rough radiation surveys were taken of all test assembly components during placement of the components in designated sections of the hot storage area.

Additionally, a warm component manual examination area was set up and activated in the beetle shed, using a contamination control exhaust hood, lead brick shields, a lead-glass viewing window, and special tooling. This area was used for examination of various reactor hardware components, dimensional measurements, examination of instrumentation, and repair of disassembly tooling.

Metallographic studies of NRX/EST components were carried out at Los Alamos, New Mexico (LASL). Studies were made of approximately 200 fuel elements and samples of various hardware components. A complete report is presented in the NRX/EST posttest report supplement, (NTO-R-0079, Supp. I). Rate-of-decay studies of 16 NRX/EST component samples were completed at NRDS.

(3) Radiochemistry Operations

IBM listings, data sheets, sample work sheets, and other required forms were prepared for use with the NRX/EST radiochemistry operations. The junior hot cell was cleaned and refurbished. Methods were tested for doing cloud, fallout samples, and other analyses for NRX/EST.

Uranium calibration wires irradiated during NRX/EST EP-I were analyzed and the result reported in the NRX/EST EP-I Test Report. Uranium and nickel rabbit samples irradiated during EP-I through EP-IV were analyzed and the results were reported in NTO-R-0072, NRX/EST Radiochemical Report.

A Beckman Electroscan was set up and electrochemical procedures for determining uranium and niobium in NERVA fuel solutions were studied. Methods of separating uranium and niobium were established by potential-sweep chronoamperimetric methods on the Beckman Electroscan.

Cloud samples from NRX/EST EP-III and EP-IVA were analyzed for iodine 131 through 135, inclusive, strontium 91, strontium 92, yttrium 93, zirconium 97, antimony 127, tin 121, cadmium 115, cadmium 115m, and lanthanum 141. The results of these analyses were forwarded to WANL, and included in a report Effluent Studies on NRX/EST, WANL TME 1476, July 1966, issued by WANL, Large Safeguards Engineering Department. Fallout samples from NRX/EST EP-III and EP-IVA were analyzed for iodine 131 through 135, inclusive. The results of these analyses were reported by memo to the Pan American Health and Safety Dept.

The activated nuclides present in soil, rocks, concrete, water, oil, and aluminum specimens irradiated in the vicinity of Test Cell A during the NRX/EST operations were determined. Whole-body ionization measurements were performed on approximately 1,000 fuel elements. Gamma spectrum measurements were completed and fuel element sections were cut, dissolved, and analyzed to determine radial and axial fission distributions in the NRX/EST core. More than 50 1-in. sections were dissolved and analyzed by electrochemical methods to determine uranium and niobium content.

Rate-of-decay studies were started on 16 different activated reactor components from NRX/EST using multi-channel gamma spectrometry to identify the nuclides that were producing most of the activity.

b. NRX-A5

(1) Test Car Preparation

The stripdown and cleanup of test car T-6 to be used for the NRX-A5 was accomplished. A template was made of the privy roof and penetrations for use by Marquardt to check for guide tube-fit after the tubes had been welded into the pressure-vessel forward closure.

The car was surveyed for radioactivity, found ready for reuse, and an inventory made to notify WANL-GSE of the hardware required to rebuild the car for NRX-A5.

Assembly of test car T-6 was started in January and the unit was ready for installation of the NRX-A5 reactor on 26 March 1966. The portable cleaning unit was redesigned to have a single-pass H_2O flush system for final cleaning of test car piping. The required hardware was purchased, and the single-pass H_2O flush system was fabricated in time for use on the NRX-A5/T-6 test car.

(2) Assembly Operations

Setup of the clean assembly area was completed and the NRX-A5 reactor was received on 23 March 1966. The peripheral poison wires were removed from the reactor core on 29 March 1966. The pulse-neutron technique of measuring delayed criticality was deleted from this operation due to operational uncertainties. Following peripheral poison wire removal, the nozzle was installed. The control drum actuators were checked out and installed on the test assembly in accordance with NTO-SOP-0013 and procedure NRX-A5-P6.

The accomplishment of procedure NRX-A5-P9 was the major change from previous NRX assembly operations. This procedure allowed removal of the central poison wires at the R-MAD building. Inverse multiplication data and single-drum, roll-out measurements were used to determine shutdown margins. Portions of the instrumentation end-to-end checkout were accomplished at R-MAD so that personnel radiation exposure could be held to a minimum.

The test assembly was transferred from the R-MAD building to Test Cell A on 19 April 1966.

(3) Disassembly Operations

The NRX-A5 test assembly, disassembly and posttest operations began on July 6, 1966, with the disconnect of the test assembly from Test Cell A and its return to the R-MAD facilities. The test assembly was not returned to the R-MAD Building immediately after the last power test on June 1966 because the fuel-examination facilities in the upper disassembly bay were not completely set up and checked out. New examination equipment was obtained and installed and upper disassembly bay modifications were made in preparation for the NRX-A5 post-test operations. The disassembly operation proceeded routinely throughout the first phase of disassembly. During the disassembly operations, the test assembly components received a visual inspection and were photographed. Representative samples were retained for post-operative examination in the hot cells.

All fuel elements were individually weighed and photographed, using automatic sequencing equipment, as the fuel clusters were disassembled in the upper bay. These photographs were the basis of visual examinations at NRDS by WANL Large Materials Department representatives.

During the disassembly operation, WANL, AGC, and SNPO observers were present. Changes of existing procedures were documented and approved by the NRX-A5 test specifications and procedures review board.

Following disassembly operations, cleanup of the disassembly bay was completed. The decontamination and routine maintenance of equipment are currently in process.

Activities for post-operative examination of NRX-A5 included the following:

- (a) Preparation of a parts-control system utilizing 2000 IBM-type cards.
- (b) Preparation and issuance of post-operative examination procedures.
- (c) Preparation of approximately 85 instruction data books.
- (d) Design and procurement of special containers, trays, etc.
- (e) Procurement and setup of new incremental weight section saw, balance, and photography position table.
- (f) Setup and checkout of all equipment, including initial installation and operations of annealing furnace, orifice leak checker, and digitized punch-tape data recording corrosion depth gage.

As part of the NRX-A5 post-operative program, the following operations were completed:

<u>Operation</u>	<u>Test Specification</u>	<u>Actual Number of Operations Performed</u>
Fuel elements		
Detail visual examinations	157 elements	400 elements
Depth of corrosion	212 elements	238 elements, 3000 traces
Air flow impedance	Posttest select	33 elements
Axial sectioning	41 + posttest select	74 elements
Incremental weight	31 elements + posttest select	80 elements (approx 3,800 pieces)
Flexure test	49 elements + posttest select	69 elements, 797 pieces
Orifice jet examinations	Posttest select	15 elements
Orifice jet leak testing	Posttest select	30 samples
Length measurements		17 samples
Metallography sample preparation	Posttest select	315 specimens
Support block visual examination	100% of core	100% of core
Support block detailed visual examination	28 + posttest select	100% of core
Support block potting/sectioning	26 + posttest select	46 blocks
Recalibration of instrumentation	13 items + post test select	17 items
Hardware examination and operations		570 pieces
Annealing studies	Posttest select	24 samples
Radiography	42 elements	32 items
Replication	Posttest select	24 items

(4) Radiochemistry Operations

The NRX-A5 program performed by Radiochemistry Operations included the radiochemical determination of radial, angular, and axial fission distributions in the core, plus chemical analyses to determine the posttest axial distribution of uranium and niobium in NRX-A5 fuel elements. The radiochemical investigations included axial gamma scanning of fuel elements, gross ionization measurements of approximately 900 unbroken fuel elements, and fission product analyses of a representative set of fuel elements.

This group also performed special analyses of debris samples as requested by observers during disassembly operations. The results of all radiochemical studies of NRX-A5 will be reported in the NRX-A5 Radiochemistry Report to be published during the next reporting period. Also, reactor effluent samples from NRX-A5 EP-III and EP-IV were analyzed to determine fractional release values for various isotopes.

Additional work included development of chemical analysis methods for cesium 137, uranium, and niobium, and reports are being prepared; preparation of samples of Cs-137 for ASTM round-robin analysis by 15 laboratories; and the investigation of a new high-resolution germanium detector system for multi-channel gamma spectrum analysis.

c. NRX-A6

(1) Test Car Preparation

The stripdown and cleanup of test car T-7, to be used for the NRX-A6, was accomplished. The nominally radioactive parts were stored, and an inventory of usable items was made.

The T-7 test car was brought into the disassembly area and buildup was begun. Current buildup has been mainly in the area of deck plate

installation and privy side-panel installation. The T-3 plug was repaired, installed, and leveled on the T-7 test car.

Ninety percent of the drawings required to complete the buildup of the NRX-A6 test car have been received and official copies were issued. In addition, the Test Car and Piping Assembly Procedure (NTO-I-0092) for NRX-A6/T7 test car has been issued. Other documentary output has consisted of the incorporation of comments into the procedure NRX-A6-P7, NTO Operating Procedure for Test Assembly Instrumentation, Receiving, Inspection, Installation and Checkout, assembly engineering comments on the draft copy of the NRX-A6 test specification, and the writing and updating of various NTO-SOPs required for NRX-A6 assembly operations.

Efforts directed toward preparation for the NRX-A6 facility flow car, have been terminated due to the elimination of this unit.

(2) Assembly Operations

Turning stand NT 600009 is being strengthened and repaired.

d. Technical Photographic Services

NTO photographic services coordinated its activities with the support services contractor and coordinated all photography performed for NERVA test operations. A full-color, sound film was produced for a science fair.

NTO photographic services, together with Pan American and ACFI team support, provided for installation of a 35 mm camera mount as a permanent fixture attached to the R-MAD Building on the first level roof for photographing Test Cells A' and C during testing.

Lights at the E-MAD facility were calibrated. Additional lighting of 3200°-Kelvin units were installed in the hot cells at the R-MAD

facility for post-operative examination work on NRX/EST. Specific efforts related to NRX/EST and NRX-A5 test articles are as follows:

(1) NRX/EST

A total of 2581 still photographs were taken and a total of 38,715 photographic prints were distributed to personnel concerned with the NRX/EST Program. Approximately 1500 feet of motion picture film was completed for NRX/EST coverage. Macro- and micro-photographs were taken to assist with the post-operative examination of NRX/EST.

(2) NRX-A5

During NRX-A5 disassembly and post examination, approximately 5600 still photographs were processed. Although the photographs were taken and developed by the support services contractor, coordination and distribution of approximately 65,000 photographic prints was performed by the NTO MAD photographic support group. Approximately 2500 feet of 16 mm color motion picture film was taken and shipped to Aerojet, Sacramento.

Approximately 2100 feet of 70 mm negative film was exposed using the automatic-sequencing photo system installed in the R-MAD upper bay. This film was used for immediate visual examination of the NRX-A5 fuel elements. A total of 3600 feet of 70 mm positive film was printed and distributed to WANL and LASL.

4. ETS Operations (7.4)

a. Steam Generator Tests

The EP-IV series of tests on module 1 were initiated in December 1965, and were completed 10 February 1966. Authorized modifications were incorporated in the steam generator and related I&C systems prior to the

initiation of EP-IV. Pretest checkouts prior to the initiation of the full steam tests were delayed by the late delivery of module 1 components, which had been repaired by Thiokol.

Modifications included installation of a pressure equalization line to enable surge-free flow during the initial water-fill of the water injector and combustion-chamber coolant circuits; revisions of the steam generator water-injector flow circuit to improve reliability and flow control characteristics; addition of a combustible-gas detector system to ensure safe operating conditions; changes in the AFEL and LSE consoles to enable the use of the permanent I&C system; addition of a temporary method of temperature conditioning the propane supply; and rebuilding the control chassis to eliminate redundancies and improve reliability.

EP-IV consisted of 17 tests, including six full-steam tests having a total duration of 334 sec. The purposes of the program were to evaluate the performance of the steam generator injectors with liquid propane at temperatures ranging from 40 to 80°F and to evaluate the modifications incorporated into the steam generator system. Results of EP-IV, reported in NTO-R-0061 indicated that the steam generator propane supply temperature should not exceed 60°F.

The EP-V series of tests were started on March 22 and concluded on 1 April 1966. This test series was made to evaluate a single module at full-steam conditions with the remaining two units at idle conditions, and with the steam plenum exhaust piping orificed to obtain a plenum pressure simulating two-module operation at full steam with the third module at idle. Preparations for EP-V included the fabrication of replacement propane, LO₂ and water headers and the repair of questionable welded joints in the lines between the headers and modules. This series included six full-steam tests for a total duration of 471 sec. Postfiring inspection revealed one small crack in S/N 0018 injector, which was repaired. Tests results were reported in NTO-R-0082.

Installation of the redesigned equipment box wiring harnesses was completed prior to the initiation of EP-VI. During this series of tests, it was necessary to install dampening orifices in the low-pressure side of the second-to-third stage pressure switches to correct a malfunction involving failure to obtain second-stage ignition. Two of the scheduled four switching tests in this test series were completed. The remaining tests were deferred when the second-stage igniter LO₂ shutoff valve ruptured following shutdown of module 1 during EP-VI-16, when second-stage contaminants entered the LO₂ line. A gaseous nitrogen purge was introduced on nonoperation stages to avoid a repetition of this condition. Postfiring inspection revealed excess porosity in some of the welds around the spud assemblies on the face of injectors S/N 0017 and 0018, and bulges in the internal liner of S/N 0016 combustion chamber.

Prior to the initiation of EP-VI, Supplement No. 1, all liquid oxygen system components were serviced to meet material-compatibility requirements and the three redesigned relay control units were installed. Two steam generator tests were conducted on August 8 and 9. The first test consisted of full-steam operation of modules 2 and 3 for 240 sec, followed by switching to modules 1 and 3, which were operated at full steam for approximately 100 sec. On August 9 an 1100-sec duration test of modules 2 and 3 was conducted, maintaining steam temperature at approximately 1300°F. At the conclusion of the full-duration run another switching attempt was made, but the units failed to switch satisfactorily. Both tests utilized the main facility steam line. Results of the EP-VI test series were covered in Test Report NTO-R-0083.

Work was initiated in September 1966 to incorporate the water system and electrical control system modifications required by the product improvement test plan. The electrical control system modifications will enable a return to idle operation from full-steam conditions without a shutdown and restart sequence.

b. NERVA Exhaust System Testing

NERVA exhaust system testing was rescheduled for contract year 1967 due to delayed fabrication of the duct. The primary section of the duct was received at NRDS on June 27, and the secondary section arrived on 22 July 1966. Field surveillance of all installation activities was performed on a continuous basis, and included the resolution of problems associated with the duct installation by Lincoln Welding. All contractor installation activities were completed on 30 September 1966, except for the hydrostatic test. During the test on 15 September 1966, the secondary exit elbow drain pipe water jacket ruptured. Leakage also occurred at the primary section-to-elbow transition weld. An initial outline of a repair program was formulated. Figure 159 shows the duct installation in the ETS-1 duct vault prior to removal of the wood shoring used during fit-up to the facility interfaces.

Installation of the NES duct instrumentation was initiated on 29 September 1966 and was constrained by the duct installation. Preparatory work included system design for the engine test compartment (ETC) purge test and the NES design demonstration tests, electrical checkout and calibration of the instrumentation components, the assembly of instrumentation kits, and determining loop resistance of strain gage cables.

Design of the NES temporary control system in conjunction with the FEP temporary control system was completed, and installation of equipment was initiated.

The NES design demonstration tests will be conducted with the temporary engine compartment (TEC) due to delayed completion of the engine test compartment (ETC) installation. Assembly of the nozzles into the TEC was completed and a successful lift test was accomplished. Installation of the TEC into the test stand is scheduled for approximately 4 October 1966 to avoid interference with installation of the upper bellows seal of the ETC. The simulated test stand adapter/upper thrust structure (TSA/UTS), which was fabricated and delivered to ETS-1, will be installed later.

Figure 159

View of NES Duct during Installation at ETS-1

Design of the NES temporary gas analyzing system to enable monitoring of the oxygen concentration of the duct exit and also within the TEC was completed. The existing flange in the TEC will be modified to incorporate the required additional electrical penetrations. The gas sampling pumping station for the permanent ETC gas monitoring system was received and vendor fabrication of the detector equipment was in process.

The preliminary rough draft test description for the NES duct water flow and calibration test was initiated. Installation of the screen filter for the NES duct water supply line is pending completion of the NES duct hydrostatic test.

c. Interface System Installation and Checkout

The construction work package for the interface system installation was approved on 12 November 1965 by SNPO-N; construction was accomplished by the Catalytic Construction Co. Field surveillance of construction activities was performed on a continuous basis. Test procedures prepared by CATCo were reviewed to ensure compliance with construction specifications and compatibility with the overall process and test stand systems. Other construction and installation documents were reviewed, including cleaning procedures, electrical test procedures, and welding procedures and tubing standards to be followed in the installation of the interface system. Approximately 80 coordination confirmation requests (CRR's) were submitted to SNPO-N for resolving construction problems and implementing the Work-Around Plan.

Due to delayed installation of the NES duct and ETC, a Work-Around Plan was devised to modify a portion of the interface system to provide subsequent tie-ins of test spools for the initiation of the facility experimental plan (FEP) in September 1966. The eight basic mechanical craft work packages were installed, and included the main engine vents, cooldown system modifications, control drum and TPCV actuation supply, ETC purge ring, fluid filters, NES fluid supply and engine valve actuation supply. Beneficial occupancy of the interface system was obtained on 30 June 1966.

Test spools and lines were installed as required for FEP-1. This package included modification of the LN_2 cooldown system, combining cooldown lines, installation of a system for simulation of engine impedance, and the design and installation of an exhaust system for propellant disposal.

The Test Stand Control System (TSCS) miscellaneous crafts work package, which was submitted to SNPO-N on 21 January 1966, was completed. This package included modifications of the facility graphic display lower racks for accepting the TSCS components and of the I&C system for accommodating the engine control system (ECS) and the interfacing of the facility process system with the TSCS.

Installation and checkout of the REON (Sacramento)-furnished equipment for the TSCS for operation of the process subsystems in support of FEP-1 was completed on 28 September 1966. Major factors that delayed the installation were late delivery of signal conditioning equipment and cabling, and the correction of electrical misterminations in work performed by craft labor.

d. Facility Systems Checkout and Activation

(1) Facility Modifications

In addition to providing the required service and day-to-day maintenance of the facility, I&C, and power systems, various design modifications are being made to ensure system performance in accordance with operational and safety criteria. These activities include:

(a) An auxiliary vacuum pumping system was installed on the LH_2 storage Dewar V-3801 for maintaining a vacuum on the inner line jacket. The liquid-level probe for V-3801 was modified to incorporate a carbon resistor level-detection system prior to the initiation of Phase IV facility checkouts.

(b) The two high-pressure Corblin compressors were replumbed for parallel operation, resulting in an increase in GHe pumping capacity of about 100%.

(c) Relief valves were installed on the pneumatic control system for each PCV Annin Domotor and in the 1000 psig GN₂ actuation header to protect the system from overpressurization.

(d) Carbon steel actuators in the remote shutoff valves of the fire protection system in valve pits 1 and 2 were replaced with stainless-steel actuators, and timing orifices were added to eliminate hydraulic water hammer.

(e) The potential hazard inherent in the design of Security Valve Company RSV pneumatic actuators was corrected.

(f) Facility tie-ins and coordination was provided for the design and installation of the LN₂ and LH₂ vaporizers that replaced the original low-capacity systems having questionable reliability.

(g) The LH₂ liquid level probes for LH₂ run vessels V-5001 and V-5002 were modified to incorporate a carbon resistor level-detection system.

(h) The electric power system modifications were incorporated for the remote control of diesel generators and synchronizing capabilities. Testing will be initiated following approval of the Operating Procedures.

(i) Ten basic modifications of the existing safety system to reflect a change in logic requested by SNPO-C and REON were initiated.

(j) Operational modifications to the data acquisition system included the replacement of cables between the digital data system formatters

and the digital recorders, the fabrication of a signal substitution test unit for the digital data system, and the installation of three Ampex tape recorders and associated electronic equipment.

(k) The facility control consoles were modified based on operating experience and as a result of the GHe and GH_2 pumping system modifications.

(2) Facility Checkouts and Activation

(a) Checkout tests of the new LN_2 vaporizer were made and the system was put into operation for supplying GN_2 to the high-pressure gas storage vessels in support of test operations and system cleaning operations.

(b) Prior to the initiation of Phase IV tests of the LH_2 system, various leaks in the vacuum-jacketed lines and valves were repaired, including fitting leaks in the vacuum jacket of LH_2 run vessels V-5001 and V-5002. Approximately 170,000 gallons of LH_2 were transferred into the LH_2 storage Dewar V-3801, for the 100 psig pressurization testing of V-3801. Following the correction of system deficiencies in the LH_2 vaporizer and supply line valve from V-3801, Phase IV, Part 2 tests on the LH_2 vaporizer were successfully concluded and the system was put into operation for supplying gas to the high-pressure gas storage vessels.

(c) The process water system flow tests were satisfactorily concluded using the NES duct-simulator test loop and with a cavitation-suppressing orifice plate installed downstream of flow control valve 50-FCV-31. The test performed on 13 January 1966 evaluated the effects of the process water piping modifications and of the steam generator and radiation-shield water flow requirements during flow simulation of the NES duct. The final test on 17 March 1966 evaluated the effect of the concrete anchor in the pipe chase at the duct vault wall, through which the 36-in.-dia water supply and return lines pass.

(d) Operational checkouts were made of the duct vault door from both the local and remote operator positions after cleanup operations for the hydraulic unit and associated plumbing and electrical systems were completed.

(e) Fire protection operational procedures were revised to conform to the changeover from the MCP to the lead safety engineer console. Following preactivation inspection of the valve pits, the fire protection system was activated from the LSE console. Included in this operation was the flushing of the deluge system and cycling of the RSV and deluge valves.

(f) Construction surveillance of the ETC installation was provided and included review and coordination of contractor erection and test procedures and the resolution of design and installation discrepancies. The beneficial occupancy of the ETC is expected on 18 November 1966. Preparations were made for the ETC mechanical, seal and leak test during the first quarter of contract year 1967, and included procurement of vacuum pumps, orifice meters, the bottom shield plug and modifications to the remote installation console (RIC). Hardware for the ETC purge test was procured and is scheduled for installation during the first quarter of contract year 1967.

(g) Procurement of the radioactive airborne and gas monitoring system was initiated, with delivery scheduled for December 1966. The system is required primarily to protect personnel from the entry of radioactive gas or particles into the below-ground air system to ETS-1.

(h) Test Cell A criticality monitoring system was transferred to ETS-1 and work was initiated for incorporating the system into the ETS-1 Area surveillance and warning system. The detectors will be mounted on the test stand shadow wall and will monitor the neutron flux from the reactor through the ETC S-2 side shield.

(i) Coordination was provided for the design and nuclear aspects of the source drive system, the reactor neutron source and the radiation source storage vault. Fabrication of the source drive system was initiated by WANL

(Large) and will be used for checking all TSCS neutron channels end-to-end prior to unlocking the drums and attempting to bring the reactor to the critical phase. Procurement of the reactor start-up source is pending receipt of the minimum reactor source level requirements. Design of a radiation source storage vault for the temporary storage of sources required at ETS-1 for neutronic calibration was completed.

(j) The first subsystem checkout, FEP-1, was started on 28 September 1966 to verify the construction and operation of the liquid-nitrogen cooldown system, related components and TSCS.

(k) The scheduled preliminary data system accuracy tests were performed and on-site preliminary analysis of Mode 16 drift data, AD/DC crosstalk and frequency response was completed prior to detailed analysis by REON. Limited data system tests were conducted on long-line, low-level signal transmission to provide data relative to engine stage test stand 2-3 (E/STS 2-3).

(l) The necessary logistic services were provided on a continuous basis, including the provisioning of spare parts, the procurement of special equipment and instrumentation, the completion of a valve data computer listing of the remotely operated valves at ETS-1, and the procurement of propellants in support of test operations.

e. ETS-1 Engineering Support

(1) The activation specifications contained in NTO-I-0094 were superseded by NTO-I-0124 and established the objectives and defined the requirements relative to completion of ETS-1 activation up to receipt of XECF.

(2) Revisions of the ETS-1 management network were submitted to the Program Management Office to incorporate the Work-Around Plan and to resolve conflicting activity schedules caused by construction delays, enabling the initiation of FEP-1 on 28 September 1966.

(3) Engineering requirements were defined for the specific support equipment required by each ETS-1 activation specification. Data pertinent to the design and procurement of checkout devices for the interface system were obtained based on XE-1 requirements.

(4) Test Descriptions for FEP-1 and FEP-2 and the operating procedure for FEP-1 were published. Work was continued preparing the test description for FEP-3 and the operating procedure for FEP-2.

(5) Test predictions for the LH_2 system in support of FEP-1 and for the gas systems in support of FEP-2 were issued. The preparation of test predictions for the LH_2 system in support of FEP-3 was partially completed. Report NTO-R-0092 was published summarizing the test predictions for FEP-1.

(6) Procedures were prepared related to ETS-1 operations, including procedures for the data acquisition system, ETS-1 facility configuration control, data handling plan, and the processing of channel engineering data.

(7) A preliminary issue of the ETS-1 facility data book NTO-R-0086 was published to provide a single-source reference for test planning and analysis.

(8) Preparation of operational and maintenance manuals was completed for the TV and communication systems and will be published as NTO-I-0191 and NTO-I-0123, respectively. An XE operator qualification and training guide and manuals covering operation of the TSE and ASE consoles are in the process of publication.

(9) The integration into channel engineering of all systems installed at ETS-1 was conducted on a continuous basis, including the establishment and maintenance of all documents necessary for the inventory of channel systems and parameters. These functions included the preparation of the data log and channel list for FEP-1, the steam generator test series, Phase IV tests, the assignment of

sequence numbers to signal conditioner bins and the TC&P system, and the preparation of criteria for computer control of the patching system.

(10) Signal conditioning requirements for the various scheduled test programs at ETS-1 were determined. A program was developed for automating the design of thermocouple and resistance thermometry mode cards and processing of associated data.

(11) Programs were developed for the processing of test data, channel engineering functions, calibration data and trouble shooting on the CDC-3200 computer. These programs included quick-look listing, slope intercept, engineering unit conversion, tape gapping, X-Y plotter application, the sorting and updating of EG&G tapes and listing of the I&C unit list.

5. E-MAD Operations (7.5)

a. E-MAD Activation and Facilities Operation (7.5.2)

(1) Facilities, Systems, and Equipment Activation

Facilities, systems, and equipment procurement, installation, checkout, modification, and repairs necessary to the activation of the E-MAD Facility were completed as follows:

(a) Heating Ventilation and Air Conditioning System (HVAC)

1 The final checkout and testing of the HVAC control system was completed on 6 January 1966. The checkout, rework, and repair of approximately 163 individual discrepancies of the HVAC control system was completed on a find-and-fix basis in accordance with the established checkout guideline procedure for the HVAC (issued 27 September 1965). The HVAC subsystem static balance was conducted to assist in locating room air leaks and to identify subsystem deficiencies.

Air leakage between individual subsystems in the building precluded maintaining design pressures. The filling of voids in the juncture of all E-MAD building metal walls, floors, and ceilings with polyurethane foam was required to reduce room air leaks detected by the static-balancing operation. The concrete walls of room 172 and the cell service area, south corridor, were caulked and regouted to seal off voids and cracks. The walls were subsequently repainted with a carboline sealer to reduce porosity. The adjustment of the fan speeds and flow system pattern for subsystem K5 (east gallery - first floor) was accomplished by interchanging the adjustable fan drive pulleys between subsystems K1 and K5. The subsystem static-balancing operation was completed on 25 August 1966.

2 The underground fuel storage tank was drained, opened, and cleaned following the clogging of fuel lines leading to the facility boilers. Additional filters were installed.

3 All discrepancies detected on the E-MAD hot water boiler by the State of Nevada Industrial Commission Boiler Inspector were corrected.

(b) Manned Control Car (MCC)/Engine Installation
Vehicle (EIV)/Locomotive

1 The MCC and EIV were delivered to NRDS on 14 September 1966 and are located in the ETSMB in preparation for acceptance testing by NTO personnel. NTO personnel closely followed the development and modification of the MCC/EIV at REON during June, July and August, 1966. A program plan was completed that defined the acceptance test operational development programs relative to the MCC/EIV and detailed programs, scope and time requirements. The MCC/EIV acceptance test procedures (NTO-I-0088) and addenda were completed and issued on 8 July 1966. A procedural outline was prepared for the shielding integrity check (SIC) test of the MCC. Window W-5 was tested for relative light transmission to provide data for evaluating the MCC window.

2 The locomotive was operated periodically and routine preventative maintenance was provided. The locomotive was used for operator training programs and hookup of flat cars for delivery of items from storage at E-MAD to ETS-1 and R-MAD. Preventative maintenance included battery and electrical servicing, cylinder liner inspections, and brake adjustment. An operational procedure was prepared to define the proper startup and shutdown of the locomotive.

(c) ETSMB, RMSF, and Interconnecting Railroad System

1 Minor modifications of the ETSMB included reworking of the roll-up doors; repair of discrepancies on the Dravo heater furnaces; correct installation of filters; and the replacement of burned switch contacts. The plans and specifications have been completed and transmitted for the ETSMB warehouse and storage facility. The bid package is being held by SNPO-N pending resolution of a strike at NRDS.

In addition to routine ETSMB maintenance, a telephone circuit was installed for hand-set stations; an intercom extension from the E-MAD building intercom was added; a government surplus air compressor and delivery lines were installed and checked out; and a battery charger for the locomotive was procured and installed in the building.

2 The radioactive material storage facility (RMSF) was completed and an NTO standard operating procedure (SOP) was prepared for those E-MAD functions associated with facility operation. The construction of the RMSF switch indicator panel was completed as part of the modification of the railroad indication switch circuitry, and coordination was provided to LASL & PAA in verification of the railroad track and switch conditions for shipment of radioactive materials from R-MAD to the graveyard.

A positive signal feedback system was installed in the railroad transport system switch circuitry to provide a visual indication in the MCR of the track switch positions.

3 The high-activity storage car, presently located at R-MAD, underwent functional acceptance tests.

4 The interconnecting railroad system was essentially completed, and a mechanical and electrical checkout of the interconnecting railroad track switches was conducted on 13 October 1965 in preparation for the delivery of the LASL hot car to the RMSF. Engineering support was provided to Pan Am to determine the electrical problem in the railroad control system panel in the MCR. An investigation revealed that a drive box was loose, causing erroneous activation of a microswitch. Railroad track switch boxes are being modified to remove the lag screws and install through-bolts in the ties as a more stable method of securing the switch boxes.

(d) Overhead Positioning System (OPS)

NTO efforts for the OPS consisted primarily of correcting deficiencies encountered during acceptance testing. Repairs were required for the electrical and mechanical systems. The OPS trolley-limit switches were reset to conform with operating specifications and the trolley inching and override functions were adjusted to operate to mechanical stops. Test and adjustment of the mast plumbness-indicating system was completed. New microswitches were installed for jack #1 in the floating head assembly, and the head circuitry was calibrated. Limit switches in the control relay in Controller B were adjusted to enable a lock-in of the auxiliary manipulators. An incremental calibration and curve plot of the floating-head readout circuitry up to 2000-lb tension and up to 1000-lb compressive load was accomplished. The OPS and V-1 crane controls were modified to enable tripping of the main breakers located in the electrical equipment room from the master control room. A new forearm section of the OPS auxiliary manipulator was installed to replace the original unit that had a damaged clutch. The OPS floating head assembly was modified by addition of high-strength bolts in the jack-screw housings to increase load handling capacity to 42,000 lb. Design deficiencies of the upper- and middle-mast limit switches were corrected and the trolley control speed was adjusted. The disposition of the material review record

for the OPS was completed, except for shock and vibration testing that will be completed during operational development, leading to the completion and signoff of the narrative end-item report. Product improvement for the OPS was conducted concurrently with use in RADA Operations. Product-improvement innovations included the addition of high visibility paint and contrasting colors to the floating head, jacks, readout box, override drive shafts and brake relay knobs.

(e) Floor Mounted Handling System (FMHS)

Testing of the floor mounted handling system was completed and the deficiencies were corrected. An operational checkout and engineering analysis of the master control room operations related to the FMHS were completed and the deficiencies were noted for correction. Deficiencies corrected included modification of the mobile carriage and dolly wheels and pickup shoes to enable them to negotiate trackage gaps at crossovers and turntables. The drive systems were modified to enable one unit to drive the other in the event of the failure of a drive system. A study was undertaken to eliminate the polarity reversal of the carriage and dolly on the ST-2 turntable.

(f) Postoperative Cells and Material-Transfer System (POCMTS)

The bus-rail installation portion of the POCMTS construction package was completed by CATCo on 8 March 1966. Final inspection and acceptance by NTO was completed on 9 March. An acceptance test procedure was issued for POCMTS on 5 May 1966, and the mechanical portion of the POCMTS installation was completed, inspected, and accepted by NTO on 7 July 1966. Modifications to the POCMTS system included rework of the intercell transfer system carts to provide adequate clearance over the cell-wall sill plates and rework of bus-rail hardware to enable proper installation of the bus rails.

(g) Construction Package Items

Plans and specifications were prepared for a number of facility construction package items and transmitted with work orders to SNPO-N. The packages prepared, dates transmitted, and status are as follows:

1 E-MAD facility security fence on 23 November 1965; the contractor completed the installation on 8 March 1966, and final inspection and acceptance was made by NTO/E-MAD on 10 March 1966;

2 E-MAD facility security fence lighting on 23 November 1965; the installation was completed, inspected, and accepted by NTO/E-MAD on 1 April 1966;

3 E-MAD facility emergency battery lighting extensions on 20 January 1966; the installation of this system was initiated on 25 April 1966, and was completed and accepted on 10 June 1966;

4 E-MAD facility materials control station on 25 February 1966; the installation was completed, inspected, and accepted on 22 July 1966;

5 Bonded storage area and security vault on 28 February 1966; these packages were completed, inspected, and accepted on 22 July 1966;

6 Flammable storage area on 28 February 1966; this package was completed, inspected, and accepted on 22 July 1966;

7 E-MAD facility air-sampling system on 8 March 1966; the installation by CATCo was completed on 25 August 1966. Testing and acceptance were initiated on 26 August 1966 and are currently in progress.

8 E-MAD facility exterior lighting on 11 March 1966; installation was completed, inspected, and accepted on 22 July 1966;

9 The plans, specifications, drawings, and pertinent information for the bid packages for the engine transport system maintenance building (ETSMB) storage area, an actuator laboratory, and for the 200-psig high-pressure air system, were completed by NTO/E-MAD and transmitted to SNPO-N for appropriate action on 21 and 22 August 1966. The actuator laboratory and the 200-psig air system are pending review by SNPO-C and resolution in FY 67 PRD funding constraints.

(h) Miscellaneous

1 New roofing was applied to a section approximately 40 by 100 feet on the cold bay area to repair windstorm damage that occurred on 26 April 1966;

2 The shielding window was removed from position W-1 (northeast corner) in the E-MAD hot bay, room 122, and was transferred to R-MAD;

3 Additional metal office partitions were received and assembled in the south gallery of the hot bay, second floor, to provide temporary additional office space;

4 A motor drive coupling for shielding door 122-1 was replaced;

5 The bed plates and roller assemblies for shielding doors 127-1 and 130-1 were reworked;

6 The temporary shielding wall between cells 166 and 171 in the postmortem area was removed;

7 The rework, modification and checkout, and acceptance testing of the V-2 crane in the hot bay (room 122) was satisfactorily completed;

8 The rework, modification, and acceptance testing of the V-1 crane in the cold bay (room 115) was satisfactorily completed;

9 Modification of the WT-1 turntable included modification of the drive assembly to reduce the turntable speed, the addition of a positive pneumatic lock pin, provision for a remote control console, and the installation of travel-limit switches. A similar modification was completed for the ST-1 turntable in the hot bay area;

10 The drive system on the ST-2 turntable was removed and modified in accordance with an NTO design to reduce the turntable speed, to provide a remote indexing system, and a positive locking device for rail alignment;

11 Ladders for access to the OPS and V-1 crane haunches at the south end of the crane maintenance balcony were completed and installed;

12 Replacement of gate valves originally installed in the E-MAD building process gas lines (helium, nitrogen and spare gas) has been completed. In addition, some manifolds in the lines were replaced and all line joints were resoldered with silver-solder, rather than the previously used lead-solder, to bring the lines up to ASME specifications;

13 Installation of the facility radiation monitoring system was completed and a notice of completion was signed by SNPO-N and NTO on 10 August 1966. A logic circuitry module was designed and fabricated by NTO for incorporation into the E-MAD building radiation monitoring circuitry. The module logic requires a signal from two or more detectors for tripping the evacuation alarm and reduced the possibility of tripping from single spurious signals;

14 Installation of the E-MAD roof protective railings was completed on 30 June 1966, and final acceptance was made by NTO-E-MAD on 1 July 1966;

15 Modifications were completed for repair of integrity discrepancies found during the SIC Phase I and Phase II testing. Shielding integrity check (SIC) test final reports for the Phase I (report NTO-R-0038 covering the hot disassembly bay and crane maintenance balcony) and the Phase III and Phase III addendum (report NTO-R-0039, covering the hot-hold transfer tunnel and cell service area, and the engine and core disassembly cells) were published on 15 October 1965. The shielding integrity check test final report (NTO-R-0062) for the Phase II (postmortem cells) and the Phase II Addendum (mating surfaces of the shielding door 173-1 and the cell service area) were published during March 1966;

16 Listing of recommended modifications of the MCR layout and permissive controls designed to improve operational capability and reliability of this system for remote handling of the X Engine and related GSE was completed;

17 Checkout of the cathodic vacuum etcher (post-mortem cell add-on equipment) was satisfactorily completed on 13 April 1966 with representatives of NTO/quality assurance, NTO engineering and the Nuclear Engineering and Materials Company, Appalo, Pennsylvania;

18 Installation of the postmortem cells add-on equipment including the remotely operated grinder, polisher, ultrasonic cleaner, vacuum oven, and cathodic etcher on a mockup of an in-cell table was accomplished to enable checkout of this equipment in cell #165;

19 Installation of the microhardness tester in PM cell 165 and acceptance testing were completed on 16 February 1966;

20 Installation of lead shielding for the remote metallograph transfer system was completed in PM Cell 165, and metallograph components such as polishers, grinders, and ultrasonic cleaners were prepared and checked out;

21 Gross and incremental gamma scanner equipment was received at E-MAD and the console for the incremental scanner was assembled;

22 Installation of the plug door transfer system was completed for postmortem cells 165 and 166;

23 The plug door transfer system was modified by torch cutting lifting eye holes in the upper lifting plate;

24 Installation and acceptance testing of 12 master slave manipulators (MSM) in the west hot bay (room 122) were satisfactorily completed on 1 October 1965;

25 Installation of lead-glass windows in the portable personnel shield (PL 50) was completed on 9 February 1966;

26 Further specifications and requisitions were processed for nine additional PRD funded master slave manipulators for use in the CDAE and the hot bay with a required date of 1 November 1966 (these were placed in hold status).

(2) Design, Review, and Engineering

(a) Engineering and design efforts included revising the binocular mount design for the shielding windows; design of controller carts for the OPS, the WMHS, and rectilinear manipulator; the design of a latch mechanism for the TSA/UTS interface; the design for lead shielding of the metallograph sample system and metallograph traversing tube (transfer system).

Major effort was expended for the engineering, design, and design review for provisioning list and add-on equipment, special GSE, and various tools and fixtures, which included: design of a latching mechanism for the plug door transfer system to develop a stronger and improved method of attachment; design of actuator mechanisms for the plug door transfer drawers; design of a platform to provide access to the number 2 cooling tower; design of lucite protective covers for the microhardness tester control panels; requirements for periscope installation; justification for an emergency power generator; and engineering studies of the master control room (MCR) circuitry and panel layout to provide for optimum remote-operations capability.

(b) Equipment specifications were prepared on the CDAE remotely operated 15-ton hoist and rectilinear manipulator; the lead-glass windows for the CDAE and the fuel element processing system (FEPS).

(c) Drawings were prepared as required to accompany the plans and specifications of systems and equipment required at E-MAD. Additional drawings were generated as required to support activation efforts. These drawings were required for as-built measurements of the CDAE for use in establishing facility equipment interfaces; the structural dimensions of the WT-1 and ST-1 turntables; the postmortem cell inter-cell walls; instrumentation transducer locations on WEMU; electrical circuitry for the several control systems in the OPS; cell wall penetrations for the gamma scanner equipment; the hot water boiler modifications; the layout for POCMTS enclosures; the postmortem cell metallographic equipment; the cobalt source shipping fixture; the MSM installation fixture; the boiler electrical circuit modifications to provide electrical interlock between the supply air fan and the oil pump; a grip mechanism for the upper thrust structure (UTS) positioning head; the center element ejection fixture; a coupler for the plug doors to hot cell material transport; and thrust bearings and seals for the OPS mast drives.

(d) Engineering reviews were made of design criteria for the PVARA stand (PL 4094); the engine hold stand (PL 4099); UTS dust covers (PL 4100); the CDAE remote hoist and rectilinear manipulator; the ACF gamma scanner; the engine

assembly/disassembly stand (PL 4021); the core cell lighting system; the installation package of the remote metallographic equipment (PL 5211); the POCMTS installation and acceptance test packages; the design modification package for the FMHS mobile carriage and dolly; the design criteria for the nozzle closure actuator (PL 4107); the operational requirements for the fuel element processing system (FEPS); the compatibility of the WMHS with existing remote handling GSE at R-MAD; the specifications for the HVAC system thermocouple recorders; and the acceptance test procedure for the stereo microscope (PL 5237).

(e) Reviews were conducted of the provisioning lists for the NRX/EST and NRX-A5 to determine the R-MAD equipment to be transferred to E-MAD, which could be included in the master provisioning listing; the NRX-A6 and XE-1 measurements requirements lists (MRL) to develop instrumentation assembly procedures and instrumentation log data books; the XECF and XE-1 test plans and operational support plans; and the RADA/XE-1 interface test plan.

(3) I & C Functions

(a) Instrumentation and controls effort was provided in activation and development of the intercom and PA systems. Mounting brackets for intercom headsets were installed at stations and provided with headsets; intercom stations were modified to accept Hannon portable isolation amplifiers to eliminate cross-talk problems. An evaluation was made of tests which were performed to ascertain the suitability of the TV vidicon protection circuit, and a key selector was installed for a telephone at the TV console.

(b) The E-MAD facility intercom and PA add-on system package was submitted to SNPO-N on 15 February 1966; the installation of this package was completed, inspected, and accepted on 20 June 1966.

(c) A modification of the intercom system was accomplished in the hot bay to enable direct contact with the master control room independent of the channel selector located in the east gallery.

(d) Instrumentation and controls support was provided for the checkout and acceptance of the public address and intercom add-on systems following installation by Systems Design Corporation.

(e) Closed circuit TV system on 25 June 1965 (installation and checkout); installation was completed, inspected, and accepted on 17 June 1966.

(f) Other I&C functions were performed including the installation of two ammeters, one in each generator circuit in the locomotive cab to provide indication of generator charge rates; the repair and restoration to service of the failed Perkins power supply unit; the continued installation of the radiation detection system (RDS); continued installation and checkout of the portal monitoring system; and the continued maintenance of the locomotive electrical systems. Additionally, investigation of citizen band type receivers was conducted as part of a study to determine the type of equipment best suited for E-MAD communication needs; and instructions covering electrical/electronic aspects of the WMHS were provided as part of the overall WMHS training course for the technicians.

(4) Safety

(a) The E-MAD safety-related efforts during this contract year included the completion of a life saving first aid training course by all E-MAD personnel (to be continued for newly employed personnel on a periodic basis); an evaluation of the MCC/EIV system was prepared by REON/NTO Health and Safety personnel for inclusion into the MCC/EIV acceptance testing package; an emergency plan for E-MAD personnel and for addition to the NRDS emergency plan, Part V, was completed; and a study to determine fire and toxicity dangers inherent in beryllium residue from grinding and machinery operations required for NRX-A6 postmortem investigations was completed.

(b) All E-MAD NTO personnel were fitted with gas masks in May 1966. Training was provided to assure that all personnel were familiar with the proper usage of this equipment.

(c) The assembly and checkout of the criticality monitoring module and portal monitor was completed.

(d) The replacement of one post indicating valve (PIV) and two fire hydrants from the north parking area at E-MAD to a point outside the traffic area was completed.

(e) Equipment for four emergency first aid stations was received and the stations were established at E-MAD. The training of personnel relative to the first aid stations is in process and will continue as the manpower of E-MAD is increased.

(f) All miscellaneous lifting equipment such as slings, safety pallets, and shackles were proof-load tested in compliance with NTO-SOP-0036.

(5) Support Service Contract Activities

NTO direction was maintained for the normal facility maintenance, housekeeping services, and minor modifications performed by the support service contractor (SSC), Pan American. Specific work order requests were prepared and activities of the SSC were monitored for such items as floor-tile replacement, boiler inspection, repair, boiler room repainting, sand blasting of the sill plates, and providing electric power for the battery charger at the ETSMB. Installation of the #1 cooling tower access walk, modification of the RMSF spur-switch system, non-destructive testing of crane slings, modifications of the WR-1 operating air supply, power and telephone extensions for the second floor office area as well as providing support to the activation and checkout and conducting the heating, ventilating and air conditioning (HVAC) subsystems static-balancing tests were conducted.

The EG&G Company is providing support services in the instrumentation and controls area at E-MAD under the negotiated agreement of understanding. Six persons are currently working at E-MAD in functions related to E-MAD activities. These include one supervisor, one secretary, three technicians, and one expeditor.

The electronic shop and its equipment were turned over to EG&G during June 1966, and work was performed under the technical direction of NTO I&C personnel in evaluating the CCTV equipment discrepancies. Additionally, EG&G personnel assisted with the routine maintenance and modifications of the PA and intercom system.

(6) Fabrication and Tooling

E-MAD facility machine shop E-MAD support included the following activities: modification, rework, and assembly of the neutron Rabbit Gun for Test Cell A, the fabrication of items for each of the two assemblies required for the fabrication of the NTO/R-MAD fatigue machine, the fabrication and machining required for the modification of the NTO/R-MAD annealing furnace capsules and other machine shop support required for the fabrication of R-MAD items, including the tensile fixture assembly, leaf spring fixture, and the fuel element disassembly wedge assembly.

(7) Planning and Documentation

The E-MAD management network was monitored and reviewed on a continuous basis with the last revision being completed on 24 August 1966. This revision reflected the deletion of a major portion of the construction activities that had been completed, the addition of several new construction items, the expansion of activities related to the RADA program, addition of the activities related to the weight envelope mock-up (WEMU) and simulated engine test stand (SETS), and the revision of facility systems activities in the cold area relative to the time schedule.

Master planning schedu-graphic bar charts of the management network were prepared periodically summarizing the major activities to be accomplished. Additionally, special monthly schedules were prepared to show progress of the RADA program.

Documentation and reporting efforts included completion of the NERVA provisional equipment list to be transferred from R-MAD to E-MAD; preparation of a document defining the interface geometry of the ETS-1/E-MAD facilities; issuance of an E-MAD equipment standards handbook; preparation of an E-MAD orientation film and accompanying script and the evaluation of standard operating procedures.

The preparation of operating procedures for E-MAD equipment included an operational checkout plan, an operational test guide, an interim operating guide, and an operational development plan for the overhead positions system, an operational development plan, and an interim operating guide for the wall-mounted handling system (WMHS).

(8) Training

Training programs and courses for technicians and engineers at E-MAD are presented periodically as the E-MAD/NTO personnel complement increases. The preparation of training outlines, programs, courses and materials is also continuous. Existing programs are updated and new programs are prepared as required to meet the delivery schedules of new facility equipment and systems. The on-the-job training program has been completed by a majority of E-MAD/NTO technicians; however, training is continuing. Training programs relative to operation and maintenance of the master slave manipulator (MSM), Phase I and Phase II; the wall-mounted handling system (WHHS), Phase I and II; the floor-mounted handling

system (FMHS) have been completed. Personnel have been trained in the remote operation of cranes, including a rigging course; operation of the metallograph and the microhardness tester; and the operation and maintenance of the manned control car (MCC), the engine installation vehicle (EIV) and the locomotive. The training program for remote-handling equipment at E-MAD was begun on 1 July 1966 and is expected to be completed by all E-MAD technicians by May 1967. Training activities include disassembly of the NRX-A5.

NTO health and safety presented a course in the fundamentals of radiological safety to E-MAD personnel as part of its overall program at NRDS. Approximately 50% of E-MAD personnel have completed this course. Figures 160 and 161 are the courses that have been presented for E-MAD personnel.

b. XE Operations (7.5.3)

Disassembly of the NRX-EST core at R-MAD was continuously monitored relative to application of postmortem operations and the possible use of equipment in future operations at E-MAD.

Meetings were held between NTO/E-MAD and NTO/ETS-1 personnel to discuss interface problems related to engine instrumentation and checkout at the test stand. Additional meetings will be required for final resolution of the interface problems.

Engineering reviews were made of the most recent issues of the operational support plans for the NRX-A6, XECF, XE-1, and REON supplied GSE design criteria for the XE-1.

Remote assembly design aid (RADA) operations included the following:

COURSE TITLE	Instruction Hours		Number of Attendees	E-MAD Instructor Hours	Course Completion Date
	Classroom	OJT			
1. Rigging-Cole Operations (Orientation Course)	6		7	7	5-13-65
2. MSM Operation and Maintenance - Phase I	28	32	12	60	12-29-65
3. Soldering (I & C Technicians)	40			6	
4. Crimping (I & C Technicians)	24		6		
5. WMHS Operation and Maintenance - Phase I	27	8	6	75	3-14-66
6. MSM Operation Phase II		18	12	108	
7. WMHS Operation and Maintenance - Phase I	27	8	13	131	8-25-66
8. MSM Operation (R-MAD Technicians)	9	20	8	28	7-29-66

Phase I is classroom presentation of operation and maintenance theory followed by familiarization demonstrations.

Phase II is operational training for full qualification and proficiency in operations.

Phase III is maintenance training for full qualification and proficiency in maintenance.

Figure 160
Engineering Personnel Training

COURSE TITLE	Instruction Hours		Number of Attendees	E-MAD Instructor Hours	Course Completion Date
	Classroom	OJT			
1. MCR Operation		40	4	160	Periodic (Cont.)
2. HVAC Operation and Maintenance	40	80	3	360	Periodic (Cont.)
3. Hydra-Set Operation	1.5		28		12-3-65
4. Fundamentals of Radiological Health	40		5		10-25-65
5. Theodolite	2		6		11-15-65
6. I & C Test Equipment Operation & Maintenance	(Cont.) to date	8	6		Periodic (Cont.)
7. RTS Familiarization		120	2		6-15-66

Figure 161
Technician Training

(1) RADA components were received on 14 April 1966 at E-MAD and were placed in the hot bay, room 122. Photographs were taken to document the as-received condition. The RADA GSE items were received on 19 April 1966. Initial assembly of the RADA (RADA P-2) was started on 19 April 1962 and was completed on 3 June 1966. Assembly/disassembly/reassembly of RADA (RADA P-3) was initiated on 3 June 1966.

(2) Components of the RADA and related ground support equipment (GSE) were received at NRDS during the period 14 April to 27 April 1966. RADA components included the lower thrust structure and shield assembly and the upper thrust structure. GSE items included the lower thrust structure stand, the upper thrust structure support stand, and the positioning head.

(3) Receiving and inspection of RADA and GSE as outlined in Procedure P-1 was successfully completed and documented with photographs. The initial assembly/disassembly was initiated on 29 April 1966 in accordance with RADA Procedure P2 and was completed on 17 June 1966. Preparations for the remote assembly/disassembly/reassembly of the upper thrust structure (UTS) and lower engine assembly (LEA), were completed on 25 June 1966. This included realignment and adjustment of fluid lines and pneumatic connectors and the installation of brackets on the lower engine stand for lower fluid line support and minor modifications of GSE tooling. The initial mating of the upper thrust structure (UTS) with the lower engine assembly, in accordance with the assembly/disassembly/reassembly (RADA-P3) procedure, was successfully accomplished on 28 June 1966. Accomplishment of the remaining cycles was in progress at the end of the report period.

(4) Problems encountered during the assembly operations were resolved by modifying some tooling and redesigning some tooling and RADA components. Design changes for the upper and lower fluid line flange guides and an improved impact torque are in process. Minor GSE tooling modifications were accomplished at E-MAD.

(5) A complete electrical checkout of the RADA electrical system and a 1500-volt Hi-Pot resistance check of the electrical connectors was accomplished. The pneumatic connectors were hydrostatically tested as part of the initial assembly.

(6) The XE weight envelope mockup (WEMU) was received at E-MAD on 2 September 1966, partially disassembled for shipment. The WEMU was subsequently reassembled and installed in the lower engine stand located in the cold bay. Build-up and installation of the shock and vibration instrumentation are in progress.

6. Training

Training programs were established for the majority of activities, with emphasis on the indoctrination of personnel in new assignments and expanding operations.

a. ETS-1

Control-point-operator training was started with the preparation of Operator Qualification Guide, Console Operations Manuals, and FEP-1 Operator Training. Twenty operators received formal training prior to conducting the first facility experimental plan (FEP-1) on LN₂ flow and chilldown tests.

The introductory course on ETS-1 Instrumentation and Controls was presented three times to a total of 49 engineers and technicians. This training provided an understanding of the overall I&C system in the following areas:

(1) NERVA program orientation, ETS-1 facilities description, capabilities of the I&C systems, and instrumentation fundamentals;

(2) Facilities systems, including process piping, electrical power, communications, television, channelization, and safety;

(3) Data acquisition systems, including signal conditioning, analog recording, events recording, digital data, and timing;

(4) Test-stand control system, including engine control, neutronics, console operation, process control, test simulation, and checkout.

Special courses were administered in on-site training by engineering representatives for Ampex tape recorders, Dana amplifiers, and SEL digital data system.

b. E-MAD

Training procedures have been prepared and proficiency tests have been established to qualify operators on the various remote handling systems. The several phases of training include: I, Theory of Operation and Maintenance; II, Development of Proficiency in Operations; and III, Qualification Demonstrations and Tests.

The following systems have training programs:

(1) Railroad transport system, including MMC, EIV, MCC, spacer car, and storage car

(2) Master slave manipulators

(3) Rectilinear manipulator

(4) Wall-mounted handling system

(5) Floor-mounted handling system

(6) Closed-circuit television

(7) Turntables, cranes, and rigging

(8) Postoperative cell material-transfer system

Instruction was provided in the operation and use of the Hydra-set lifting device, theodolite, and fork-lift and strato-lift trucks. A 12-min training film, "Nuclear Rocket Engine Handling," was completed and has been useful for on-site training as well as for several off-site showings of E-MAD operations.

c. Test Cell A

Control-point-operator training was presented to qualify 26 new operators in conducting NRX/EST and NRX-A5 tests.

d. General

Because of the need for training in soldering and crimping, a soldering school and a crimping school were established. These two schools were attended by 28 personnel in soldering and 31 personnel in crimping. Personnel receiving this training were technicians, engineers, and Product Assurance people. In addition, seven persons received factory training in the application of weldable strain gauges.

A 12-hr course in "The Fundamentals of Radiation Safety" was given twice to include all persons in NTO who had not received this training previously; a total of 86 persons attended.

Three instructors attended various training courses: NASA Crimping School, Huntsville; NASA Soldering School, Long Beach; Basic Radiological Health, Las Vegas; and Kintel/Cohu Television, San Diego.

H. LARGE-DIAMETER REACTOR AND ADVANCED SYSTEMS STUDIES

Task 9

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H. LARGE-DIAMETER REACTOR AND ENGINE STUDIES (Task 9)

1. General

The major effort under subtask 9.0 during CY 66 was to examine and evaluate an engine of increased size by varying the major components and evaluating the effect on the overall engine system. These studies were based on current NERVA technology, the large diameter reactor, and the PHOEBUS II nozzle. The study started with an evaluation of preliminary approaches and included three design reviews before the concept was established based on: 5000 Mw Power; 4500°R chamber temperature; 625 psia chamber pressure; and 245,000-lb thrust.

In addition, a NERVA development plan was prepared and issued as RN-DR-0079 that presents all effort necessary to design and test the NERVA Engine through PFRT and delivery of two flight-ready engines. Preliminary design documentation was also included.

A summary of this effort is presented in the following paragraphs.

2. NERVA Engine Design

Initial design activity in CY 1966 resulted in basic system design concepts to meet the objectives related primarily to flight systems: maximum system performance (I_{sp}); minimum engine length; and minimum engine weight.

Five system concepts (Figures 162 through 166) were devised to show possible significant improvements compared with the E-Engine design concept that was used during NERVA flight-configuration design. These concepts are all based on decreases in engine length and weight, large nozzle-skirt area ratios, high turbine-inlet temperature, the use of turbine-exhaust gas for cooling the nozzle skirt, and thrust recovery.

Figure 162
Expansion Deflection Nozzle Concept

Figure 163
Expansion Deflection Nozzle Concept

Figure 164
Spike Nozzle Concept

Figure 165
Multiple Nozzle Concept

Figure 166
Multiple Nozzle Concept

The conceptual studies included a minimal amount of functional analysis to enable estimates of engine length and weight, as well as preliminary design of major components. Major design and development problems were also identified.

Small-diameter reactors with multiple nozzles parallel to the pressure vessel were used in the first two system concepts; the other three concepts were based on large-diameter reactors with integral nozzles. Thrust-vector control capability was considered to be a fundamental design requirement, but it was assumed that the roll-control system was not required to be an integral part of the engine.

The turbopump assembly (TPA) mounted within a thrust structure, was located between the propellant tank and the reactor in all concepts and was connected directly (or through a short bellows) to a hydrogen-actuated poppet-type shutoff valve in a spherical tank bottom; the turbine-inlet duct was mated with the forward pressure-vessel closure from which the turbine drive gas was obtained.

Comparison of the design and development problems related to these five advanced engine concepts and the NERVA E-Engine concept indicated that significant additional study was required before any of the advanced approaches would be competitive with the E-Engine.

Figure 167 shows the scaled-up E-Engine (LDRE) configuration released in December 1965. The overall length is 35 ft, with a nozzle-skirt exit-area ratio of 40:1 consistent with the current ground test facility criteria. Flight system requirements are expected to increase the area ratio to 100:1 or greater. The nominal power level is 5000 Mw and the nominal engine thrust is 245,000 lb. Significant differences between the LDRE and the E-Engine are as follows:

Figure 167
NERVA Engine Concept

<u>Design Feature</u>	<u>LDRE</u>	<u>E-Engine</u>
TPA	Eight-Stage	Two-Stage
TVC Concept	Skirt Gimballing	Center Body Gimbal
Hot-Bleed Port	Two NERVA 4-in. Ports	One Port
TPCV	Trim-Type	Single TPCV
Skirt Cooling	Turbine Exhaust Gas	Liquid Hydrogen
Reactor Installation and Support	Aft End of Pressure Vessel	Forward End of Pressure Vessel

Preparation and maintenance of engine layout drawings employing both Rao and 17-1/2-degree half-angle, conical nozzle-skirt assemblies was started in December 1965 for ground test configuration engines. System flow schematics or P&I diagrams were also prepared and updated to ensure compatibility with the engine layout drawings, state point charts, and design guidelines.

The current engine layout drawings, P&I diagram and engine/GTM interface drawing were reviewed during an LDRE status review meeting in February 1966. Action items resulting from this meeting were to:

- a. Use TPA's capable of zero-NPSP operation on all engines.
- b. Use test stand services to replace integral pneumatic supply systems on DE-1 and DE-2.
- c. Consider reducing the weight of the Phoebus 2 nozzle for use on DE engines.
- d. Reduce the turbine inlet pressure from 500 to 450 psia to provide for pressure loss in the turbine inlet line.
- e. Study alternative sources of nozzle skirt coolant after completion of the current study of the turbine exhaust coolant source concept.

f. Conduct further analytical studies to determine the optimum location for diluent extraction.

g. Continue evaluation of alternative TVC systems and submit a report to SNPO on May 1966.

h. Accelerate the systems analysis effort.

i. Make selection and use of the flight weight pressure vessel design throughout the engine development program.

Subsequent to this status review meeting, other changes in design ground rules were requested by SNPO-C in conjunction with CY 67/68 budget studies. These changes were put in effect in subsequent design activities. The definition of interfaces between the engine and the mating E/STS-2/3 ground test module tank was modified to be compatible with the engine configuration presented in the February status review meeting.

A conceptual design study of the mechanical design aspects of the portion of a test facility intermediate shield in the vicinity of the outside surface of the engine assembly was started in March 1966. The main objectives of this study were to evaluate (a) an engine-mounted versus a facility-mounted shield concept; (b) the practicality of assigning design responsibility for part of the intermediate shield to the engine designer and the remainder to the facility designer; and (c) to provide input to define the design criteria for the portion of this shield to be designed by Kaiser Engineers.

This study revealed that (a) both support methods are feasible, but the facility-mounted shield appears desirable unless a more complete definition of nuclear shield requirements causes a change in this conclusion; and (b) that detailed design criteria for the intermediate shield cannot be provided at present. Current activities are concentrated on defining the internal radiation shield design criteria. When this effort is completed, nuclear analysis effort will be directed to the facility intermediate shield.

Dimensional engine layout drawings were prepared to support optimization and parametric studies. These included the following: various quantities of TPA's; of TPA ports (single and dual ports); single and dual lines between TPA and nozzle-skirt; and of control valves (one or two TPCV's). Figures 168 through 174 present these drawings.

The conceptual design study of the remote-operations aspects of NERVA engine design was conducted. The program plan of CY 66 activities is summarized as follows:

- (a) Prepare design guidelines
- (b) Study the X-Engine remote interface and remote handling equipment designs.
- (c) Prepare alternative design concepts.
- (d) Evaluate candidate design concepts.
- (e) Prepare design-concept layout drawings.
- (f) Prepare a remote design topical report.
- (g) Prepare remote interface design criteria input to component design specifications.

Technical Memorandum RN-TM-0387 was issued to document CY 66 accomplishments.

A study indicated that NRDS would be the best assembly location for NERVA engines in terms of cost.

The following items resulted from an informal NERVA review meeting in June 1966.

- (a) Aerojet was assigned the responsibility for design and development of both the TSOV and PSOV (if both are shown to be required) and will indicate this responsibility in the development plan. The TSOV will be designed for zero leakage (prior to initial operation).

Figure 168

NERVA Engine Concept Layout-Ground Test Flight Configuration

Figure 174
PFS Concept "D" (Elevation)

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(b) It was mutually agreed that the gimbaled engine concept should be used to provide TVC trim, thereby compensating for engine thrust vector misalignments referenced in LMSC Report A 794909, dated 3 March 1966.

(c) Altitude-simulation testing of the nozzle skirt was discussed; no conclusions were reached.

(d) NERVA design documentation was discussed and rough-draft copies of the NERVA Engine Design Specification and Reactor Design Criteria were submitted for comment.

(e) Delivery of a TPA to MSRC is not a firm requirement, and the TPA program should not be constrained on the basis of this requirement. Inconel 718 is the reference pressure-vessel material.

(f) The two-flange pressure vessel design will be retained and the Phoebus 2 nozzle-pressure-vessel interface configuration and bolt-ring diameter will be used for NERVA.

(g) Hastelloy X is the reference NERVA nozzle material. The skirt material selection will be withheld until parametric studies are completed.

(h) Structural support flow variations will be handled so that nozzle coolant operating parameters are not perturbed.

(i) The nozzle contour selection reported in RN-PA-006 will be reviewed and revised, if necessary.

(j) Different nozzle contour designs will be investigated and a report prepared by 1 August 1966 to determine the I_{sp} penalties associated with (1) nozzle contour optimized at various exit area ratios from 40:1 to 100:1, cut off, and operated at exit area ratios of 40:1 to 100:1, where applicable; and (2) with the nozzle contour optimized at 40:1 and optimum extensions used at various exit area ratios from 40:1 to 100:1.

(k) Nozzle-skirt-cooling parametric studies will include cryogenic cooling to a 40:1 area ratio with parallel flow and turbine exhaust cooling from 40:1 to the skirt extension exit plane.

Additional changes in engine layout drawing, P&I diagram, and engine installation drawing were made after the July status review meeting.

At a design status review meeting in August 1966 the following drawings were presented: engine envelope comparison; engine assembly drawing; engine flow schematic; engine installation drawing; engine station 0 remote interface drawing; module remote handling design features; ETS-1 engine installation schematic; and a typical PFS layout drawing.

Planning parts lists were prepared in August 1966 to describe the engine components for each engine in the development plan presented in RN-DR-0079, NERVA Engine Development Program Plan (u).

The following drawings were prepared in September 1966 for NE-1 testing in ETS-1 (Figures 175 through 178):

<u>AGC Drawing No.</u>	<u>Title</u>
1118341	Preliminary NE-1 Flow Schematic
1118342	Preliminary Interface Control Drawing, NE-1/ETS-1
1118397	Preliminary NE-1 Engine Assembly Drawing
1118398	Preliminary NE-1 Engine Installation

The following drawings show the current NERVA PFRT engine configuration for ground testing (Figures 179 through 182):

1117925	Preliminary NERVA Engine Flow Schematic
1117926	Preliminary NERVA Engine Installation
1118396	Preliminary NERVA Engine Installation Envelope
1117896	Preliminary NERVA Engine Assembly

Preliminary NE-1 Flow Schematic

Figure 176
Preliminary Interface Control Drawing NE-1/ETS-1

Figure 177

Preliminary NE-1 Engine Assembly

Figure 177
Preliminary NE-1 Engine Assembly

Figure 178
Preliminary NE-1 Engine Installation

Figure 178
Preliminary NE-1 Engine Installation

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Figure 180

Preliminary NERVA Engine Installation

Figure 181
Preliminary NERVA Engine Installation Envelope

Figure 181
Preliminary NERVA Engine Installation Envelope

A preliminary operations analysis was prepared in September 1966 to assist in development program planning and to support E/STS-2/3 design activity by Kaiser engineers.

A preliminary NERVA engine instrumentation list was prepared in August 1966 to assist in preparation of the development program plan.

A preliminary weight control program was started in August 1966. Three issues of preliminary NERVA engine and component weight estimates were prepared in CY 1966.

3. Systems Engineering

An analysis of the preliminary NERVA engine system operating at steady-state conditions of approximately 245,000-lb thrust was made relative to the effect of major system variables on steady-state total system performance. Both system specific impulse and thermodynamic performance analyses were made. The effect on system performance of three pumps and two turbines was determined, together with the effect of chamber pressures and temperatures, system pressure drops, bypass flow, turbine inlet and exit conditions, turbine and pump efficiencies, and pump inlet conditions. The 12013 transient analysis program was used to obtain the data. Based on an initial reference system, a specific impulse increase of 21 sec is possible by making improvements in the design of the reference system and decreasing the component operating margins.

The objective of the engine system study was to determine the basic response of the system to variations in component characteristics and behavior. A systems analysis reduced to terms involving incremental changes in design variables also indicates the most sensitive areas in system improvements and assists in the selection of discrete candidate components.

a. NERVA System

Studies were made of a large NERVA engine system having six turbine-pump combinations, a cryogenically cooled main nozzle (100:1 expansion

ratio expanding to vacuum conditions), and a reactor system made up of reflectors, shields, and core. The system was designed to operate at a steady-state power level of 5000 Mw with a total hydrogen flow rate of approximately 300 lb/sec to give 245,000 lb of thrust. Design point reactor exit temperature is 4500°R. Figure 183 shows the general engine relationships.

Computer calculations were made with a mathematical model of this system to determine the effects of important variables on system performance (Figure 184).

b. System Boundaries

Pump operation stall boundaries were found for the six TPA combinations (two turbines, two centrifugal pumps, and one axial pump). The centrifugal pump, compared with the axial pump, enables a larger operating region at peak chamber temperatures. The operating range was determined to be approximately 190 psia wider.

c. Nozzle Parameters

Nozzle chamber temperature has a major effect on system specific impulse; the higher the temperature, the greater the specific impulse. Nozzle inlet pressure has a nonlinear and interaction effect on system specific impulse. The optimum pressure, thermodynamically, was about 500 psia. Changes in nozzle area under constant system thrust primarily affected the system pressure. The large nozzle also had an adverse effect on system operating boundaries.

d. System Pressure Losses

The sources of system pressure losses had different effects on system I_{sp} . Changes in reactor system pressure drop had no significant effect, but changes in nozzle tube pressure loss had a significant effect. In both cases, system I_{sp} improved as system ΔP was decreased. The use of bypass-flows reduced pressure drop and improved system I_{sp} slightly, but reduced thermodynamic performance.

Figure 183
Hydrogen Flow Paths, NERVA Engine System

	<u>Variable</u>	<u>Units</u>	<u>Steady- State Level</u>	<u>Isp Slope, Sec⁻¹ Unit Variable</u>
1.	Nozzle Chamber Temp	°R	4500	+0.111
2.	Nozzle Chamber Pressure	psia	642	-0.04
3.	Reactor Core Δ P	psi	142	-0.01
4.	Nozzle Tube Δ P	psi	420	-0.017
5.	System Bypass Flow	lb/sec	31	+0.05
6.	Turbine Efficiencies (var turbine)	1%	70	+ .26
7.	Turbine exit pressure	psia	60	-0.088
8.	Turbine Inlet Temperature	°R	1660	+0.017
9.	Turbine Inlet Line Size	in.	5.47	0
10.	Pump Fluid Inlet Temp	°R	38.5	-0.31
11.	Pump Efficiency (var pump)	1%	70	+ .27

Figure 184
General System Steady-State Specific Impulse Responses

(Figure 185, Operating Map Boundaries
NERVA Engine System, has been
deleted from this report)

e. Turbine Variables

Increasing the fraction of energy extracted by the turbine from the inlet stream and increasing the temperature of the turbine inlet stream increased system specific impulse. Turbine efficiency had a nonlinear effect on system specific impulse: the effect is significant at higher chamber pressures, but becomes insignificant at low chamber pressures over small ranges of possible changes in turbine efficiency. The major difference between the two turbine studies (a three- and a seven-stage turbine) was found to be in the turbine inlet and exit areas.

f. Pump Variables

Of the three pumps studied (two centrifugals and an axial pump) the axial pump was found to be the most efficient. With reference to a high efficiency centrifugal (75% efficiency), the axial pump (78% efficiency) added 0.1 I_{sp} unit to the system, and the low efficiency pump (64% efficiency) reduced system specific impulse by 3-sec^{-1} . System balances generally resulted in the operation of the pump at peak efficiency for different chamber pressures, and changes in turbine efficiency and conditions were made internally to maintain system balances. Changes in pump efficiency were found to be best handled as changes in the product of turbine efficiencies (combined efficiency). Improving pump efficiency improved system specific impulse. A reduction in pump inlet temperature (at constant pressure) also improved system specific impulse. Summary data for the optimization of the two turbine and three pump designs are shown in Figure 186.

REON provided technical support to TRW Systems for engine parametric studies. This support included technical transmission of data and consultation with TRW Systems personnel.

At a coordination meeting on 14 April TRW Systems was provided with REON Report No. RN-PA-0006. On 12 May 1966 a second meeting was held at Sacramento. The design of all engine components was discussed, including nozzles, TPA, and pressure vessels.

Figure 186
Turbopump Performance Comparison

TYPE PUMP	C	A	C	A	C	C	2C
NUMBER OF TURBINE STAGES	3	3	7	7	3	6	3
PUMP EFFICIENCY, %	75	78	75	78	75	75	77
TURBINE EFFICIENCY, %	62.4	62.4	77	77	60.7	74	62.4
LH ₂ LEAKAGE TO TURBINE, LB/SEC	1.5	1.5	2.5	2.5	1.5	2.5	1.5
TURBINE INLET TEMPERATURE, °R	1660	1660	1660	1660	1800	1800	1660
TURBOPUMP Δ WEIGHT, LB.	-400	-400	0	+50	-350	-20	-200
TURBOPUMP Δ LENGTH, IN.	-10	-10	0	+6.4	-10	-2	+4
$\dot{W}_T$ (INCL LEAK), LB/SEC	18.87	18.80	16.70	16.82	17.50	16.16	18.42
Δ I _{sp} , SEC	+0.0195	+1.23	0	-0.80	+2.99	+1.97	+0.07
RELATIVE FAILURE POTENTIAL	1.0	1.4	1.5	1.9	1.0	1.4	1.2
Δ WEIGHT FOR EQUAL R.F.P.	0	+48	+60	+120	0	+57	+27
Δ I _{SP} (ADJUSTED FOR = R.F.P.), SEC	+1.15	+1.27	0	-1.00	+3.19	+1.97	+0.18

On 30 June 1966 the data shown in Figure 187 was transmitted to TRW Systems. On 7 July 1966 a TRW was informed of the nozzle flow split, the estimated turbine exhaust gas temperature, bearing coolant flow rate, and applicable data of stage-turbine efficiency.

4. Engine Criteria and Component Integration

During CY 66 the NERVA engine effort, Subtask 9, was supported by subsystem and component design studies, facility and reliability and quality assurance planning. Preliminary engine and component requirements were documented. Parametric design studies, including performance and weight, were made to support the engine optimization studies. With some components this effort was completed, enabling the selection of a reference design or material; for others, a base of information was established that will enable a rapid progression of reference design selections in the next contract year. These studies were supported by data relative to heat generation, thermodynamics, nuclear analysis, stress, and materials. Sacramento test facility and reliability and quality assurance planning and studies were performed in support of the NERVA engine goals. A documentation plan was established and preliminary engine specifications and component criteria were formulated.

Details pertaining to these studies are as follows:

a. Pressure Vessel

Preliminary design, material selection studies, and fabrication investigations were started in CY 66 for the NERVA pressure vessel and are reported in RN-TM-0385. This study included the four reactor reflector configurations initially considered and several types of materials (nickel base, aluminums, and titanium alloys). Nuclear-radiation heating effects on the pressure-vessel wall temperature and the effect of radiation on material properties were criteria used in determining pressure vessel wall thickness and weights for the various options. Figure 188 shows the design yield strength for the material. For the several material and reflector options, Figure 189 shows the margins of safety that result with a given pressure-vessel wall thickness. Figure 190 shows the pertinent

1. PV

Material Density	Inconel 718, density = .3
Allowable Stress	Not available to date
Joint Efficiency	Not available to date
Environment	Not available to date
Conductivity	Use published data for Inconel 718
Weight	Total 2900 lb
	Dome - 471 lb
	Upper flanges -348 lb
	Cylinder - 1409 lb
	Aft shell - 427 lb
	Nozzle flange - 209 lb
Thickness	Dome apex thickness - .27 in.
	Shell thickness .27 in.

2. NOZZLE

Divergent section half angle	33 degrees for 100/1 contoured nozzle
Nozzle convergent angle	45 degrees
Plenum length: Cylinder section	13 in.
Throat length: Radius of curvature	Convergent section R = 8.0 in.
	Divergent section R = 1.691 in.
	Throat length = 0
Nozzle tube allowable stress	Not available
Tube wall thickness and geometry (throat)	Wall thickness .014 in.; Leg height .32 in.; Hot side radius .08 in. (Phoebus II)

Figure 187
Information for TRW Studies

Operating pressure	Chamber pressure: approximately 525 psia
	Coolant: 1100 psia inlet
Skirt thickness and material density	For radiation skirt - N/A
Pressure drop across main nozzle (coolant)	400 psia maximum
Coolant temperature rise across main nozzle	120°R
Jacket wall thickness and diameter at chamber	Chamber diameter - 50 in. Jacket wall thickness: reactor support skirt: .6 in. convergent section: .8 in. Throat: .4 in.
Maximum jacket area ratio	4/1
Jacket material and density	Material: Hastelloy X Density: .297 lb/in.
Nozzle tube material and density	Main - Hast X Cryo skirt - 347 sst Density - .29 lb/in ³
Nozzle efficiency	.985
Nozzle expansion ratio for turbine exhaust	8/1
Nozzle weight	main 2600 lb skirt/.0175 lb/in. ² surface area (100/1 skirt - 1750 lb)

3. TPA

Weight (three-stage)	1600 lb
Efficiency (turbine)	63%
Efficiency (pump)	75%
Pressure ratio across TPCV at full power	1.3
Turbine pressure ratio (three stage)	5.65

Figure 187
Information for TRW Studies

4. LINES

All line weights	Not available at this time
Material Density	Not available at this time
Allowable stress	Not available at this time
Pressure drop across each line	Not available at this time

5. AUXILIARY COMPONENTS WEIGHTS

Gimballing (TVC)	TRW estimate: 342 lb Aerojet suggests approx 500 lb
Destruct system	Not available at this time
Thrust structure weight	1500 to 2000 lb
Tank valve	500 lb
Roll control	TRW: 158 lb
Control	TRW: 790 lb
Pneumatic	TRW: 800 lb (1000 more likely)
Instrumentation	TRW: 200 lb

Figure 187
Information for TRW Studies

Figure 188
Design Yield Values

Figure 189

Margin of Safety vs Pressure Vessel Thickness for Maximum Heating Rates

REFLECTOR MODEL	REFLECTOR PLUS INTERFACE CYL. WEIGHT (LBS)	P.V. I.D. (IN.)	PRESSURE VESSEL DATA								
			INCONEL 718			Ti 5AL-2.5 Sn (ELI)			AL 7039		
			MIDWALL TEMP. (°R)	WALL THICKNESS (IN.)	P.V. WEIGHT (LBS)	MIDWALL TEMP. (°R)	WALL THICKNESS (IN.)	P.V. WEIGHT (LBS)	MIDWALL TEMP. (°R)	WALL THICKNESS (IN.)	P.V. WEIGHT (LBS)
3.0" Be	1870	68.6	727	.260	2560	-	-	-	525	.825	3206
6.75" Be	4450	74.6	470	.270	2888	-	-	-	331	.860	3556
8.0" Be + 2.3" AL	7830	81.7	376	.285	3375	325	.390	2594	245	.915	4063
7.5" Be + 2.3" C	6800	79.1	436	.280	3207	-	-	-	318	.910	3940

Figure 190

Estimates of Pressure Vessel and Reflector Weights for Various Reactor Configurations and Pressure Vessel Materials

temperatures, wall thickness, and pressure-vessel weights for the several options with a zero margin of safety. Based on these studies Inconel 718 was recommended for the reference NERVA pressure-vessel material. Further nuclear heat-generation and heat-transfer studies were made of the nozzle/pressure vessel and closure/cylinder joints, and a parametric study was made of the pressure vessel/reflector annulus cooling. Materials engineering effort was directed toward a materials development program, RN-66020, for Inconel 718.

b. Design Documentation

During this contract year design documentation to be used in the NERVA program was defined and preliminary engine specifications and component design criteria were issued.

Design documentation in the NERVA engine program will be as follows:

(1) NERVA Model Specification

This document will be prepared at the beginning of the development program. It specifies the required performance of the flight-engine system, including system functional requirements, and references the preliminary flight rating test (PFRT) and acceptance specifications to demonstrate the suitability and reliability of the engine for a flight program. It is used to describe the requirements of the end product and to give technical direction to the program. Initial issuance, will in many areas, contain only a listing of the characteristics for which requirements have not been established.

(2) NERVA Engine Design Specification

This document will be prepared subsequent to the issuance of the preliminary engine model specification. It specifies envelope, interface performance requirements and design constraints for the design of the

engine system and components in greater detail than specified in the model specification. It is used to transmit design criteria from project to design engineering.

(3) NERVA Engine Development Specifications

One of these documents will be issued for each development (NE) engine. It specifies envelope, interface performance requirements, and design constraints for the design of each development engine and its components based on the requirements of the engine flight design specification. It is used to transmit design criteria from project to design engineering. Final issue will reference a development test plan for engine evaluation.

(4) Component Design Specification

This document will be issued prior to design initiation. It specifies envelope and interface performance requirements and design constraints, and is used to transmit the following data from project to design engineering: design criteria and a quality assurance program that will identify development tests for accumulation of design data, design verification tests that specify the performance and environment testing requirements for approving the component for use in the PFRT engine, and acceptance tests for accepting the component for use in the PFRT engine. This document will be issued as a general specification covering design and test requirements that will be common for all applications. Specific deviations, deletions or additions to these requirements for components for individual engines will be covered by supplemental specifications associated with the general specification by a slash-sheet number. Prior to procurement of the component for use in the PFRT engines, each specification will be revised to delete development criteria and will be reissued as a component specification.

(5) Component Specification

Component specifications will be issued at the PFRT design freeze to specify performance requirements, design verification, and acceptance tests. These component specifications will be referenced in the final issue of the engine model specification.

(6) Engine Preliminary Flight Rating Test (PFRT)
Specification

This document will be prepared at the beginning of the development program. It specifies functional and environmental tests that will be used to verify the suitability of the flight-engine design prior to the initiation of a flight-test program.

(7) Engine Acceptance Test Specification

This document will be initiated at the beginning of the development program. It specifies nondestructive tests that will be used to accept deliverable flight engines subsequent to the completion of the PFRT program.

(8) NERVA Engine Data Book

The NERVA engine data book will be compiled during the development of the NERVA engine and will contain descriptions, detailed information and list specifications related to the engine, its systems, and major components. Its purpose is to supply, from one source, complete engine development and design information to NERVA program participants. It will include summaries of the following information: engine systems analysis; engine systems descriptions; major components criteria, loads and environment, parametric studies, design studies, descriptions, drawings, photographs, fabrication history, and test results; engine assembly, including layouts, schematics and diagrams; GSE criteria; instrumentation lists; data requirements; test plans; and test reports. The NERVA engine data book will be compiled and issued by the engine contractor and updated as required. This document is the official source of information for the flight engine, its systems and components.

The following documents were prepared, coordinated, and released:

AGC-90101	NERVA Engine System Design Specification
AGC-90103	NERVA Engine System Model Specification

AGC-90104	NERVA Engine PFRT Specification
AGC-90107	NERVA Engine Environmental Requirements

Preliminary design criteria for each of the major components was written and published in RN-DR-0079, Volume 5, Book 2.

Additional standards in the process of preparation or revision for future inclusion in the NERVA program during this period are:

AGC-STD-1004	Terminology, Symbols and Abbreviations for NERVA
AGC-STD-9012	Wiring, Routing & Termination of
AGC-STD-9003	Brazing Leaks on NERVA U-tube
AS4044	Plate, Identification, Foil-Type AGE

c. Thrust Vector Control (TVC)

An evaluation and comparison of various methods of deflecting the engine thrust vector were completed and results are presented in RN-TM-0356; preliminary design studies were conducted for the gimbale engine concept and are reported in RN-TM-0390.

In RN-TM-0356 data for comparing the various systems (gimbale engine, gimbale nozzle skirt, and fluid injection) are presented in terms of the efficiency; that is, the loss in axial impulse caused by thrust deflection resulting from aerodynamic design or the use of propellant for thrust deflection. Actuator power requirements are compared and the design features are discussed, including weight, mechanical complexity, and previous experience. In this study the various systems are compared relative to the side-force requirements for a constant jet-deflection angle as a function of the thrust or specific impulse loss caused by deflecting the main exhaust flow. Figure 191 shows a comparison of the performance of the candidate thrust-deflection systems. These data show that the gimbale NERVA engine had a loss in thrust of about 76 lb compared with the performance of an engine in the undeflected position. This corresponds to a decrease in engine specific impulse of 0.26 sec. Figure 192 further summarizes the study, comparing the various system performances, weights, and actuation torque requirements. A trade-off factor of 300 lb/sec of specific impulse, which corresponds

Figure 191
Performance Comparison of Thrust Deflection

	<u>I_{sp} Loss, sec</u>	<u>Weight, lb</u>	<u>Actuation Torque, ft-lb</u>	<u>Mars Transfer Weight Loss, lb</u>
Gimbaled Engine	0.26	600 to 1500	287	1578
Gimbaled Nozzle Skirt	0.36	3654	62	3762
Fluid Injection				
Nozzle Bleed	18.0	3792	4	9192
Turbine Exhaust	14.09	3702	4	7929

Figure 192
Thrust Vector System Comparison: Effect on Engine Performance

to the weight for an earth-to-Mars transfer, has been applied. Based on this study the gimballed engine appears to provide the highest efficiency, the lightest weight, and the least complexity of any method for providing thrust vector deflection for NERVA engines.

Following completion of the efforts reported in RN-TM-0356, preliminary evaluations of various methods of gimbaling the engine and locations of the gimbal plane were made and are reported in RN-TM-0390. Three methods of gimbaling were evaluated: ring gimbal or gimbal bearing; offset or three-point suspension; and four-point suspension.

The gimbal ring or gimbal bearing consists of a universal or ball joint bearing on the engine centerline and two linear actuators located 90-degrees apart that are used to rotate the engine about the bearing in the center. The gimbal bearing or ring would transmit all axial and lateral loads.

The three-point suspension system consists of three attachment points located 120-degrees apart. Motion is imparted to the engine by actuators located at two of the three attachment points that connect the engine to the mating hardware. Thrust loads are transmitted through the actuators and the fixed pivot point. Side loads are restrained by a radial flex mount attached to the fixed pivot and one actuator.

The four-point suspension system consists of four linear actuators mounted in diametrical pairs 90-degrees apart. Motion is imparted to the engine by actuating opposing actuators in opposite directions, and the engine rotates about the point of intersection of the two diameters. All axial loads are carried by the actuators and side loads are restrained by a circumferential web with flexibility in the axial direction.

Two gimbal plane locations have been considered: between the forward closure of the pressure vessel and the thrust structure; and between the

thrust structure and the stage tankage. Although both locations are ideal relative to minimum performance loss, significant propellant-feed system and thrust-structure design problems must be resolved.

Locating the gimbal plane between the pressure vessel closure and the thrust structure (below the pump discharge and turbine inlet) would require large deflection and angulation of the high-pressure propellant feed lines. Gimbale bellows or large expansion bends would be required to take up the high deflections, adding to overall system weight, design complexity, and system pressure drop.

With the gimbal plane located between the thrust structure and stage tankage (forward of the turbopump) it would be necessary to impart angular motion to the pump inlet line. This may be undesirable if it contributes to the inability to achieve zero net positive suction pressure at the pump inlet. With the gimbal plane in this position it would be desirable to rotate about the engine centerline, as is the case with a gimbal ring or the four actuator suspension system, so that elongation of the pump inlet line during actuation is minimal. With the three-point suspension system in a 50-in. radius, the pump inlet line deflection would be approximately ± 1.5 in. for angulations of ± 1.5 degrees.

The location of the gimbal plane will impose design problems on the propellant feed system, and the type of gimbaling will affect thrust structure type and configuration. If a three-point suspension system is used loads must be transmitted from the structural shell by beams to the three load points. With a gimbal ring or gimbal bearing the loads transmitted by the structural shell will have to be transmitted by beams to two load points diametrically opposed, then carried through the ring or bearing housing for 90 degrees into two similar load points on the mating structure. With the four-actuator suspension system it is likely that the shell structure would be capable of transmitting all loads into the four points without significant additional structure.

No decisions have been made on an optimum gimbaling system for the NERVA engine. The system selected will depend on trade-offs between added engine weight and the effect on other engine components.

d. Thrust Structure

A predesign study of the NERVA engine thrust structure was made and reported in RN-TM-0382. The objectives of this study were to identify candidate materials and to investigate various design concepts, providing a basis from which to start the thrust structure design effort for the NERVA engine in CY 1967. Selection of a reference material or design for the thrust structure have not as yet been made.

e. Pneumatic Supply System

The NERVA pneumatic supply system (PSS) consists of a storage tank and control and distribution components to provide gaseous hydrogen at the required pressures and flow rates to the engine actuators and the stage tank pressurization supply during engine startup, steady-state operation, shutdown, and cooldown. Recharging of the system storage tank during engine steady-state operation is provided to enable multiple engine starts.

During CY 66 a design study of the PSS was made. A preliminary system schematic and design criteria for each component were established, and a parametric study of the storage tank weight vs volume for spherical and toroidal tanks was prepared.

REON Technical Memo RN-TM-0389, Preliminary NERVA Pneumatic Supply System Study, describes the design activities on the PSS during the contract period.

f. Propellant Feed System Lines and Valves

(1) Engine Lines

Preliminary PFS line sizing and material selections for the NERVA engine (NE Series) were accomplished. The lines considered were

those for the pump discharge, turbine inlet, turbine discharge, diluent, special purpose, nozzle bypass and emergency cooldown. Studies of the system bellows and flange/seal configurations were made, but selection of flange/seal configurations was deferred pending definition of leakage criteria and further testing.

REON Technical Memo RN-TM-0388, Preliminary Study of NERVA Lines was issued.

(2) Engine Valves

Design activity for the propellant feed system (PFS) valves during CY 66 consisted of studies of valve configurations and materials for the NERVA engine (NE Series). Included were the propellant shutoff valve (PSOV); discharge shutoff valve (DSOV); special purpose valve (SPV); turbine power control valve (TPCV); turbine block valve (TBV); discharge check valve (DCKV); and reactor cooldown valve (CV). Most of the effort involved study of several PSOV concepts. The poppet and ball types were chosen as primary candidates for further design effort. Preliminary selection of the PFS valve configurations and materials was accomplished.

REON Technical Memo RN-TM-0391, Preliminary Study on NERVA Valves, was prepared that describes the design activities on PFS valves during the year.

g. Turbopump Assembly

Activity involving the turbopump portion of Subtask 9.0 was concentrated in the following three categories:

(1) Turbopump Predesign and Support of Engine Optimization Studies

The objective of this effort was to select the basic configuration of the turbopump for a reference engine. In conjunction with the

parametric design of the turbopump components, five basic turbopump arrangements designed for maximum performance with minimum weight and length were evaluated. Performance characteristics of the reference engine used as the basis for comparison were: power: 5000 Mw; thrust: 245K lb; chamber pressure: 625 psia; chamber temperature: 4500°R; pump net positive suction pressure: 0 psi.

The configurations evaluated were:

- (a) Centrifugal pump with three-stage overhung turbine
- (b) Multistage axial pump with three-stage overhung turbine
- (c) Centrifugal pump with seven-stage straddled turbine
- (d) Multistage straddled axial pump with seven-stage straddled turbine
- (e) Two-stage centrifugal pump with three-stage overhung turbine

All turbopumps had a low-speed inducer driven by a single turbine stage downstream of the main turbine. The tradeoff factors were:

Pump Efficiency	$\frac{\Delta I_{sp}}{\eta^p}$	=	0.27 sec/point
Turbine Efficiency	$\frac{\Delta I_{sp}}{\eta^T}$	=	0.25 sec/point
Coolant Leakage Flow Rate	$\frac{\Delta I_{sp}}{\dot{w}_L}$	=	2.3 sec/#/sec
Turbine Inlet Temperature	$\frac{\Delta I_{sp}}{T}$	=	1.6 sec/100°R

$$\text{Turbopump Weight} \quad \frac{\Delta I_{sp}}{\Delta w} = 0.33 \text{ sec/100 lb}$$

$$\text{Turbopump Length} \quad \frac{\Delta I_{sp}}{\Delta L} = 0.10 \text{ sec/in.}$$

Based on these factors, all configurations were compared at consistent values of pump pressure rise, pump flow rate, turbine pressure ratio and temperature, shaft speed and critical speed margin. Performance (efficiency) values reflected the potential to be realized with a reasonable amount of component development. Since a meaningful comparison can only be made with consistent and adequate reliability levels, reliability techniques were used to devise a relative failure potential index based on data applicable to other turbomachinery. Using the known modes of failure for each configuration, it was possible to reduce the modes such as stress, blade loading, speed, bearing load, thrust, pressure or temperature by derating until the indexes are alike, and to recompute the performance characteristics in terms of relative engine performance. The more complex configurations showed a degradation of performance or an increase of weight compared with the less complex turbopump at comparable indexes.

The turbopump selected based on this detailed, numerical evaluation has a single-stage centrifugal pump driven by a three-stage, overhung, axial-impulse turbine. Operation at near-zero NPSP tank conditions is enabled by a low-speed inducer forward of the main pump, the hydrodynamic and mechanical design being integrated with the propellant-shutoff valve. The inducer is driven by a single turbine stage aft of the main turbine, and the power is transmitted to the inducer through a coaxial inner shaft. Axial and radial support for both rotating assemblies is provided by propellant-cooled, rolling-element bearings with tandem ball bearings carrying main rotor residual thrust. Thrust balance is achieved with main impeller backvanes. Internal instrumentation is incorporated for determination of performance and ease of development. High strength-to-weight ratio, radiation resistant alloys (forged titanium, Inconel 718, and possibly Rene 41) are used for minimum weight. The turbopump will be capable of tank pressure bootstrap

start in the engine system and may be started dry without chill-down. Design life of the turbopump will be 60 minutes; it may be operated safely for limited periods at 20% above nominal speed. Weight will be approximately 1600 lb; length about 60 in.

(2) Parametric Design of Turbopump Components

To enable maximum performance with minimum weight and length and comparable reliability, parametric designs were completed for the turbine and pump. The results will allow rapid optimization of the final configuration after the specific engine operating conditions have been defined, since the method of approach has been refined, significant trends determined, and a method of relating all of the aerodynamic/hydrodynamic and mechanical interactions devised.

The turbine parametric study related performance, blade stress and weight, and rotating and total weight and determined the optimum combination for the turbine variables of flow rate, number of stages, efficiency, pressure ratio, inlet temperature and pressure, shaft horsepower, shaft speed, and mean blade speed.

Key variables of the three basic pump configurations (centrifugal, axial and two-stage centrifugal) were evaluated to determine the most effective combination of performance, weight, and length. For the centrifugal configurations, three variables were evaluated together with axial thrust:

(a) Shaft speed was varied to investigate the performance advantage of increased specific speed and the weight advantage of decreased size.

(b) Suction specific speed (inlet pressure and inducer pressure rise) of the main impeller was varied to evaluate the effect of impeller proportions on efficiency and weight.

(c) Impeller discharge angle was varied to determine the stall margin and weight advantage of the head coefficient and its resulting size.

The axial pump study related performance, length, and weight through the four primary variables of speed, number of stages (blade loading), size (diameter) and limb/tip ratio. Three types of blades, two methods of performance prediction, and various degrees of reaction and reaction distribution, were investigated for representative solidities and aspect ratios.

Detailed stress, vibration, and critical speed analyses supported the preliminary design and parametric evaluations. Mechanical layouts provided a basis for weight, length, and relative failure-potential estimates.

(3) Detailed Program Planning

This effort consisted of determining manpower, hardware, and test facility requirements to meet the requirements of the turbopump development program. The development program has the following two major elements.

(a) Subcomponent Development Program to Support Turbopump Development

Test plans were prepared and engineering and hardware requirements determined and facility criteria were defined. The objective of this phase of the program is to provide performance and operational characteristics and operational limitations of the pump, turbine, bearing and key structural and dynamic elements of the turbopump in more detail and over a wider range of conditions (including peripheral conditions) than are possible during turbopump tests. Detailed investigation of unique mechanical construction elements and the adequacy of special fabrication techniques, and of special transducers needed for accurate turbopump performance assessment will be conducted. These subcomponent data will provide a basis for performance improvement and safe turbopump operation, and will provide the engine analysis activity with refined data. In addition, study of subcomponent hardware and facilities will enable the resolution of problems that occur during turbopump and engine operation, and the verification of modifications in turbopump operational conditions.

(b) Planning of Engineering, Fabrication, and Facilities
for Turbopump Testing

Following design and fabrication, an extensive turbopump development test program will be conducted. Its purpose will be to qualify the turbopump for application to the NERVA engine. This qualification will proceed through a series of intermediate performance and maturity goals. Following the demonstrated compliance of the turbopump with design criteria, test and development support will be provided for the engine test program.

h. Manrating

Planning was initiated to define factors related to future man-rating (MR) objectives for the NERVA engine. These MR objectives for manned-flight engines after PFRT include maximum assurance that chances for crew survival will not be impaired by operation of the NERVA engine. Factors that contribute to meeting these objectives include engineering design and configuration of hardware, environmental and operational safety, reliability of the engine and facility hardware, quality of hardware, and concepts of remote engine hardware during earth-orbit and interplanetary flight. Study of these and other factors will be continued, and the results will be implemented into current program design, fabrication, testing, and analysis. Present activity also includes establishment of a pertinent bibliography summary and backup supporting file of reports and published papers on MR activities in the NERVA and other programs. Plans are being made to meet with other industrial firms and with various government agencies concerned with present and future man-rating problems in connection with space flights. Design load factors and associated safety margins for mechanical and pressure loads are being developed to provide adequate MR safety without unneeded weight penalties. The SNPO-C Structural Design Specification, SNPO-C-1, Revision 0, is given full consideration, and the probabilities of failure are calculated for these design safety factors. A manual is being planned that will consolidate the above documents and others related to MR requirements. Items to be considered for future MR of the NERVA engine were included in AGC Report RN-DR-0079.

i. Reliability and Quality Assurance

Program planning and estimates for the NERVA long-range reliability and quality-assurance program were submitted to SNPO-C in November 1965, March 1966, and April 1966. These three submittals represented successively finer estimates of long-range program requirements.

During the fourth quarter of contract year 1966, input was provided to the REON program study to define the reliability and quality-control program through PFRT (AGC Report RN-DR-0079, Volume V, Book 1, Section III). This planned activity is in interpretive compliance with NASA Documents NPC 200-2, 200-3, and 250-1. Supplementary reliability studies of the TPA and the propellant feed system were made to assist the study effort.

General reliability and quality-assurance support is documented in separate quarterly reports.

j. Sacramento Test Facilities

Engineering activity during contract year 1966 was primarily directed toward the TPA test facility in Test Zone E. As-built drawings of Test Stand E-1 were completed by AETRON, and preliminary design was initiated to modify the stand for cold-gas-drive TPA testing.

Several assumptions regarding test hardware have been made to allow the design effort to proceed. Since the overhead LH_2 run vessel (V-E21) is offset within the superstructure of Test Stand E-1, the configuration of the test hardware is assumed to permit the vessel to remain in its present position and be connected to the hardware by a straight suction line. The configuration of the TPA is also assumed to include dual turbine inlet and exhaust systems.

Test variables to be controlled during the initial series of cold-gas-drive TPA tests are: run-vessel pressurization to control NPSP, turbine

speed, and pump flow. A low-pressure (state of the art) transducer will be installed in the pump suction line to measure net positive suction pressure (NPSP) and can be utilized for control purposes. A tachometer will be used to determine turbine speed, and a flowmeter in the pump discharge line will provide feedback on pump flow. A mathematical model of the control systems applicable to this initial series of tests has been completed as part of a preliminary control-system analysis that takes all phases of TPA testing into consideration, including hot-gas testing.

The hot-gas-drive control system is envisioned to be comprised of approximately 24 loops. Investigation of the interactions between individual subsystems at an early stage of the test program is important in uncovering and resolving possible system difficulties at an early date and assisting in the mechanical-systems design. The model prepared during the preliminary analysis will be continuously updated and refined as additional information and conceptual data become available.

The controls systems proposed for the TPA test facility include the use of an on-line hybrid sequence unit and a simulator-checkout unit. A study was conducted in which these concepts were analyzed and data were obtained that pertain to various modes of mechanization. Results of the study are now being used to prepare preliminary specifications for both units.

Preliminary design activity related to a hydrogen heater system was initiated and continued throughout the period. Two subcontracts were awarded in July for engineering studies on methods of heating hydrogen. The firms conducting the studies are expected to make recommendations on how to achieve a heater output of 40 lb/sec at 2000°R. Originally the studies were to be completed by the end of contract year 1966. However, both firms have been granted 30-day extensions to finalize their findings and prepare a formal presentation of their results and recommendations.

A preliminary evaluation of liquid-hydrogen recovery methods was made, with activity primarily centered around a study of LH₂ recovery methods

made for the M-1 engine program. This study was made by AiResearch Division of Garrett Corporation and is described in NASA Report CR-54010. In the report, AiResearch recommended two recovery systems. Indications are that neither of the systems proposed would produce any substantial saving over the existing catch-vessel recovery system. Investigation of hydrogen recovery will be continued during contract year 1967.

k. NERVA Engine Controls

Control studies for CY 1966 were specifically in support of the engine preliminary design studies. Development of basic control hardware for this engine was not attempted, as the dynamic character of the engine control problem is still being explored.

Coordination was established between WANL and AGC for engine-systems analysis.

The NERVA-engine common systems model was evolved with WANL reactor subsystem equations combined with AGC overall engine-system equations. The initial detailed equation set was transmitted 16 June 1966. A common engine flow diagram with station identification was also generated and distributed.

Both analog and digital programming for the NERVA CSM common systems model (CSM) was accomplished.

The digital code TAF was secured from LASL and used for both open-loop frequency-response dynamic analysis at the design point and as a cross check for the CSM analog-computer programming.

TAF open-loop frequency-response tests were conducted without the TPA or turbine bleed-port dynamics. This approach permitted a more accurate definition of the inner-loop coupling between reactivity, power, and flow without the internal dynamics of the TPA. Some insight into the selection of alternative

control variables is also provided. Figures 193 through 202, present the results. Magnitudes of the two forcing functions, pump discharge pressure and drum position, were 0.3% of the design values prescribed by LASL for the TAF code operation. The greater reactivity influence from the support-structure flow, as compared with control-drum motion, is illustrated in Figures 197 and 198, where both the phase-shift and amplitude characteristics indicate that pump-discharge-pressure perturbations have a more uniform dynamic behavior over the frequency range investigated. This result emphasizes the fact that control of pumping conditions influences reactivity to an even greater degree than the drum position near design-point conditions. Alternative NERVA-engine control schemes in relation to the controlling variables have the same general behavior as previously reported for the technology engine in RN-S-0304. Control of thrust-chamber temperature from pump discharge pressure (Figure 201) offers no dynamic advantage over control by drum position (Figure 202), and control of flow rate (chamber pressure) is affected more by pump discharge pressure (Figure 193) than by drum position (Figure 194).

A comparison of closed-loop frequency-response-test analog data from the NERVA engine and the EST common analog model is shown in Figures 203 through 205. These data indicate that the general dynamic character of the engine systems is comparable. The analog data predate the CSM reactor model, but, the earlier REON reactor model is adequate for this comparison.

These preliminary results indicated that the basic NERVA-engine-controls analytical and overall design investigations this year should concentrate on XE-type feedback control concepts, in which chamber temperature and pressure are the primary control variables. Performance requirements in all cases were dictated by engine specifications.

As part of the current program to investigate the use of existing XE controls components, initial dynamic studies were conducted to determine the feasibility of using the present REON 4-in. TPCV and Bendix actuator as a propellant control valve to control the structural-coolant flow. Dynamic compatibility of this hardware was established by examining its use in the

Figure 193

Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Core Exit Flow Rate ($W_{c.3R}$)-lb/sec to Pump Discharge
 Pressure (P_4)-psia

Figure 194
 Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Core Exit Flow Rate ($W_{c.3R}$)-lb/sec to Drum Position
 (θ_D)-Degrees

Figure 195

Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Average Core Material Temperatures (ϕ_c)-°R to Pump
 Discharge Pressure (P_4)-psia

Figure 196

Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Average Core Material Temperature (ϕ_c)-°R to Drum
 Position (θ_D)-Degrees

Figure 197

Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Reactivity Feedback (σK_F) to Pump Discharge Pressure
 (P_4) -psia

Figure 198

Digital (TAF) Open Loop Frequency Response at Design Conditions;
Ratio of Reactivity Feedback (σK_F) to Drum Position (θ_D)-Degrees

Figure 199

Digital (TAF) Open Loop Frequency Response at Design Conditions;
Ratio of Reactor Power (η)-% to Pump Discharge Pressure (P_4)-psia

Figure 200
 Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Reactor Power (η)-% to Drum Position (θ_D)-Degrees

Figure 201
 Digital (TAF) Open Loop Frequency Response at Design Conditions;
 Ratio of Chamber Temperature (T_{15})-°R to Pump Discharge Pressure
 (P_4)-psia

Figure 202

Digital (TAF) Open Loop Frequency Response at Design Conditions;
Ratio of Chamber Temperature (T_{15})-°R to Drum Position (θ_D)-Degrees

Figure 203

Frequency Response of Core Exit Gas Temperature to TPCV Demand

Figure 204

Frequency Response of Core Exit Gas Temperature to Reactor Power Demand

Figure 205
Frequency Response of Chamber Pressure to TPCV Demand

chamber-temperature control loop. A step-response test was performed for a 50°R change in chamber gas-temperature (ΔT_{15}) demand, as shown in Figure 206, with the control drums held constant at 77° and the temperature-loop electronic compensation similar to that for the XE design. The temperature loop responded in less than 3 sec to achieve 90% of its final value. For comparison, the same step-response test was performed with the flow of structural coolant controlled at 30 lb/sec at design and the control drums operated with XE-type actuators to control reactivity. This test (Figure 207) shows that the incremental change in temperature took over twice as long (greater than 7 sec) to react to 90% of its final value and had about a 10% overshoot with XE-type compensation. For this type of a system, the inherent system dynamics favor structural-coolant flow control for small step changes in reactivity requirements. The REON TPCV and Bendix actuator also appear to be adequate.

Controls were studied to evaluate the engine operational requirements between the 60 and 100% thrust level while maintaining thrust-chamber temperature constant. Two types of thrust commands were studied, a step change and a 20-psi/sec ramp-rate change. The step change was chosen because its design requirements would be the most stringent and it would define the limit of the engine performance capability for a flight mission. Initial feedback control methods examined were the EST temperature-flux control loop without chamber-pressure coupling and a temperature control loop without a flux loop. Both of these systems used support-structure flow control (orifice control). Principal results from this study were for a step command in thrust from 100% to 60%.

The EST-type temperature-flux loop with a maximum control-drum velocity of 5°/sec gave a chamber-temperature overshoot or undershoot (depending on the step command) of approximately 10%.

With the flux loop removed and the temperature-loop gain increased, a maximum drum velocity of 10°/sec was necessary to reduce chamber-temperature overshoot to within 3% (150°R).

Figure 206

T_{15} Demand = $4500^\circ R$, P_{15} Demand = 625 psia, Stepped T_{15} Demand = $50^\circ F$:
Support Structure Valve Control

Figure 207

T_{15} Demand = 4500°R, P_{15} Demand = 625 psia, T_{15} Stepped 50°R, EST Control

Alternative schemes were examined to investigate means of reducing the required control-drum velocity because changing of the proposed 18 or 24 control drums would be a serious design problem if a high velocity were required.

These alternative control schemes utilized a control valve instead of an orifice for the support-structure flow because dynamic response of the control valve looked promising in the initial controls study.

In scheme A (Figure 208), the support-structure valve was linked directly to the temperature error loop for fast regulation. In series with the valve was a dead-band valve-position sensor that a control signal sent to the control drums to begin motion whenever the position moved outside of the dead band. In other words, when a small error correction was demanded, the control drums did not move. The control-drum velocity was limited to $1^\circ/\text{sec}$ in the positive direction and $1.4^\circ/\text{sec}$ in the negative direction. Results from a step and ramp command are shown in Figures 209 and 210. The support-structure valve was prevented from closing beyond the design limit specified by WANL. This scheme is particularly attractive during the startup phase, as it would always maintain a balance between drum position and support-structure valve position. Improvement in response characteristics may be possible if an anticipatory command to the drums is linked to the initial P_c error. Nominal support-structure flow was 16 lb/sec with an 800°R support-structure temperature (Figures 209 and 210).

In scheme B (Figure 211), no drum motion is required. The drums are held constant at the 94° position.

The support-structure valve is still the regulating valve, but its range of control is increased by inserting a flow-diverter (pump discharge) valve between the pump and the nozzle inlet.

The pump discharge valve (PDV) also operates on the support-structure-valve position when the position error is sufficient. The PDV either

Figure 208

NERVA Engine Control, Scheme A

Figure 209

NERVA Control System, Scheme A, Response to a Pump Command
(20 psi/sec) in Thrust from 100% to 60%

Figure 210

NERVA Control System Scheme A, Response to a Step Command in Thrust from 100% ($P_c = 625$) to 60% ($P_c = 375$)

REACTIVITY (δk) CONTROL WITHOUT DRUM MOTION
(RANGE OF S.S. REACTIVITY CONTROL AUGMENTED BY PUMP DISCHARGE VALVE FLOW DIVERSION)

Figure 211

NERVA Engine Control, Scheme B

closes or opens to a preset position. This preset position then diverts enough flow through the support-structure passages to increase the range of reactivity control. Without this feature, the control capability of the support-structure valve is insufficient to maintain temperature constant when decreasing thrust to 60%. Without the pump discharge valve, the chamber temperature decreases to 4000°R at the 60% thrust level (Figure 212). The relation between area and position for the pump discharge valve was assumed to be parabolic. This relation imposed an additional 200-psi line pressure drop when the valve moved to the 50%-open position for the thrust command of 60%. An additional 16 lb/sec of propellant was diverted through the support structure to permit this system to replace the drum reactivity at 60% thrust (10% loss of nozzle flow at 375-psia P_c). This system could be made to work with a finite-position type of pump discharge valve (two or more positions) that would not require infinite resolution of stem position.

Results for both a step and ramp thrust command are shown in Figures 213 and 214. The pump discharge valve was positioned on a 3-sec ramp. Improvement in the P_c loop response may eliminate some T_c loop overshoot. This system used two technology engine TPCVs in parallel, as one TPCV plus an orifice was too sluggish.

The final control scheme, Scheme C (Figure 215), had parallel controls for the chamber temperature and support-structure temperature. The chamber temperature error controlled the support-structure valve, and the support-structure temperature error controlled the control-drum position. Results for ramp and step responses are shown in Figures 216 and 217. The maximum control-drum velocity was approximately 1.5°/sec for the ramp and 2°/sec for the step.

The next phase of this study will consider startup and shutdown with these three schemes from either sub- or cold-critical conditions.

Engine programmer concepts will consider reference commands for both chamber temperature and chamber pressure as time-based, programed with no interlinking of commands such as existed on the EST. As no significant

Figure 212

T₁₅ Demand, 4500°R, 625 psia; Then Ramped to 375 psia at 10 psia/sec
Using Core Support Structure Flow Control

Figure 213
 NERVA Controls System Scheme B, Response to a Ramp Command
 (20 psi/sec) in Thrust from 100% to 60%

NERVA CONTROLS SYSTEM SCHEME B

RESPONSE TO A RAMP COMMAND (20 PSI/SEC) IN THRUST FROM 100% TO 60%

Figure 214

NERVA Controls System Scheme B, Response to a Step Command in Thrust from 100% to 60%

Figure 215

NERVA Engine Controls Scheme C

Figure 216

NERVA Controls Scheme C, Response to a Ramp Command in Thrust from 100% to 60% (20 psia/sec)

Figure 217

NERVA Controls Scheme C, Response to a Step Command in Thrust
from 100% to 60%

improvement in control-system stability is possible with interlinked commands and the engine has variable-thrust requirements, this approach will not be considered as a primary control device.

Alternative control variables will not be studied in depth at this time because of the successful testing of the chamber-temperature thermocouple. If a change in system requirements should warrant it, alternative schemes will be studied.

Alternate control schemes, as reported in RN-PA-0006, are:

- a. Measurement of thrust and flow rate.
 - b. Measurement of chamber pressure and flow rate.
 - c. Thermal-radiation measurement of hot end of core and chamber-pressure measurement
 - d. In-core thermocouples and chamber pressure.
1. Nozzle Skirt Assembly

(1) Introduction

The NERVA nozzle design and performance studies accomplished during contract year 1966 may be divided into five categories as follows:

- 1. Selection of a nozzle hot-side contour based on performance trade-offs and design feasibility.
- 2. Selection of a nozzle area ratio for engine-system studies based on performance and weight trade-off studies.

3. Selection of a nozzle coolant system for use in engine system studies based on mechanical feasibility and thermodynamic response, with consideration for test requirements.

4. Parametric studies of flexibility of the selected nozzle design for variations or changes in design selection parameters.

5. NERVA nozzle design considerations.

(2) Technical Discussion

Under Category 1, the NERVA nozzle contour has been selected. The selected contour is the optimum Rao contour that represents the highest thrust for any given area ratio or, if desired, for any given length. The basis of selection is shown in Figures 218 and 219.

Because there are infinite numbers of nozzle configurations to choose from but only one choice to be made for maximum payload gain, a variety of nozzles had to be examined with respect to their payload gain capabilities. Among conical nozzles, the choice of configuration was reduced to a 15° divergence half-angle as a reference model. Within the family of contoured nozzles, the choice was narrowed down to two models: one that gives maximum performance for a given length (hereafter referred to as optimum Rao nozzle) and another one whose length, at a given area ratio, is 80% of the length of the reference 15° -half-angle conical nozzle. The latter contoured model is known as the 80% Rao nozzle. Figure 218 shows the theoretical performances of these three nozzle models as functions of length and of area ratios. Also shown for comparison is the performance of a conical nozzle of $17\text{-}1/2^\circ$ half-angle, to illustrate that it can be eliminated from further consideration. Figure 218 does not make it evident which of the models is most suitable for the reference engine, for in addition to the differences in performance, there are differences in surface areas (weight) and lengths.

Figure 218

Nozzle Performance Comparison

I_{sp} TRADE OFF ASSUMED
 $1 \text{ SEC } I_{sp} = 300 \text{ LB PAYLOAD}$

Figure 219

Nozzle Useful Payload Gain Comparison for Various Contours

Figure 219 compares the gain in useful payload for the three models under consideration, with a nozzle of 40:1 area ratio used as the basis for comparison.

The optimum Rao nozzle is superior to the other two over a wide range of area ratios. Because of its evident superiority, an optimum Rao nozzle contour has been selected for the reference engine.

Under Category 2, a NERVA nozzle area ratio of 100:1 has been selected for the engine system studies.

Having established that an optimum Rao nozzle is superior to other configurations in terms of performance and weight trade-off, the analyses related to optimization of nozzle area ratio were limited to this configuration. These analyses involved performance trade-off studies with respect to the increase in weight of the skirt extension and associated weight increases of the interstage structure that are chargeable to the nuclear engine for changes in the nozzle area ratio. The influence of the chargeable weight penalty for an interstage structure ranging from zero to 26 lb/in. of structure has been determined for various types of skirt-extension construction where the weight per unit surface area was varied from a minimum of 0.015 lb/sq in. up to 0.04 lb/sq in.

Figures 220 through 223 illustrate the interrelation of these parameters and their effect on optimum nozzle area ratio for maximum allowable engine or useful-payload gain. These graphs indicate the strong dependence of optimum area ratio on interstage penalty and skirt weight; however, when the relative flatness of the curves near the optimum area ratio is considered, this dependence is somewhat reduced and more latitude can be allowed in the selection of area ratio.

With the current weight-penalty estimates of 0.02 lb/sq in. of surface area for the turbine-exhaust-cooled skirt extension and 10 lb/in. for the interstage structure, the optimum skirt-extension area ratio is 107:1, as indicated in Figures 223 and 224. However, because the curves are relatively flat near the optimum area ratio (Figure 223), the change in useful-payload gain is

I_{sp} TRADE-OFF ASSUMED
 1 SEC $I_{sp} = 300$ LB PAYLOAD

Figure 220

Optimum Nozzle Area Ratios Under Various Interstage Penalties

I_{sp} TRADE-OFF ASSUMED

1 SEC $I_{sp} = 300$ LB PAYLOAD

OPTIMUM RAO NOZZLE

I_{sp} , SEC (REF NOZZLE $\epsilon = 40:1$)

Figure 221

Optimum Nozzle Area Ratios for Various Skirt Weights

Figure 222

Nozzle Area Ratio Optimization for Engine Useful Payload Gain
Under Various Skirt Weights

Figure 223

Nozzle Area Ratio Optimization for Engine Useful Payload Gain Under Various Skirt Weights

OPTIMUM RAO NOZZLE SKIRTS
START AT = 40:1

PAYLOAD GAIN = 300 LB/l_{sp}

OPTIMUM AT:

$$\frac{d(\text{PAYLOAD})}{d} = \frac{d(\text{WT GAIN})}{d}$$

SKIRT WEIGHT, LB/IN² AREA

A	.015
B	.0175
C	.025
D	.030
E	.040

Figure 224

Optimum Area Ratio vs Interstage Penalty for Various Skirt Weights

insignificant over a range of deviations of ± 10 from the optimum area ratio. Therefore, to minimize overall length, the area ratio of 100:1 was selected for the reference engine. Accordingly, an optimum Rao nozzle contour has been generated that originates at the nozzle throat and extends the necessary axial distance to give an area ratio of 100:1.

The pronounced effect of interstage-structure weight penalty on optimization of area ratio has not been overlooked. If the effect of the interstage structure could be eliminated from consideration above an area ratio of 40:1, an additional 6 sec of specific impulse (an equivalent of 1800 lb) could be gained, as illustrated in Figures 220 and 225 by following the line of zero interstage penalty. In this case, an area ratio of 135:1 could be justified (as shown in Figure 221). The zero interstage weight penalty could be achieved by incorporating into the design an expandable radiation-cooled extension and combining the turbine exhaust gases with the main nozzle flow. The retracted position during launch would make the assembly approximately 160 in. shorter than the 100:1-area-ratio assembly. As this approach would also permit reduction of the required turbine discharge pressure, an additional performance gain could be achieved from the resulting higher pressure ratio across the turbine.

Selection of the ground test configuration has been based principally on the desire to test as much of the first flight configuration as possible with assurance that the test assembly can be operated below 100% power without flow separation in the skirt and can meet the 2-psia limitation on test-cell ejector pressure. Thus, a skirt providing for an area ratio of 40:1 was selected.

The test assembly will include the main nozzle with bleed-port inserts, the cryogenically cooled skirt, and a short segment of the turbine-gas-cooled skirt extension. This assembly will permit evaluation of all joints and connections and verification of thermal, structural, and flow characteristics. However, to maintain the nozzle skirt assembly in the same configuration as it is in the 100:1 reference engine, the skirt extension will be truncated to the 40:1 area ratio rather than having an optimum contour for the 40:1 area ratio.

SKIRT - OPTIMUM RAO NOZZLE
REF AREA RATIO 40:1
PAYLOAD GAIN = 300 LB/I_{sp}

- SKIRT WEIGHT
1. $.015 \text{ LB/IN}^2$ AREA
 2. $.0175 \text{ LB/IN}^2$ AREA
 3. $.025 \text{ LB/IN}^2$ AREA
 4. $.030 \text{ LB/IN}^2$ AREA
 5. $.040 \text{ LB/IN}^2$ AREA

Figure 225

Optimum Useful Payload Gain vs Interstage Penalty for Various Nozzle Skirt Weights

Under Category 3, a nozzle coolant system was selected for use in engine system studies.

(a) General Description

The cooling system was selected on the basis of no interference by the thrust-vector system, and the cooling circuits were selected to be unaffected by the differences between the truncated 40:1 and the flight 100:1 configurations.

Thus, the use of the turbine flow as the skirt-extension cooling medium has been incorporated into the truncated 40:1 nozzle skirt assembly. This arrangement permits testing and evaluation of hot-cold joint between the segments cooled with the pump discharge and turbine discharge fluids, respectively. Also, under this arrangement, the predicted thermal conditions in the turbine-exhaust-cooled segment can be verified. For safety and reliability, the point of introduction of turbine exhaust gas into the skirt has been located as far aft as mechanically possible, where the area ratio is approximately 38:1.

Because of pressure-drop considerations and the flexibility in nozzle-contour selection (see Category 4), the main nozzle was terminated at an area-ratio location of 4:1. Thus, the cryogenically cooled skirt extends from an area-ratio location of 4:1 to 38:1.

The cooling feasibility study led to several basic conclusions, all based on the self-imposed ground rules that:

(1) The maximum wall temperature anywhere in convectively cooled systems will not exceed 1500°F.

(2) The pressure drop from the pump discharge to the reflector inlet will not exceed 460 psi.

(3) The pressure available at the entrance of the turbine exhaust line is 80 psia maximum.

Within the above constraints, it has been established that:

(1) The requirement for 1500°F maximum wall temperature in the main nozzle can be met.

(2) The minimum flow rate of cryogenic hydrogen for cooling the entire skirt from an area ratio of 4:1 to the exit is 10 lb/sec.

(3) The convective utilization of turbine exhaust gases as the skirt cooling medium is feasible at area ratios of 25:1 and higher.

(4) The minimum flow of turbine exhaust gas required for skirt cooling is 12 lb/sec (more is available).

(5) Thermal-radiation cooling of the skirt is feasible within the considered locations between area ratios of 20:1 and 140:1, if construction materials of high melting temperature are used. Wall temperatures range from 2500 to 3200°R (2900°R at area ratio of 40:1).

(b) Main-Nozzle Cooling

The main-nozzle coolant passages have been designed to operate at a 1500°F maximum wall temperature and a 400-psi pressure drop, with 50 lb/sec of pump discharge flow diverted for special-purpose cooling. The flow rate of 158 lb/sec for main-nozzle cooling has been established on the basis that 13 lb/sec will be used for cooling the bolts and the pressure-vessel mating flange and the balance will be used for skirt cooling. This proportioning of the total available coolant flow between the nozzle and the skirt results in identical temperature rises through the respective cooling circuits. When the two flows are combined in the pressure vessel at the reflector inlet, all detrimental effects associated with mixing and stratification are precluded by their identical state points. The pressure drop through the main nozzle is very sensitive to changes in coolant flow rate. For example, an increase of 12 lb/sec in coolant flow rate results in a 30-psi increase in the pressure drop through the system.

(c) Skirt Cooling

As stated previously, the entire skirt could be cooled (up to 100:1 area ratio) with as little flow as 10 lb/sec of cryogenic hydrogen. However, this ability is based on the assumption that the flow would be expanded to vacuum conditions at the aft end and that there would be no other functions assigned to this flow. The skirt segment between the area-ratio locations of 4:1 and 38:1 must have a pressure-drop limitation if the coolant flow is to be used again elsewhere in the system. If the pressure drop is not to exceed that through the main nozzle (400 psi), the minimum flow rate for maintaining the gas side-wall temperature of 1500°F or lower is 26 lb/sec. However, because of uncertainties in the accuracy of the calculated heat-transfer coefficient, it is wise to consider a higher flow rate than the calculated minimum required. If this is the case, any amount over 26 lb/sec is in excess of what can be used as hot-bleed diluent and bolt coolant combined. Also, any additional complexity in proportioning this flow between the two circuits is undesirable. The skirt coolant flow is also too warm for special-purpose cooling. Cooling the skirt and the nozzle in series by utilizing the total coolant flow rate available would result in a 650-psi pressure drop, which eliminates this arrangement.

The one alternative left is to duct the skirt coolant in parallel with the nozzle circuit to the reflector inlet. With this approach, it is most desirable that the two streams combine at the same temperature. Calculations show that, to satisfy this condition, a flow of 82 lb/sec is required for skirt cooling. With this flow available and within the 400-psi pressure drop (including the bypass line and manifold losses), the gas side-wall temperatures were calculated to be less than 1000°F. Aside from insignificant reductions in heat losses, there are no advantages in allowing the wall temperatures to be higher. A larger tube flow area would result in a weight increase, and the resulting reduction in pressure drop would be of no consequence because an artificial flow impedance would have to be added to maintain the desired flow distribution between the skirt and the main nozzle. Finally the calculated 1000°F wall temperature is low enough to compensate for almost any uncertainties in calculating methods at this time.

For the ground test nozzle, approximately 10 in. of the aft end is cooled with the turbine exhaust gases. Most of this length constitutes a flow-expansion device designed to have an exit pressure of 2 psia (the same as the eject or duct pressure). The turbine exhaust system will include flow-impedance devices to match the flow with that of the 100:1 skirt extension. For this reason the coolant passages will be designed for lower-density fluid and will be different from the 100:1 extension in this location. Most important, however, is the need to determine with what degree of accuracy the induced thermal conditions have been predicted. A series of figures has been included to help in visualizing the system described above.

Figure 226 shows a general flow schematic. The skirt coolant manifold was located at an area ratio of 15:1. This location was chosen (subject to optimization) over locations closer to the main nozzle to provide accessibility to the remote flange connection between the two units. The coolant manifold is internally divided (not shown). The lower half serves as an inlet manifold; the upper half, as a coolant outlet manifold. The coolant outlet is located 180° from the coolant inlet, and so are the coolant inlet and outlet lines.

The coolant path, as indicated, is toward the nozzle aft end, turns at an area ratio of 38:1 to flow toward the main nozzle, turns again at an area ratio of 4:1, and returns to the collecting manifold, from which it is ducted into a manifold on the pressure vessel, bypassing the nozzle.

Although the flow schematic shows only one bleed port, the reference engine is conceived to operate with two bleed ports located 180° apart. The two hot-bleed streams are combined in a single turbine inlet line. The diluent flow is obtained from the reflector inlet rather than the reflector outlet, which was the diluent source in the XE engine. Using the reflector inlet as the diluent supply reduces the length of the diluent lines, provides for a greater available pressure drop through the diluent circuit, and makes the diluent fluid a more efficient coolant for the bleed-port insert because of its lower bulk temperature (compared with reflector outlet conditions).

Figure 227 shows the effect of coolant proportioning between the skirt and the main nozzle on bulk temperature rise as a function of flow rate of the special-purpose coolant.

The above descriptions summarize the cooling system selected for the NERVA engine. There are many details and refinements yet to be considered with regard to pressure drop, minimization of weight, and optimization of components; but the selected system is generally concluded to satisfy the engine operating requirements without undue risk and without excessive pressure drop or weight penalty anywhere in the system due to extreme conservatism.

Under Category 4, it was desired to parametrically evaluate areas around the selected nozzle to show the effect of variations in nozzle skirt weight, interstage penalty, useful-payload trade-off with specific impulse, and skirt contour design for both flight-testing, and ground-testing considerations. Figures 224, 225 and 228 through 230 show the results of these studies.

Figures 224 and 225 show the effect of skirt weight and interstage penalty on area ratio and useful-payload gain; decreases in skirt weight and interstage penalty or an increase in the payload trade-off factor of 300 lb per unit of specific impulse will increase the optimum area ratio, and vice-versa.

To consider the possibility of a future change in the skirt-extension area ratio, a study was made to determine what performance penalty is involved in substituting a portion of the 100:1 optimum Rao contour with the best available one extending to a different area ratio. Two locations were considered at which the substitution could be made. In each case, the previously committed contour (optimum for the 100:1 area ratio) between the throat and the skirt attachment point was retained. If the main-nozzle configuration was to be retained up to an area ratio of 4:1 and a best-available substitute contour was added at this location, the performance of the substitute contour would match that of the optimum nozzle of area ratio 100:1 and higher. The same

Figure 227

Effect of Flow Split on Coolant Bulk ΔT with Interface at $A/A_t = 4:1$

Figure 228
Nozzle Skirt Performance for Equal Length Nozzles

$\dot{W}$ = 283.5 LB/SEC LH_2
 T_c = 4500°R
 P_c = 625 PSIA
 I_s = SPECIFIC IMPULSE (SEC)
 A_s = SURFACE AREA (IN^2)

Figure 229

Optimum Rao Nozzles for Performance Comparisons at Truncated Area Ratios

Figure 230

Nozzle I_{sp} Theory and Actual vs Area Rat

would be true if the main nozzle geometry was retained up to an area ratio of 7:1 and the contour substitution was made at this location. However, there would be performance losses at area ratios lower than 100:1. Figure 228 shows the penalties involved beginning with an area ratio of 40:1. Within the range of area ratios examined, the maximum performance degradation with a substitute contour attached at an area ratio of 4:1 is 1.5 sec, and is approximately 5 sec if the substitution is made at an area ratio of 7:1. The results of these analyses contributed materially to the decision to terminate the primary nozzle at the 4:1 area ratio and to complete the assembly with a skirt detachable at this location.

Because of their use in ground testing and possibly in initial flight testing, it was decided to establish the effect of using truncated optimum Rao nozzles; this effect is shown on Figure 229.

An optimum substitute contour would provide better performance than the truncated nozzle but would induce several changes in design and operating characteristic with respect to the future flight configuration of higher area ratio. These differences are delineated below:

- (1) The cryogenically cooled portion of the skirt would be approximately 60 in. longer.
- (2) The turbine discharge line would be approximately 60 in. longer, and the location of the turbine exhaust gases would be 60 in. aft of the location in the reference design.
- (3) The heat-transfer area of the cryogenically cooled skirt would be 10,300 sq in. (45.7%) greater than it is in the reference design.
- (4) The skirt discharge temperature into the reflector inlet would be 53°R higher than in the NR system during the reactor development test for the same coolant flow distribution.

(5) The change in skirt contour and length would necessitate procurement of a different set of skirt fabrication tooling; primarily mandrels and coolant tubes.

(6) Because of the increase in the skirt heat-transfer area, the portion of the flow through the main nozzle would have to be reduced from the reference design level to avoid a 53°R difference between the nozzle coolant and skirt coolant discharge temperatures, as noted in (4).

Because of the above differences, it has been decided to truncate the reference configuration to the area ratio of 40:1 and thus retain all the design and operating characteristics, even though this approach results in further reduction of theoretical performance from 852 to 827 sec of specific impulse.

Figure 229 gives the effects of truncating optimum Rao nozzles to lower area ratios. The terminal point at the maximum area ratio of each curve indicates the available theoretical performance (weight). The values of specific impulse shown at lower area ratios are for truncated optimum nozzles. A good illustration is the case of an optimum 100:1 Rao nozzle, which, when truncated to 40:1, exhibits a specific-impulse loss of 44 sec. By comparison, an optimum 40:1 nozzle, which exhibited a performance of 852 sec, is capable of 25 sec more than the truncated nozzle. Recognizing that the truncated 40:1 nozzle is 60 in. shorter than a 40:1 optimum nozzle, 2.5 sec of specific impulse has to be subtracted from the optimum nozzle performance for a net gain of 22.5 sec over the performance of the truncated nozzle. Similar results are obtained for other comparisons between truncated and optimum nozzles; however, as the area ratios of the truncated nozzles are increased, the performance difference between truncated and optimum nozzles becomes smaller.

The effect of area ratio and comparisons between truncated and optimum nozzles have thus far been discussed in terms of changes in theoretical performance. Figure 230 indicates the difference between theoretical values of specific impulse and those expected to be attained under actual operating

conditions for optimum nozzles with area ratios ranging from 40:1 to 100:1. A performance loss of approximately 3.5% is shown, of which 2.5% accounts for unrecoverable heat losses and 1% is attributed to losses in nozzle efficiency and to frictional effects. The latter factors still require additional study for more accurate assessment. Also shown in Figure 230 are performance losses resulting from truncating optimum contours to an area ratio of 40:1.

Under Category 5, the NERVA-nozzle reference design evolved from feasibility studies of various cooling systems, structural aspects, pressure drop, and consideration of possible effects induced by the thrust-vector system if integrated into the nozzle skirt assembly or its cooling circuits.

The results of the thrust-vector study, as reported in RN-TM-0356 and RN-TM-0390, have clearly shown that the selection of total engine gimbal will not perturb the nozzle design and may therefore be neglected.

The effects of differential temperatures across structural members have been studied, and there are three major areas where temperature gradients are induced during the engine operation; these are:

- (1) Across the coolant-channel walls.
- (2) Across the nozzle-jacket wall and within the flanges.
- (3) Between the skirt and the skirt-extension flanges.

The existence of a temperature gradient across the coolant-channel wall is neither unique nor new to nuclear-engine technology. Nonetheless, due consideration has been given to the increase in magnitude of such gradients as encountered in the reference engine so as to avoid cracking or buckling of the coolant-channel walls.

The temperature gradient induced across the jacket wall by nuclear radiation heating has also been considered. Within the current estimates of radiation heating rates, special arrangements such as external cooling do not appear to be required to minimize the thermal stresses.

A factor previously unencountered in the NERVA technology engine has been introduced in the reference engine by utilizing cooling media at vastly different bulk temperatures. The flange connection between the aft end of the cryogenically cooled skirt and the forward end of the skirt extension that is cooled with the turbine exhaust gas is subject to the resulting effects. Because of the thermal gap between the two flanges, the temperature of the skirt flange is assumed to attain a thermal equilibrium as induced by the 120° coolant, and the temperature of the skirt extension flange will be governed by the turbine-exhaust-gas temperature of 1260°R. The assembly will be made at room temperature, but provision must be made for relative motion between the two members. Figure 231 shows the location of the joint, and Figure 232 illustrates the method by which freedom of movement has been ensured to avoid stress build-up in the two flanges.

Use of the tongue-and-groove principle, with the groove oversized with respect to the tongue, permits the hot member to expand. The pins shown spaced around the circumference do not restrict free and uniform relative motion between the flanges. External leakage is prevented by an external, flexible, welded-on manifold.

Figure 201
Skirt Extension on Corner

DETAIL A

Figure 232
Skirt Extension Joint, Detail A

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