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NUCLEAR DIVISION

REPORT NO. RN-DR-0148

NERVA PROGRAM

Technical and Programmatic

Requirements (U)

NERVA Program

Contract SNP-1

February 1968

NUCLEAR ROCKET OPERATIONS

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28 February 1968
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Mr. R. W. Schroeder
Space Nuclear Propulsion Office
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135

Dear Mr. Schroeder:

The purpose of this letter is to transmit Aerojet Report RN-DR-0148 which sets forth technical and programmatic objectives for the design, development, qualification and delivery of a 75,000 pound thrust nuclear rocket engine to be used for space propulsion. This document will serve as the Program Requirements Baseline from which preliminary design and data items required to establish the Design Requirements Baseline will be prepared. It should be noted that in several instances, optimization and trade studies are yet to be made. It is planned that these shall be completed, in general, by the submission of CEI specifications and discussed in the Preliminary Design Review.

Figure 1 of Section IV.C.1 of the enclosed document indicates the chain of events that are planned to occur leading to the conduct of the Preliminary Design Review. The first block, Guidelines and Requirements, is indicated to be an SNPO responsibility. The establishment of guidelines and requirements to date has been partially accomplished by the NERVA Engine Task Force, which was created by SNPO in October 1967 for the purpose of establishing the requirements and guidelines for the design, development, qualification, and delivery of the NERVA engine.

In the first meeting of the NERVA Engine Task Force, a preliminary document prepared by SNPO, "NERVA Program Requirements," was discussed and was used to form the basis of studies to be performed by Aerojet, Westinghouse and SNPO to verify and/or augment the requirements stated in this preliminary document. During the period from October 1967 to January 1968, the Task Force met several times to review the results of Aerojet and Westinghouse as well as SNPO studies. During the course of the several meetings, the engine, facility, and mission requirements were discussed, data were reviewed, and tentative conclusions reached. In addition, there have been meetings conducted by various subcommittees as well as meetings conducted outside the cognizance of the Task Force in which other tentative conclusions were reached, which affect the engine, facility, and mission requirements.

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Mr. R. W. Schroeder

2

Aerojet, utilizing input from Westinghouse relative to the Nuclear Subsystem, has undertaken to consolidate requirements for the NERVA Program into the enclosed document. The enclosed document represents our best understanding of the requirements for the mission assumed. Figure 1 of Section IV.C.1 of the report indicates that the establishment of the requirements represents a constraint on the path leading to conduct of the Preliminary Design Review. In order to achieve the effort required by recently negotiated Contract Year 1968 work statements, Aerojet and Westinghouse are proceeding at present with the NERVA Program on the basis of objectives contained in the enclosed report. We look forward to your comments or guidance.

Very truly yours,

AEROJET-GENERAL CORPORATION

C. M. Rice
Program Manager
Nuclear Rocket Operations

RVE:sam

Enclosure: (1) RN-DR-0148, "NERVA Program Technical and Programmatic Requirements," 5 copies

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REPORT NO. RN-DR-0148

NERVA PROGRAM

Technical and Programmatic
Requirements (U)

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NERVA Program

Contract SNP-1

NUCLEAR ROCKET OPERATIONS

February 1968

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REPORT NO. RN-DR-0148

NERVA PROGRAM

Technical and Programmatic
Requirements (U)

C. M. Rice
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TABLE OF CONTENTS

	<u>Page</u>
I. SCOPE	1
II. APPLICABLE DOCUMENTS	1
III. TECHNICAL PERFORMANCE REQUIREMENTS	2
A. MISSION DESCRIPTION	2
B. ENGINE PERFORMANCE OBJECTIVES	4
1. Functional Characteristics	4
2. Transportability	9
3. Maintainability	9
4. Safety	10
C. ENGINE TEST PROGRAMS	10
1. Test Definitions	10
2. Test Plans	12
3. Guideline Engine Test Program	13
4. Guideline Reactor Assembly Test Program	18
5. Guideline Special Test Assemblies Test Programs	20
6. Guidelines for Component Test Programs	21
D. AEROSPACE AND GROUND SUPPORT EQUIPMENT PROGRAM REQUIREMENTS	23
1. Operational Support Planning	23
2. Ground Support Equipment Program	23
3. Aerospace Ground Equipment Design	23
E. FACILITY PERFORMANCE REQUIREMENTS	24
1. General	24
2. E-MAD Modifications Requirements	25
3. ETS-1 Modification Requirements	25
4. ETS-1 Guideline Tentative Modifications Program	26
5. Facility GSE Modification Requirements	29
6. Other Facility and Specialized Test Equipment	29
7. Acceptance of Facility Items	30
F. SYSTEM DESIGN AND CONSTRUCTION STANDARDS	30

TABLE OF CONTENTS (Continued)

	<u>Page</u>
IV. PROGRAMMATIC REQUIREMENTS	31
A. ENGINE DELIVERIES	31
1. For Category II Engine Ground Tests	31
2. For Category III Engine-Stage-Vehicle Flight Test Program	31
3. Acceptance Test of Delivered Engines	31
B. GROUND AND FLIGHT SUPPORT OPERATIONS	32
1. General	32
2. Aerospace Ground Equipment	32
C. NERVA MANAGEMENT PLAN AND CONFIGURATION MANAGEMENT	34
D. NERVA PROPULSION SYSTEM PROGRAM-GUIDELINE SCHEDULE	36

LIST OF TABLES

	<u>Page</u>
1. Nuclear Propulsion Module Parameters for Synchronous Orbit Ferry Mission, Based on Block II S-IC and S-II Stages and on a 75,000 lb. Thrust Nuclear Engine	3
2. NERVA Guideline Engine Test Program - Tentative Data Acquisition Plan vs. Engine Designation	15
3. NERVA Guideline Reactor Assembly Test Program - Tentative Data Acquisition Plan	19
4. NERVA Guideline Component Test Program Tentative Data Acquisition Plan Requiring Category II Tests with Tentative Next Assembly Major Test Article Designation	22
5. Guideline List of NERVA Aerospace Ground Equipment	33
6. NERVA Propulsion System Program Guideline Schedules-SJC-275	37

LIST OF FIGURES

	<u>Page</u>
1. Guideline Initial Portion of NERVA Management Plan Tentative Constraints on PDR	35

I. SCOPE

This document establishes program requirements for the performance, design, development, test and scheduling of the NERVA Propulsion System.

The NERVA Propulsion System includes the engine assembly, ETS-1 facility modifications, and the Aerospace Ground Equipment.

II. APPLICABLE DOCUMENTS

The following documents shall be used as the guide for NERVA program planning, except as modified by this document.

Military

MIL-D-1000	Drawings, Engineering and Associated Lists, dated 1 March 1965
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Air Force

AFSCM 375-1	Configuration Management During Definition and Acquisition Phases, dated 1 June 1964
AFSCM 375-4	System Program Management Procedures, dated 31 May 1966
AFSCM 375-5	Systems Engineering Management Procedures, dated 10 March 1966
AFSCM 310-1	Management of Contractor Data and Reports
Volume I	Dated 16 January 1967
Volume II	Dated 15 March 1964

NASA

MSFC-PPD-600	Preferred Parts, Volumes 1 and 2, dated 1 July 1966
MSFC-SPEC-250	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, dated 26 Feb. 1964

SNPO-C-1 Structural Design Specification

AGC

AGC-STD-9007 Cleanliness Levels, Components and Assemblies,
(latest issue)

RN-TM-0335 Basic Loads and Structural Design Criteria for
the NERVA Engine, (latest issue)

Report No. 2275 Materials Properties Data Book, (latest issue)

III. TECHNICAL PERFORMANCE REQUIREMENTS

A. MISSION DESCRIPTION

The reference mission used to establish engine design criteria shall have an unmanned suborbital start. It shall be a ferry mission to and from synchronous (equatorial) earth orbit, terminating in circular orbit at 300 NM altitude. The inclination of the final circular orbit shall approximate that of the parking orbit achieved during ascent from launch at Cape Kennedy. The assumed launch vehicle is the Block II Saturn V, with the S-IVB stage replaced by the Nuclear Propulsion Module. Velocity increments are listed in detail in Table 1, together with tank volume, stage length, and equivalent full-thrust burn times. Where necessary, the velocity increments include allowance for gravity loss. The net payload is 35,934 lb., exclusive of all parts of the nuclear stage. Data are presented for five burns of the nuclear engine. The first of these burns is suborbital, extending to a near-circular parking orbit at an altitude of approximately 100 NM. Unless phasing is necessary, the coasting ascent from near 100 NM to a synchronous altitude requires about 5.25 hours; the time for coasting descent after de-orbit is about the same. No meteoroid shield is planned. It is assumed that the nuclear stage shall remain at synchronous altitude for 30 days.

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TABLE 1

Nuclear Propulsion Module Parameters for Synchronous Orbit Ferry Mission,
Based on Block II S-IC and S-II Stages and on a 75,000 lb. Thrust
Nuclear Engine

<u>Velocity Increment for Engine Burn, (ft/sec.)</u>	
Suborbit to Parking Orbit	2017
Parking Orbit to Transfer Orbit	8617
Transfer Orbit to Synchronous Orbit	5887
Synchronous Orbit to Transfer Orbit	5887
Transfer Orbit to 300 NM Altitude Circular Orbit	<u>8175</u>
Total	30583

<u>Impulse Propellant, (lb.)</u>	
First Burn	22985
Second Burn	80213
Third Burn	41242
Fourth Burn	32810
Fifth Burn	<u>34741</u>
Total	211988

<u>Nuclear Propulsion Module Net Payload, (lb)</u>	35934
--	-------

<u>Tank Volume, (ft³)</u>	
Propellant	51735
Ullage	<u>2587</u>
Total	54322

<u>Stage Length, (ft.)</u>	113.69
----------------------------	--------

<u>Equivalent Full-Thrust Burn Time, (minutes)</u>	
First Burn	4.09
Second Burn	14.26
Third Burn	7.33
Fourth Burn	5.83
Fifth Burn	<u>6.18</u>
Total	37.69

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B. ENGINE PERFORMANCE OBJECTIVES

1. Functional Characteristics

a. Design Characteristics

(1) Nominal Design Point Parameters (Based on Use of Equilibrium LH_2 , MIL-P-27201)

(a)	Thrust, F	75,000 lb
(b)	Chamber Temperature, T_c	4,500°R
(c)	Chamber Pressure, P_c	450 psia
(d)	Specific Impulse, Isp	825 lb-sec/lb
(e)	Engine Weight less Shield	16,000 lb
(f)	Tank Pressure	30 psia

(2) Endurance at Rated Conditions

(a) Flight - 38 minutes accomplished in a maximum of 5 cycles.

(b) Ground Test - 75 minutes accomplished in a maximum of 10 cycles.

(3) Throttling

The engine shall be capable of throttling from the engine design point at a constant chamber temperature of 4500°R to a chamber pressure of 270 psia at a maximum rate of 50 psi/sec.

(4) Startup and Shutdown

The engine startup and shutdown shall be accomplished at a maximum chamber pressure rate of 50 psi/sec and a maximum chamber temperature rate of 150°R/sec. Total impulse shall be maximized during the

startup and shutdown transients without degradation of reliability objectives. The engine shall be capable of a bootstrap startup with a tank pressure of 30 psia and with 0 psia main nozzle and turbine exhaust nozzle back pressure. Engine bootstrap characteristics shall be designed to be relatively insensitive to ambient pressure ranging from hard vacuum to approximately 2 psia. Engine cooldown fluid shall be used to provide thrust at the highest possible chamber temperature to maximize total specific impulse. The engine shall be capable of startup during the suborbital phase of boost flight.

(5) Total Impulse

The total impulse shall not deviate from the predicted total impulse by more than $\pm 20,000$ lb-sec, including all after-cooling pulses.

(6) Net Positive Suction Pressure, NPSP

The propellant feed subsystem shall be capable of operation with zero NPSP at the inlet to the propellant shutoff valve, PSOV, under all operational conditions including all malfunction conditions that affect engine operation.

(7) Thrust Vector Control

The thrust vector control system shall be designed to correct for thrust misalignment using a gimbaled engine system having a maximum displacement of 1.5° in any direction at a maximum rate of $0.25^{\circ}/\text{sec}$, with a maximum acceleration of $0.5^{\circ}/\text{sec}^2$. Trade studies shall be made to determine optimum total attitude control to be used during engine operation.

(8) Leakage

The engine shall be designed to eliminate all joints possible where leakage may occur without compromising maintainability and reliability requirements.

(9) The engine shall be designed for single module (engine) operation.

(10) The engine shall be compatible with use as the third stage of a standard Saturn V booster.

(11) Reliability

The reliability goal shall be 0.995.

(12) Shielding

The engine shield design shall be determined by module shielding requirements for propellant heating and component radiation tolerances.

(13) Environment

The engine shall be designed to operate after being subjected to all ground, launch, and flight environments. When these data are obtained, they will be included as a specification in Section II.

(14) The nozzle length shall be optimized, compatible with engine specific impulse requirement and payload trade-off studies.

(15) Engine-to-Stage Interface

The formal qualification engine, the preliminary qualification engines, and to the extent practical, the development engines shall interface to a simulated-stage interface incorporated in the ETS-1 test stand adapter. Special provision for ground-test-data acquisition and control may be incorporated, but these features may be eliminated in the deliverable engines. These features shall be designed so that their elimination from deliverable flight test engines shall not affect the validity of the qualification program or the engine reliability.

(16) Storage

The engine shall be capable of satisfactory operation after storage under the following conditions:

- (a) Two years on the ground in a suitable container.
- (b) Thirty days maximum in synchronous orbit between power operations.
- (c) Five hours minimum in Earth orbit between full-power operations.

(17) Nuclear Subsystem

(a) The nature of the nuclear subsystem requires that the development, preliminary qualification, and formal qualification tests be conducted at NRDS as a reactor test assembly. Nuclear subsystem components shall be subjected to preliminary qualification and to formal qualification tests prior to the nuclear subsystem formal qualification tests.

(b) The engine requirements indicated are also applicable to the nuclear subsystem of the engine. Deviations required to enable testing of the nuclear subsystem in the reactor assembly tests shall not invalidate the above reactor requirements or specific requirements relative to the nuclear subsystem.

(c) Specific Nuclear Subsystem Requirements

1 The nuclear subsystem shall deliver a mixed mean gas temperature of 4500°R to the thrust chamber.

2 The nuclear subsystem apportionment of reliability shall be 0.997.

3 The internal shield requirements shall be in accordance with Section III.B.1.a.(12).

2. Transportability

The engine shall be designed such that it can be handled and shipped in both the vertical and horizontal positions in accordance with the Basic Loads and Structural Design Criteria for the NERVA Engine (latest issue).

3. Maintainability

Engine maintainability requirements are applicable only prior to vehicle lift-off.

a. The engine shall be designed so that all components are capable of functional and electrical checks after engine assembly.

b. The engine shall be designed so that it is capable of being purged by an external source of inert gas prior to launch or ground operation.

c. The engine shall be designed so that all actuators are accessible for repair or replacement prior to engine operation without engine disassembly.

d. The engine shall be designed for ground testing so that it can be:

(1) Remotely installed and removed from the test facility.

(2) Remotely removed to enable replacement of the thrust structure subassembly.

(3) Remotely checked out following remote replacement of the thrust structure subassembly.

4. Safety

a. Ground Safety

The NERVA Propulsion System shall provide safeguards to protect the health and assure the safety of operating personnel and of the general public.

b. Range Safety

The following provisions for range safety shall be included in the engine system:

(1) An anti-criticality poison wire system capable of automatic withdrawal and disposal during suborbital startup.

(2) Utilization of emergency cooldown fluid.

C. ENGINE TEST PROGRAMS

1. Test Definitions

The following definitions are in accordance with AFSCM 375-1 and are cited to support the descriptions of the guideline test programs.

a. Engineering Test and Evaluation (Development Tests)

Engineering test and evaluations, i.e., development testing, include those test and evaluations necessary to acquire engineering test data for the direct support of the design and development activities.

Such tests may be for the purpose of (1) confirming design calculations and assumptions, (2) collecting data not readily available through analysis, calculation, or past experience, and (3) exposing the components to natural or simulated environments. These test data will establish the basis for confidence in the design, fabrication, and operational processes for the item under test, for release of the item to its preliminary qualification, and for formal qualification test programs.

b. Preliminary Qualification Tests

The preliminary qualification test of an item or system is a series of tests designed to demonstrate that the item or system satisfies the design requirements to the specified level. Successful completion of the preliminary qualification tests is the basis for the use of similar items in the next higher assembly item preliminary qualification test program, and/or will indicate that the item is suitable for release to formal qualification test program. In the latter case the release to formal qualification test may be additionally supported by development tests that provide test data about features not previously demonstrated in the preliminary qualification program. Preliminary qualification testing shall be limited to the CEI level of item, with the exception of components designated as Engineering Critical Components. The latter shall be individually qualified.

c. Formal Qualification Tests

The formal qualification test of an item or system shall be a series of tests designed to demonstrate that the item or system satisfies the design requirements to the specified level. Successful completion of the formal qualification test shall be the basis for the use of similar items in the formal qualification program of the next higher assembly, and shall indicate that the item has completed its design and development phase. In addition, completion shall indicate that similar articles are suitable for delivery to the next higher assembly. For example, completion of the

engine qualification test program shall indicate satisfactory release of deliverable engines for use in stage-development, preliminary qualification, qualification, or flight-test programs. Formal qualification testing shall be limited to the CEI level of item with the exception of components designated as engineering critical components, which shall also successfully complete formal qualification tests.

d. Reliability Test and Analyses

The reliability test and analyses are activities specifically conducted to obtain reliability data beyond those provided by engineering tests and evaluation, preliminary qualification, and formal qualification. When no reliability tests are conducted, those data to be used in reliability assessment will be obtained from development, preliminary qualification, and formal qualification programs and will be designated as reliability test data.

e. Acceptance Tests

The acceptance test of an item or system is a test conducted subsequent to inspection to demonstrate functional characteristics that are demonstrable only during the operation or simulated operation of the item. The acceptance test, together with the inspections, is intended to verify that the component is in accordance with specification and is acceptable for delivery to inventory or use in accordance with the qualification rating of that configuration of the item or system.

2. Test Plans

The above defined tests may be conducted on the article in any one of the three following categories.

a. Category I Tests

Tests on items are considered to be Category I tests if the article can be tested with equipment simulating the interfaces and environmental conditions without the need for other test articles or systems. That is, the component can be developed and qualified per specification with only test support equipment.

b. Category II Tests

Where the features of an item cannot be adequately demonstrated by the use of simulated interfaces and environments and the actual development interfaces or environments can only be achieved by the use of other test articles or system elements, the feature of the item is considered to be demonstrable in Category II type tests. It is possible that the total qualification of a component to its specification will require some demonstrations in the Category I and Category II-type tests. Some items will be fully qualified only by means of Category II testing. The system test would be a Category I test of the system. If system features can only be demonstrated in a multisystem test, this test would be designated as a Category II test for the system.

c. Category III Tests

Category III tests are conducted by the Government as operational flight tests incorporating the nuclear propulsion system with other elements of the total system.

3. Guideline Engine Test Program

a. The engine test program includes development, preliminary qualification, and formal qualification test series. These tests shall be classified as Category I NERVA engine tests.

Features of components that are required to be demonstrated for the formal qualification of the component and which can only be demonstrated in conjunction with these engine tests shall be considered to be demonstrated in Category II tests as a part of the engine. However, all components in an engine assembly will have first successfully completed a specified component preliminary qualification test.

b. Features of the engine that are required to be demonstrated in the engine development, preliminary qualification, and formal qualification test series have been tentatively assigned to specific engines to divide the acquisition of demonstration data among a fixed number of engines, taking into account the expected life, the nature of test, the status of development, and the guideline characteristics tentatively planned for the ETS-1 engine test facility. Table 2 summarizes this tentative guideline distribution of the data acquisition plan relative to engine number. The engines are divided relative to the kinds of test plans.

TABLE 2 - NERVA GUIDELINE ENGINE TEST PROGRAM
- TENTATIVE DATA ACQUISITION PLAN VS ENGINE DESIGNATION

Guideline Engine Test Plan		Devel- opment	Preliminary Qualification			Formal Qualification				
Data to be Acquired	Engine Desig.	E-1	E-2	E-3	E-4	E-5	E-6	E-8	E-C	E-X
<u>General</u>										
1. Weight, C.G., Moments of Inertia		-	P.Q.	-	P.Q.	Q	-	-	-	
2. GSE Compatibility		D	P.Q.	-	P.Q.	Q	-	-	Q	Spare
3. Facility Proof		-	P.Q.	-	-	-	-	-	-	Engine
4. Tank/Engine Interactions		-	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	for
5. Interface Compatibility		D	P.Q.	-	P.Q.	Q	Q	Q	-	Formal
6. Hardware		D	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	Qualification Test Plan
<u>Checkout & Maintenance</u>										
1. Transportability		-	-	-	-	-	-	-	Q	
2. Acceptance Test		-	P.Q.	P.Q.	P.Q.	Q	-	-	-	
3. Leakage Test		D	P.Q.	P.Q.	P.Q.	Q	-	-	-	
4. Purge Capability		D	P.Q.	-	-	Q	-	-	-	
5. Maintainability		-	P.Q.	-	-	Q	-	-	Q	
<u>Environment</u>										
1. Environment Extremes		-	P.Q.	P.Q.	-	-	-	Q	-	
2. EMI		-	P.Q.	-	-	-	Q	-	-	
3. Radiation Characteristics		-	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	
4. Vibration		D	-	-	-	-	-	-	Q	
5. Space Storage		-	-	-	-	-	-	-	Q	
6. Ground Storage		-	-	-	-	-	-	-	-	Q
<u>Operational Performance</u>										
1. Full Power, Full Duration - Nominal		-	-	-	-	Q	-	-	-	
2. Mission Simulation Cycles - Nominal		-	P.Q.	-	P.Q.	-	Q	-	-	
3. Performance & Endurance at Spec Extreme		-	-	P.Q.	-	-	-	Q	-	
4. Performance Mapping		D	P.Q.	-	-	-	-	Q	-	
5. Reproducibility		-	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	
6. Cold Flow		D	P.Q.	-	-	Q	-	-	-	
<u>Operational Control</u>										
1. Dynamics		D	P.Q.	P.Q.	P.Q.	Q	-	-	-	
2. Start, Stop, Aftercool, Restart		D	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	
3. EPIC Demonstration		-	P.Q.	P.Q.	P.Q.	Q	Q	Q	-	
4. Thrust Vector Control		-	P.Q.	-	P.Q.	Q	-	-	-	
<u>Reliability & Safety</u>										
1. Malfunction Detection		-	-	P.Q.	P.Q.	Q	Q	Q	-	Data Code: D-Development PQ-Preliminary Qualification Q -Qualification
2. Malfunctions		-	-	P.Q.	P.Q.	Q	Q	Q	-	
3. Emergency Cooling		D	P.Q.	-	P.Q.	Q	Q	Q	-	
4. Malfunction Detection		-	-	-	-	Q	Q	Q	-	
5. Malfunctions		-	-	-	-	Q	Q	Q	-	

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(1) Engine E-1 shall be designated for engine development testing. Component models delivered for assembly into E-1 shall have completed the specified preliminary qualification test related to E-1; i.e., the preliminary qualification test of the component shall have demonstrated that the component is capable of operating under the most severe E-1 test conditions. The engine remote plane shall have been previously demonstrated in conjunction with the Weight and Envelope Mockup (WEMU) Test Program.

(2) Engines E-2, E-3, and E-4 shall be designated as preliminary qualification test engines. All component models delivered for assembly into E-2 shall have successfully completed the Category I formal qualification test program for the component, with the exception of the electronic power instrumentation controls (EPIC) and the anticriticality poison system (APS). Relative to the EPIC, the principal EPIC system development tests shall be conducted as Category II tests with engines in the preliminary qualification test program. The formal qualification tests of the EPIC shall be conducted as Category II tests with the engine formal qualification test program. The nozzle skirt extension simulator will only be hot-fired in conjunction with engines beginning with E-2. Engine E-3 and beyond shall contain all engine systems except the nozzle skirt extension and the anticriticality poison system extraction device. The nozzle skirt extension shall, because of facility limitations, be replaced with a nozzle skirt extension simulator, which shall test the attachment and flow paths of the nozzle skirt extension. The anticriticality extraction device shall be provided for engines beginning with E-4; its preliminary qualification shall be conducted in conjunction with engine E-4. Test Stand ETS-1 shall be checked out with the aid of an engine simulator and the weight and envelope mockup prior to the installation and testing of E-2.

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(3) Engines E-5, E-6, and E-8 shall be designated as formal qualification test engines. Formal qualification of the Anti-criticality Poison System will be conducted in conjunction with E-5 assembly in E-MAD and utilizes subsequent E-5 performance data. The formal qualification of the EPIC shall be conducted in conjunction with this engine test series.

(4) A spare engine shall be assigned to the formal qualification test program and designated as E-X. If not required as a replacement for one of the formal qualification test engines, this engine may be used to demonstrate the ground storage requirement.

(5) An engine with an unfueled reactor shall be assigned to the formal qualification test program and is designated as E-C. This engine shall be used to demonstrate the transportability, and vibration environment, and possibly portions of the Anticriticality Poison Extraction (ACPS) device formal qualification test requirements.

(6) No separate reliability test series shall be included in this program. The reliability analysis shall establish the elements and data of the component and engine test programs, which will be included in the assessment of reliability through analysis.

(7) The engine test program shall be supported by a spares inventory of suitably qualified parts. The spares inventory shall include seals, clamps, fasteners, valves, actuators, instruments, and other small hardware starting with the initial development engine. A spare thrust structure subassembly shall be provided prior to the initiation of power testing of Engine E-2. This spare thrust structure subassembly shall be updated as required to provide a spare throughout the engine test program.

(8) The program plan shall provide for interface gages and matchplates to aid in the assembly of reactor test articles starting with R-2, ground-test engine articles starting with E-2, and flight test engine articles.

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4. Guideline Reactor Assembly Test Program

a. The reactor assembly test program includes development, preliminary qualification, and a formal qualification test series to demonstrate the nuclear subsystem. Relative to the components of the nuclear subsystem this assembly represents Category II testing. Completion of the qualification test series shall indicate completion of the development and qualification test program of the nuclear subsystem.

b. The features of the nuclear subsystem required to be demonstrated in the reactor development, preliminary qualification, and formal qualification test series have been tentatively assigned to specific reactors to divide the acquisition of demonstration data among a fixed number of reactors, taking into account expected life, nature of test, status of development, and the characteristics tentatively available at the Test Cell C reactor test facility. Table 3 summarizes this tentative guideline distribution of the data acquisition plan relative to reactor assembly number. The reactors are subdivided relative to kinds of test plans.

c. Reactors R-1 and R-2 are designated for nuclear subsystem development testing. This represents the major Category II development tests of the nuclear subsystem components. Component models delivered for assembly into R-1 and R-2 shall have completed the specified preliminary qualification test related to R-1 and R-2, respectively; i.e., the preliminary qualification test of the component shall indicate satisfactory completion of tests, demonstrating that the component is capable of operating under the most severe R-1 and R-2 test conditions. The reactor assemblies shall be tested with an operating map profile to duplicate the expected engine operating plans and to determine the performance at the extremities of the operating map.

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TABLE 3 - NERVA GUIDELINE REACTOR ASSEMBLY TEST PROGRAM
- Tentative Data Acquisition Plan -

<u>Guideline Reactor Assembly Test Plan</u>		<u>Development</u>		<u>Prelim.</u>	<u>Formal</u>
<u>Data to be Acquired</u>	<u>Reactor Assembly Designation</u>	<u>R-1</u>	<u>R-2</u>	<u>Qual.</u>	<u>Qual.</u>
<u>I. General</u>					
1. Weight, C.G., Moments of Inertia		D	D	PQ	Q
2. GSE Compatibility		D	D	PQ	Q
3. Facility Proof		-	-	-	-
4. Tank/Engine Interactions		-	-	-	-
5. Interface Compatibility		D	D	PQ	Q
<u>II. Checkout & Maintenance</u>					
1. Transportability (as a reactor subassembly)		D	D	PQ	Q
2. Acceptance Test		D	D	PQ	Q
3. Leakage Test		D	D	PQ	Q
4. Purge Capability		D	D	PQ	
<u>III. Environment</u>					
1. Environment Extremes		-	-	-	-
2. EMI (1)		D	D	PQ	-
3. Radiation Characteristics		D	D	PQ	-
4. Vibration		D	D	PQ	-
<u>IV. Operational-Performance</u>					
1. Full Power, Full Duration-Nominal (2)		-	-	-	Q
2. Mission Simulation Cycles-Nominal (3)		D	-	PQ	-
3. Performance at Parameter Extreme		-	-	-	Q
4. Performance Mapping		D	D (4)	-	Q
5. Reproducibility		D	D	PQ	-
6. Cold Flow		D	-	-	-
<u>V. Operational-Control (Reactor Only)</u>					
1. Dynamics		D	D	-	-
2. Start, Stop, Aftercool, Restart		D	D	PQ	Q
3. Flight Controller Demonstration		-	-	-	-
4. Thrust Vector Control		-	-	-	-
<u>VI. Manned Reliability & Safety</u>					
1. Malfunctions		-	-	-	-
2. Emergency Cooling		-	-	-	-
3. Anticriticality		D	D	PQ	-

- (1) Demonstration of Standard Specification Requirements
(2) One run - 45 minutes duration - rated conditions
(3) 6 to 10 runs - 75 minutes total duration - rated conditions
(4) Total duration reduced by time required for mapping

Code: D - Development
PQ - Preliminary Qualification
Q - Qualification

d. R-3 is designated as preliminary qualification test reactor assembly. All component models delivered for assembly into R-3 shall have successfully completed the formal qualification via Category I or Category II component tests.

e. The R-4 reactor assembly shall contain all the nuclear-subsystem components and is designated the nuclear-subsystem formal-qualification-test reactor assembly.

f. The reactor test program shall be supported by a spares inventory of suitably qualified parts. The spares inventory will include seals, clamps, fasteners, actuators, instruments, and other small hardware, starting with the initial development reactor assembly.

5. Guideline Special Test Assemblies Test Programs

a. A Weight and Envelope Mockup (WEMU) shall be acquired to aid in developing and demonstrating the suitability of handling and facility equipment and to acquire design data applicable to the requirements for engine transportability and for development of the engine-to-stage interface components. The WEMU shall sufficiently simulate the weight, moment of inertia, structural characteristics, interface functions, and needed dimensions for the above purpose. The testing program shall demonstrate design adequacy for the remote installation and removal of the engine from ETS-1, of the MCC/EIV in performing that installation and removal, and for the training of personnel and development of procedures. Suitable demonstrations shall be performed prior to installation of E-1 and E-2 in ETS-1.

b. A Remote-Assembly and -Disassembly (RADA) item shall be acquired to aid in developing and demonstrating engine features involved in the RADA operations required of the engine during the development phase and to meet the requirements for engine maintainability. The RADA shall demonstrate design adequacy of the remote plane between the Thrust Structure

and Pressure Vessel and Reactor Assembly (PVARA). The RADA program shall be completed prior to the testing of E-2.

c. The program shall provide for an engine simulator capable of performing checkout tests in ETS-1 prior to the power test of E-2. This simulator shall basically consist of all elements contained in the thrust structure, including the turbopump with a suitable load valve to represent impedance downstream of the turbopump. The unit shall be driven by facility-supplied cold hydrogen gas and be capable of delivering the engine full-power flow rate.

6. Guidelines for Component Test Programs

a. Category I and II Tests

The component development program shall be conducted to provide hardware for the development tests, preliminary qualification tests, and formal qualification tests and to provide suitably qualified components for use in the guideline engine test program, reactor-assembly test program, and special-test-assembly programs. Components shall complete preliminary qualification and formal qualification tests via Category I test prior to testing of E-2. The exceptions to this are tentatively the Electrical Power Instrumentation and Controls (EPIC), the nozzle, the nozzle skirt extension, and the Anticriticality-Poison-System (ACPS) extraction device. In these cases, the preliminary and formal qualification-test requirements shall be demonstrated in conjunction with the development, preliminary qualification, or formal qualification engine-test programs, as listed in Table 4. The component development program phase is completed upon successful conclusion of the component formal qualification test. The configuration of a component successfully passing the formal qualification test shall be the configuration made available for assembly into the engines designated for the engine qualification test program. The E-1 Thrust-Structure Subassembly shall be cryogenically tested prior to incorporation into the E-1 assembly.

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TABLE 4

NERVA GUIDELINE COMPONENT TEST PROGRAM
TENTATIVE DATA ACQUISITION PLAN REQUIRING CATEGORY II TESTS
WITH TENTATIVE NEXT ASSEMBLY MAJOR TEST ARTICLE DESIGNATION

COMPONENT	COMPONENT TEST DATA TYPE		
	DEVELOPMENT	PRELIMINARY QUALIFICATION	FORMAL QUALIFICATION
Electronic Power Instrumentation and Controls (EPIC)	Laboratory and E-2 through E-3.	Laboratory and E-4.	Laboratory and E-5, E-6, and E-8.
Nozzle	Technology and Phoebus data. Chemical tests for bleed ports.	R-1, R-2. R-2 only for bleed ports.	R-3, R-4.
Nozzle Skirt	Laboratory, R-1 Skirt Simulator, E-2.	E-3	E-4
Nozzle Skirt Extension	Laboratory	Laboratory and E-2 for attachment and nozzle flow via NSES.	Laboratory and E-5 for attachment and nozzle flow via NSES.
Nozzle Skirt Extension Simulator (NSES)	Laboratory	Non-flight hardware for ground tests only but gives data on flight-type attachment and flow paths for the Nozzle Skirt Extension.	
Anti-criticality Poison System	Laboratory at AGC and WANL.	E-4 cold tests in E-MAD.	E-5 cold tests in E-MAD.

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b. Inspection and Assembly Tests

All components to be made available for assembly into the test engine, reactor, or special test assemblies noted above shall successfully complete the inspection and assembly test delineated in their component specifications.

D. AEROSPACE AND GROUND SUPPORT EQUIPMENT PROGRAM REQUIREMENTS

1. Operational Support Planning

Operational studies shall be provided to establish the necessary ground support equipment for the support of the development program, and for the qualification and acceptance testing of the reactor and engine assemblies at NRDS and in the contractor's home plants. The operational studies shall be extended to include the assembly, checkout, acceptance testing, transportation, installation, and maintenance of delivered engines at Michoud.

2. Ground Support Equipment Programs

Ground support equipment shall be supplied throughout the engine test program in accordance with the needs established by the preceding operational study. Maximum use of ground support equipment available from the NERVA Technology Program will be achieved by modification of the equipment to meet requirements for the NERVA Program. Additional new ground support equipment for use at NRDS and the contractor's home plants will be provided.

3. Aerospace Ground Equipment Design

The design of aerospace ground equipment for the support of deliverable engines shall be, as much as possible, based on data derived

from the performance of similar ground support items provided for the support of the development program. The AGE checkout equipment will incorporate automatic checkout with self-diagnosing features to improve the reliability of the checkout equipment.

E. FACILITY PERFORMANCE REQUIREMENTS

1. General

The testing of the NERVA engine and reactor assemblies shall be performed at NRDS. Existing facilities shall be used to the maximum extent possible without modification from the condition prevailing at the completion of the NERVA technology program. Engine tests shall be conducted in ETS-1. Reactor tests shall be conducted in Test Cell C. Maintenance, assembly, and disassembly shall be conducted in the E-MAD building. Facility-support GSE, such as the MCC/EIV shall also be used to the maximum extent without modification.

Modifications of facilities and special test equipment located at the contractor's plant shall be provided as required to conduct the component development and preliminary and formal qualification tests.

Additional government-owned or controlled facilities shall be made available for the performance of specialized test requirements of this program; e.g., materials and irradiation tests.

2. E-MAD Modification Requirements

Existing facilities and equipment shall be employed to the maximum extent possible with minimum modification to perform maintenance, assembly, disassembly, and acceptance tests of the engine and reactors specified herein and in accordance with safety requirements. The specific modifications to be acquired are to be developed.

3. ETS-1 Modification Requirements

a. The ETS-1 facility shall be modified to permit the development testing, preliminary qualification, and formal qualification of the NERVA engine in accordance with the requirements of the engine CEI specification but not to exceed the following:

(1)	Thrust, F	75,000 lb (1575 Mw)
(2)	Chamber, Pc	450 psia
(3)	Chamber temperature, Tc	4500°R
(4)	Nozzle area ratio, Ae/At =	32:1 and nozzle area, At
		97.273 in ²
(5)	Nozzle gimbal travel:	$\pm 0.5^\circ$
(6)	Total engine flow rate	95 lb/sec
(7)	Environmental pressure	± 2 psia
(8)	Engine-duration specification for ground test of 75 min to be accomplished in a maximum of 10 cycles to be achieved via multiple tests in ETS-1 with duration determined by existing propellant tankage.	

b. The facility's readiness to accept and test fire engine E-1 shall be demonstrated through the use of tests performed on the facility. Facility readiness for E-2 testing shall be demonstrated with the aid of an engine simulator.

4. ETS-1 Guideline Tentative Modifications Program

Only minor modifications of ETS-1 are tentatively planned for the E-1 engine test because the engine test conditions will be of a limited nature.

The guideline tentative modifications required to test the engines beginning with E-2 are as follows:

a. Test Duration

The facility shall be modified to allow demonstration and proving of all engine characteristics with the exception of continuous full power duration. Modifications to the existing facility components shall be provided for a 15-min run capability at full power.

b. Propellant Feed Line

The existing propellant feed line is sized for the XE engine and will deliver a maximum of 80 lb/sec of LH_2 . The line must be modified or replaced with a larger line to meet the required pump inlet conditions for the 75K engine and to adapt the facility run tank to the NE engine interface. The line shall contain components that the existing line has, which include a shutoff valve, a flowmeter, a strainer, a propellant-shutoff-valve adapter section, a line bleed-in and vent section, and others as required.

c. Interface Gas Systems

The interface systems that supply engine purge gas, valve actuation gas, control-drum actuation gas, etc., will require modification to accommodate the NE interface and the increased flow requirements. This modification encompasses existing-system removal, rework, and salvage and installation of the systems necessary to support the NE test requirements.

d. Thrust-Structure Modifications

The existing carbon-steel thrust structure will become activated during the first test, thereby restricting access by personnel during subsequent engine installations. Relocation and enlargement of the interface systems and the cooldown-system piping will necessitate modifications to pipe support structure within the thrust ring.

e. Top Shield

Modifications will be required to accommodate the new propellant feedline, other fluid lines, and I&C cabling penetrating the ETC. These modifications are relatively minor in that they will require no additional penetrations of the shield.

f. LH_2 Topping Line

The requirement to flow approximately 91 lb/sec of LH_2 for extended run durations is beyond the capability of the existing topping system. Line 7- LH_2 , which currently runs from the storage Dewar (V-3801) to the base of the test stand, will be extended into run tank V-5001 with an 8-in. (rather than 12-in) vacuum-jacketed pipe.

g. Power-System Modifications

Additional power will be required for the newly proposed steam system.

h. New Duct

A new duct is required to accommodate the larger 75K-thrust engine utilizing a 32:1 nozzle. The NERVA exhaust system (NES) shall be designed to produce a 2 psia engine-test-compartment (ETC) pressure during engine startup and shutdown.

i. New Steam-Generator System

A new steam-generator system will be required to supply the higher steam flow rates of the new duct.

j. Steam-Generator System Water Piping

To accommodate the new steam generation system, it will be necessary to supply piping and valves to connect this new equipment to the existing water storage and transfer systems.

k. New Steam Line at Stand

This modification will provide the piping and valving necessary to connect the outlet of the steam-generation system to the inlet of the secondary-ejector plenum on the new exhaust duct.

1. NES Controls

This item covers the remote-control modifications associated with the new steam-generation system.

5. Facility GSE Modification Requirements

Provide as required the minimum modifications to the facility GSE (e.g., MCC/EIV attach and mount engine lift points) to support the requirements herein.

6. Other Facilities and Specialized Test Equipment

a. Sacramento Test Zone H

Modify as required to support the testing requirements of nonnuclear components, such as nozzle hot-bleed port, TPA, and associated hardware.

b. Sacramento Test Zone A

Modify and/or provide equipment as required to support the cryogenic-testing requirements of nonnuclear components.

c. Sacramento Other Laboratories

Modify and/or provide equipment to support the nonnuclear component and engine assembly.

- d. WANL Facilities
- e. Government-Provided Facilities

7. Acceptance of Facility Items

The acceptance criteria for the above ETS-1 facility modification items shall be as specified in the applicable CEI specification. Other facility items shall be considered completed when the facility is proven ready for the first test article installed in the facility through appropriate facility-checkout test programs.

F. SYSTEM DESIGN AND CONSTRUCTION STANDARDS

The general design and construction and design-discipline requirements applicable to this program are delineated by means of documents listed in Section II.

IV. PROGRAMMATIC REQUIREMENTS

A. ENGINE DELIVERIES

1. For Category-II Engine Ground Tests (i.e., with Stage)

Two engines of the formally qualified configuration designated E-7 and E-9 shall be assembled, acceptance-tested, and delivered in E-MAD for ground test of the flight stage at NRDS at a facility other than ETS-1. Engine E-7 shall be subjected to the first-article configuration inspection (FACI).

The three engines of the formally qualified configuration designated E-10, E-11, and E-12 shall be assembled, acceptance-tested, and delivered at E-MAD for ground testing during the flight-test program.

2. For Category-III Engine-Stage-Vehicle Flight-Test Program

The four engines of the formally qualified configuration designated as E-13, E-14, E-15, and E-16 shall be delivered for flight testing. It shall be assumed that the flight-engine subassemblies will be shipped from AGC and WANL and assembled at Michoud, where the engine will be acceptance-tested and mated with the flight stage.

3. Acceptance Test of Delivered Engines

All delivered engines shall be subjected to the following acceptance tests:

- a. Functional Tests
 - (1) Electrical continuity
 - (2) Leak Test

- (3) Operational
- (4) Calibration

b. Inspection

- (1) Engine-vehicle interface dimensional check
- (2) Engine Alignment Check
- (3) Engine log-book review

B. GROUND AND FLIGHT SUPPORT OPERATIONS

1. General

Ground testing of the engine assembly with the stage at NRDS and the assembly and mating of the engine with the stage for flight testing at Michoud shall be provided with the necessary technical support for the delivery, assembly, installation, and flight-test program in accordance with the needs established by the operational-support-plan studies.

2. Aerospace Ground Equipment

Provision shall be made for training in the use of the equipment and in its maintenance and repair.

The items of equipment to be supplied are provided in Table 5, Guideline List of NERVA Aerospace Ground Equipment. One set of the guideline equipment shall be delivered for use at NRDS to support the ground-test program, and one set shall be delivered to Michoud to support the flight-test program. The quantity of items (e.g., storage containers) will be determined in the operational-support-plan study.

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TABLE 5

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GUIDELINE LIST OF NERVA AEROSPACE GROUND EQUIPMENT

	<u>P/L No.</u>
PVARA Shipping Closure Kit	8000
Nozzle/Skirt Shipping Container	8003
Nozzle Holding Stand (Mod)	8015
PVARA Holding Stand (Mod)	8016
Thrust Structure Module Shipping Container	8100
Propellant Line Shipping Container	8101
Flight Skirt Shipping Container	8105
Thrust Structure Module Assembly Stand	8110
Thrust Structure Module Personnel Platforms	8111
Engine/Thrust Structure Handling Fixture	8113
Engine Assembly Stand (Mod)	8114
Engine Assembly Cage	8115
Engine Assembly Personnel Platforms (Mod)	8116
Engine Nozzle/Skirt Closure	8117
Engine Leak Test Closure Kit	8118
Propellant Line Assembly Fixture	8119
Thrust Structure Module Closure Kit	8121
Nozzle/Skirt Sling	8122
Engine Storage Container	8124
Flight Skirt Handling Sling	8125
Engine Storage Kit	8126
Pneumatic Supply Tank Handling Fixture - Remote	8163
Engine Reassembly Stand	8179
Engine Simulator	8200
E Checkout Interconnection Kit	8250
Thrust Alignment Checkout Fixture	8251
NERVA Preflight Checker (includes control-drum pneumatic-actuator checker)	8252
PVARA Shipping Equipment (includes containers, instrumentation, trailers, and lift fixtures)	Not Assigned

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C. NERVA MANAGEMENT PLAN AND CONFIGURATION MANAGEMENT

The design, development, and supply of articles under this program shall be in accordance with the requirements and procedures contained in the NERVA Management Plan. This plan shall be developed by the contractor and approved by the government and shall be the document that establishes the specific procedures for this program. It shall thereby delineate the extent of the incorporation of the principles and procedures of systems development described in AFSCM-375 series documents. The NERVA Management Plan shall delineate the data items of AFSCM-310-1 to be delivered under this program.

The NERVA Management Plan shall be the primary source document delineating program requirements, responsibilities, approvals, logic, and program and administrative constraints.

Figure 1 shows the guideline initial portion of a flow chart delineating the above requirements, constraints, logic, etc. for the program. The portion shown indicates the tentative constraints on conduct of the preliminary design review on the contract end items. This figure, when completed and incorporated in the NERVA Management Plan, will describe the phases, logic, constraints, etc. in conducting the program in conformance to the technical and programmatic requirements listed herein.

GUIDELINE INITIAL PORTION OF NERVA MANAGEMENT PLAN
TENTATIVE CONSTRAINTS ON PDR

2-19-68
 FIGURE I

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 35

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LEGEND:

SNPO
 RESPONSIBILITY

AGC
 RESPONSIBILITY

D. NERVA-PROPULSION-SYSTEM PROGRAM - GUIDELINE SCHEDULE

Table 6 contains the guideline schedules for major events in the program that shall be used by the contractor in preparing a proposed program plan for the acquisition and operational phases of the NERVA Propulsion System Program.

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TABLE 6

NERVA PROPULSION SYSTEM PROGRAM GUIDELINE SCHEDULES-SJC-275 (U)

<u>Test Program</u>	<u>Desig.</u>	<u>ARRIVE</u>		<u>COMPLETE</u>	<u>COMPLETE ASSY & ACCEPTANCE TEST AT MICHOUUD</u>
		<u>AT</u>	<u>START</u>	<u>ASSY & ACCEPT. TEST IN E-MAD</u>	
		<u>USE</u>	<u>POWER</u>		
		<u>FACILITY</u>	<u>TEST</u>		
<u>Guideline Engine Test Prog.:</u>					
Develop. Test (Engineering Test and Evaluation)	E-1		1-15-71		
Preliminary Qual. Test	E-2		9-15-72		
	E-3		3-15-73		
	E-4		9-15-73		
Formal Qual. Test	E-5		3-15-74		
	E-6		9-15-74		
	E-8		3-15-75		
(with unfueled reactor for transportability & vibration environment)	E-C			7-27-73	
(spare qualification or ground storage demo)	E-X			11-15-73	
<u>Guideline Reactor Assembly Test Program:</u>					
Development Test	R-1		9-15-70		
	R-2		3-15-71		
Prelim. Qualification	R-3		12-15-71		
Formal Qualification	R-4		10-15-72		
<u>Special Test Assemblies Prog:</u>					
Weight & Env. Mockup	WEMU		7-5-70		
Remote Assy & Disassy	RADA		10-15-71		
Engine Simulator	ES		2-18-72		
<u>Delivery Program</u>					
<u>Formal Qual Test Model Eng:</u>					
(for ground test of	E-7			7-15-74	
flight Stage at NRDS)	E-9			4-15-75	
(for ground testing	E-10			10-15-75	
during flight program)	E-11			4-15-76	
	E-12			10-15-76	
(for flight Test program)	E-13				4-15-77
	E-14				10-15-77
	E-15				4-15-78
	E-16				10-15-78
<u>Aerospace Ground Supp. Equip.</u>					
Guideline List Del. AGE	Set 1		1-15-74		
Storage Containers for E-7			1-15-74		
Storage Containers for E-9			10-15-75		
Guideline List Del. AGE	Set 2		10-15-76		
Storage Containers			To be developed		

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