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TITLE: NERVA PROGRAM REQUIREMENTS DOCUMENT

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MILTON KLEIN
Manager
Space Nuclear Propulsion Office

R. W. SCHROEDER
Chief
Space Nuclear Propulsion Office
Cleveland Extension

NERVA PROGRAM REQUIREMENTS DOCUMENT

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I. Scope

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

The NERVA Propulsion and Test Systems includes the engine assembly, engine and component test and qualification facilities, aerospace ground equipment, and supporting systems and services.

II. Applicable Documents

The procedures and requirements of the documents listed in Appendix A, "Applicable Documents", are applicable to the NERVA Program, except as modified by this document. The interpretation and application of the contents of the documents listed in Appendix A shall be in accordance with the NERVA Program Management Plan, dated_______________.

III. Technical Performance Requirements

A. Mission Requirements

The engine shall be designed for multiple missions as described in the Systems Engineering Requirements Documents, Appendix B, attached hereto.

B. Engine Performance Requirements

1. Functional Characteristics

a. <u>Performance Requirements at Rated Conditions</u>

Rated conditions shall be based on MSFC Spec. 356A (liquid) hydrogen, delivered at the tank outlet (upstream of the main propellant shutoff valve (PSOV)) at 30 psia., and saturation temperature, containing zero % vapor; with the engine at zero ambient pressure; zero gimbal angle; and single module (engine) operation, utilizing a full-flow cycle to drive the turbopump(s) and assuming a contoured 6
nozzle expansion ratio of 100:1. The engine shall be capable of performing as specified herein.

(1) Thrust, F	75,000 ± 2000 lb.
(2) Nominal Mixed Mean Chamber Inlet Temperature, Tc	4250°R
(3) Nominal Chamber Pressure, Pc	(tbd) psia
(4) Nominal Specific Impulse, Isp	825 sec.
(5) Minimum Specific Impulse, Isp	(tbd) sec.
(6) Engine Weight Max.	(tbd) lb.
(7) Shield Weight Max.	(tbd) lb.

The reactor design will incorporate such features as necessary (exclusive of fuel element features) to allow growth, as shown by analysis, to operation at 4500°R nominal mixed mean chamber temperature for two hours' duration (12 cycles).

b. <u>Endurance at Rated Conditions</u>

600 minutes at rated conditions. The operating time shall be utilizable in multiple cycles, up to 60, of varying lengths totaling a minimum of 600 minutes.
This rated endurance is not to be construed as the 6
limit of life of all components. Rather, the endurance of such components (except fuel elements) shall

be greater than 600 minutes and shall be established by reliability, maintainability, performance, weight, 6 manufacturing and cost considerations.

c. Throttling

The engine shall be capable of throttling at rated chamber temperature from the engine design point of (tbd) psia chamber pressure to a chamber pressure of (tbd) psia at a maximum rate of 50 psi/sec for a duration of (tbd) minutes per thrust period, sufficient to allow optimum removal of delayed neutron power production at rated chamber temperature. At any time up to 595 minutes of engine operation, the engine shall be capable of pro- 6 viding 22.5 million pound-seconds impulse at rated chamber temperature and tbd pounds thrust while operating with hydrogen delivered at the tank outlet (upstream of the main propellant shutoff valve) at 30 psia, saturated temperature containing up to 15% vapor by volume.

d. Startup and Shutdown

Optional modes of bootstrap startup shall be provided. One mode shall provide highest possible integrated specific impulse, within the (thermal) stress limitations of the reactor structure(s), during the starting transient.

The temperature rates shall be optimized. This mode shall follow the reactor structural (temperature) limits up to the rated temperature and maintain this temperature to rated thrust. Another mode shall provide the highest possible integrated thrust during the transient from flow initiation to rated operating conditions. This can be accomplished by increasing the engine chamber temperature at an optimum rate with chamber pressure increasing at an optimum rate. Notwithstanding, during the major portion of the transient ramps, the engine shall have the capability and the controllability of $150^{o}R$/sec. chamber temperature and 50 psia/sec. chamber pressure rate.

The engine shall be capable of initially bootstrap starting and restarting at any time and at pressures within the venting range of the propellant tank. The pressure range will be (24) to (30) psia, at saturated propellant conditions in the locked tank mode.

The engine shall be capable of providing hydrogen pressurizing gas to the propellant tank during startup, steady state, and shutdown operations in the quantities and on schedule shown in Figure (tbd). Engine bootstrap characteristics shall be designed to be relatively insensitive to back pressure at pressure levels ranging from vacuum to that obtainable with the modified ETS-1 (2 psia).

During the shutdown transient, impulse lost by using propellant at less than full I_{sp} shall be minimized. However, after (tbd) seconds of coolant flow, the system should provide for either using the available impulse or for dissipating the coolant flow with zero thrust. The user shall have the option of either using the available impulse or counteracting the thrust.

e. Controllability

The control system shall provide sufficient precision for the range of propellant conditions specified in the System Engineering Requirements Document (Appendix B) to accurately control the operations in such a manner that the missions outlined in the System Engineering Requirements Document (Appendix B) may be planned and executed successfully. In the various modes of operation the performance shall be controlled within the following 3 sigma limits:

(1) Startup (both startup modes)

(a)	Impulse	(tbd)
(b)	Time	(tbd)
(c)	Propellant Consumption, including Chilldown Propellant	(tbd)

(2) Steady State

(a)	Specific Impulse	$\pm$ 0.75%
(b)	Thrust	$\pm$ 2%

(3) Shutdown

(a)	Total Impulse	$\pm$ 20,000 lbs-sec.
(b)	Time	$\pm$ 15 sec.
(c)	Propellant Consumption including Cooldown Propellant	(tbd)

The total impulse controllability requirements set forth above apply during the period which starts with departure of engine operation from the rated chamber-temperature point and which ends with termination of thrust for a given engine cycle. The time controllability requirement applies over this same period. 3

f. Thrust Vector Control

The thrust vector control system shall provide a gimballed engine system having a displacement of at least 1.5^{o} in any direction at a maximum rate of 0.25^{o}/sec. with a maximum acceleration of $0.5^{o}/\text{sec.}^{2}$.

g. Leakage

To minimize leakage the engine shall be designed to minimize joints where leakage may occur. Furthermore, maintainability and reliability shall not be compromised. Maximum leakage during all non-operating periods shall not exceed 400 standard cubic inches of hydrogen per minute. The engine design shall be capable of handling leakage without problems such as ice, including solidified hydrogen, forming in any place in the engine or engine valving. It shall also dispose of all leakage in a safe manner.

h. Booster

The engine shall be designed for use as part of the vehicles specified in Appendix B. 6

i. Man-rating

The engine system shall be man-rated (see Paragraph 8).

j. Reliability

The reliability requirement for the NERVA engine shall be 0.995, i.e., the probability at 90% confidence level that the engine shall successfully fulfill the endurance requirements set forth in
Section "b" at rated operation while meeting all 6
mission related requirements of this document shall be 0.995 or greater. Confidence level need not be established by attribute testing.

k. Shielding

(1) The engine shall include vehicle shields which protect components from radiation degradation of reliability, performance or endurance beyond the limits specified elsewhere herein.

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(2) The vehicle shield shall also provide propellant tank protection such that the combined effects of heating, temperature gradient, and/or vapor content will not degrade engine performance beyond the limits specified elsewhere herein or unduly reduce the payload.

(3) Provision shall be made for additional crew shields, and installation thereof, to reduce the dose due to engine radiations per round-trip to 10 rem at the location of each passenger and 3 rem at the location of each flight crew member 6
in the spacecraft for nuclear-shuttle operations (configuration to be supplied).

An additional design objective will be to allow reductions in the crew shielding with minimum redesign should mission requirements permit.

(4) The overall engine design, including reactor, lines and nozzle shall be such as to minimize the penalty for crew radiation protection.

1. Environment

The engine shall be capable of rated operation after being subjected to all ground, launch, and flight environments. Environmental data are included in SNPO-C-6.

m. <u>Nozzle</u>

The nozzle length and area ratio shall be optimized, compatible with engine specific impulse requirements and payload tradeoff studies.

n. <u>Storage</u>

The engine shall be capable of operating without degradation of reliability, performance, and endurance under the following storage conditions:

(1) Five years on the ground in a suitable container.

(2) Three years in space, operating and non-operating. 6

(3) Six (6) months under pad environment.

o. <u>Engine to Stage Interfaces</u>

In general, special provisions for ground testing, data acquisition, and control will be incorporated. These features may be eliminated in the deliverable engines (and stages) and will be designed so that their elimination from deliverable flight test engines (and stages) shall not affect the validity of the qualification program or the engine (and stage) reliability.

The engine interfaces with the stage and the test stand shall be defined by the Interface Control Document approved by SNPO. The Interface Document will define the following characteristics:

(1) Functional, including structural loads, induced environments, fluid flows, electrical circuit characteristics and pin functions designations.
(2) Physical, including mechanical assembly and spatial relationship of parts at the interface. Such parts include electrical connectors, fluid line couplings and structural attachments.
(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrain end item design. These constraints include assembly, disassembly, alignment, maintenance and safety (310 documentation).

p. <u>Engine Interface With Orbiting Propellant Depot and With Space Station</u>

The engine interfaces with the Orbiting Propellant Depot and with the Space Station shall be defined by the Interface Control Document approved by SNPO. This Document will define the following characteristics:

(1) Functional, particularly engine component maintenance, checkout, logistics and disposal.
(2) Physical, including mechanical connections, spatial relations, shielding, etc.
(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrains end item design. These constraints include maintenance, safety and checkout.
(4) A record of engine requirements allocated to the Orbiting Propellant Depot and to the Space Station shall be maintained as part of the NERVA systems engineering.

q. <u>Safety</u> 7

Maximum effort shall be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the completion of the mission, the flight crew, the launch crew or the general public.

In the event the planned mission must be abandoned the effect of each mode of failure on engine performance must be minimized so as to make the optimum use of remaining propellant and at the minimum to provide an integrated engine performance of:

(a) 30,000 pounds thrust (to be verified)

(b) 500 seconds specific impulse (to be verified)

(c) 10^8 pound-seconds total impulse including cooldown propellant with the total impulse controllable up to a maximum of 10^8 pound-seconds.

These requirements shall be provided by a single engine cycle in the degraded state. Operation in an emergency mode must be attainable from all operating modes of the engine cycle including all shutdown modes and coast phases. If mission abandonment is required during the normal steady state operation immediate retreat to an emergency mode shall be made. If the malfunction occurs during engine modes following the steady state power modes, provision shall be made for cooling up to five hours prior to entering an emergency mode. Ramps from the normal operational modes to an emergency mode are TBD. Shutdown ramps from the emergency modes are TBD. Final cooling shall preclude engine disassembly
and, if it can be done at no additional risk to popula- 7
tion, passengers or crew, preserve the engine in a restartable condition.

The required total impulse must be provided in a sustained emergency mode at any of the points above the required minimum and within the normal operating map. The operating point selected after the failure has occurred will be determined by the nature of the failure and the reliability of retreating to and operating at the emergency mode operating point.

Potential failure modes that would preclude attainment of these requirements shall be identified and presented to the Government for review with justification for retention.

A Contingency Analysis and Planning Process shall be continuously conducted to ensure that these requirements are met.

2. <u>Transportability</u>

The assembled engine or major subassemblies shall be transportable in any attitude by land, sea, or air without degradation.

The complete engine assembly shall be transportable after final checkout.

The engine shall be transportable either vertically or horizontally when assembled to the propellant tank.

Suitable handling points and devices shall be provided to permit assembly to the propellant tank in both the vertical and horizontal attitudes.

The requirements of Air Force Specification (tbd), "Transportability Demonstration" and SNPO-C loads and environmental specifications shall be satisfied before shipment of the engine or any of its subassemblies.

3. Maintainability

(a) The engine shall be designed and constructed to meet the following requirements:

(1) All mission-critical components external to the reactor pressure vessel and nozzle will be maintainable by repair, replacement or substitution (switching or redundancy) before and after operations. Trade studies will be conducted to investigate: (a) the extent to which modular versus individual-component designs affect reliability, maintainability and performance (including weight); and, (b) the extent to which remote or direct maintainability will be employed.

(2) Such maintenance will be achievable during non-operating periods in the mission.

(3) All mission-critical components will be capable of functional and electrical checks remotely after engine assembly or engine maintenance.

(4) It will be possible to purge the engine by an external source of inert gas prior to ground operation or launch.

(5) The engine will be remotely installed and removed from engine test facilities (listed elsewhere herein).

(6) After space operations, manual maintenance will not be required in excessive radiation environments.

(7) For the storage periods previously specified, no periodic routine engine maintenance will be required.

(b) Trade-off studies, concurred in by SNPO, will determine the advisability of designing and constructing the engine such that it is replaceable on the stage; or that the reactor/pressure-vessel/nozzle assembly is replaceable on the engine. The trade-off studies shall also address themselves to the question of disposal of these assemblies.

(c) A maintenance program and program plan shall be provided in accordance with AFSCM 310-1 and AFLCM 310-1. This program and plan shall also be in accordance with the following sections of this NPRD:

(1) Page 18, Section (3) and Page 19, Section (4):

diagnostic instrumentation for failure detection and display of information in-flight;

(2) Page 21, Section (1): trend-data program; and

(3) Page 22, Section (2): certification of deliverable hardware.

The plan shall consider, in addition, the logistical requirements of engine maintenance in earth orbit or elsewhere in space.

(d) Utilization of maintainability concepts may be necessary to achieve the required reliability over the endurance stated in Section II.B.1.b. However, maintainability will not be used as a substitute for reliable design. The maintainability program will be developed to extend the results of the reliability design process described in Section III.B.8 to aid, where necessary, in achieving the reliability requirement.

4. <u>Acceptance</u>

The engine assembly will be accepted on the basis of successful functional and cold flow tests, together with a review of the production and test history of those components in the assembly and all other related components in the program.

Some additional criteria for acceptance are provided in paragraph 8, "Quality Assurance."

5. Cleanliness

The engine shall be designed to handle any unlimited flow (rate) of 600 micron or less particles throughout its operating life. The estimated weight to be handled is 220 grams of materials with the density of aluminum.

The design and construction of parts, components, subsystems, and systems shall satisfy the requirements of AFSCM 310-1/AFLCM 310-1 S-21-17, "Contamination Control." The above requirements are also applicable to self-contamination.

6. Electromagnetic Interference

The engine shall be designed and tested to satisfy the requirements of military specification MIL-E-6051-C and others.

7. Interchangeability

All qualification hardware shall be interchangeable down to the component level.

8. Man Rating, Reliability, Quality Assurance, and Safety

a. Man Rating

The NERVA engine shall be man rated. Equipment is man rated when its utilization in manned space vehicles provides for and protects the crew's well being and utilizes man's ability to control and repair. It follows that man rated equipment, and especially propulsion, must be highly reliable. Man rating is not attained solely by compliance with some particular specification or rule.* Rather it results from that

* As a minimum, the requirements of SNPO-C1 stress specification and SNPO-C loads and environment specifications will be met. However, compliance with these requirements alone does not insure achievement of the required reliability of man rating.

fastidious approach to the total effort from concept to final disposition in flight which takes every reasonable step to assure the safety of the astronauts, the launch crew and the general public. Special steps are required to assure the elimination of errors and, in particular, errors caused by the use of "engineering judgment" by individuals during design, test or fabrication. To give visibility to the use of judgment special procedures and approaches will be devised to assure that the judgments do not stand unreviewed.

The practice of man rating begins with a study of the functional flow diagrams for representative missions coupled with a recognition of undesirable stresses and dangerous situations for the crew. A thorough, analysis (Fault tree analysis, for example) must then be conducted (and continuously updated) to determine ways in which normal operation, single failures or credible combinations of failures can result in these undesirable circumstances. A contingency plan must then be prepared (also continuously updated). From these analyses, requirements must be included in the Requirements Allocation Sheets.

The reliability and safety goals previously stated are to be achieved through inherent design whenever possible. In particular, maximum effort should be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the completion of the mission flight crew, launch crew of the general public. If that proves impossible or results in an excessive penalty, redundancies internal to the component in question will be incorporated. If that is impossible, ways in which other components can compensate will be explored. If cases occur where no practical solution can be found by inherent design and where credible single or multiple failures can jeopardize crew and/or population safety, then countermeasures must be provided and/or techniques such as maintainability and alternate operating modes must be employed.

The nature of nuclear rockets is such that man rating and reliability must be obtained primarily through consistent, thorough, rigorous design practices applied throughout the programs. These design practice standards shall be prepared by the contractor(s) and approved by the Government.

These design practice standards shall include the following: 6

(1) The compilation of a complete statement of the environment which the component will see during inspection, storage, transportation, checkout, ground test and flight.

(2) A complete listing and analysis of imposed loads of all kinds.

(3) A complete listing and analysis of all input data utilized in the design including an analysis of the variation and uncertainties of these data.

(4) Complete stress, thermal, vibration and other special analyses as required.

(5) A thorough failure modes, effects, and criticality analysis.

(6) A reliability prediction based on the above analyses in addition to one based on historical data of similar components.

(7) A carefully considered plan to provide experimental verification of all the above factors.

All of these steps shall be recorded by the designer, carefully reviewed within the contractor organization, and furnished SNPO for further review and appropriate action.

The process of review of requirements, analysis, design, redesign, prediction and verification described above must be periodically and formally reiterated and updated so that improvements can be made, new information and requirements incorporated, and changes accounted for and documented.

The NERVA engine shall incorporate the following features:

(1) Means of preventing accidental criticality during all ground and space operations. An 7
anticriticality destruct system shall be provided for launch and ascent.

(2) Throughout the mission means shall be provided for preventing credible core vaporization, disintegration or violation of the thrust/load path to the payload.

(3) Judicious selection of diagnostic instrumentation adequate to detect the approach of a failure or an event which could injure the crew or damage the spacecraft directly and provisions to preclude such an event.

(4) Judicious selection of diagnostic instrumentation adequate to detect deteriorating situations or incipient failures.

(5) 3

(6) Ability to override the engine programmer remotely by the crew and ground control, the ability for remote thrust cutdown independent of the engine program. In addition, the engine control system shall have the ability to preclude excessive or damaging deviations from programmed power and ramp rates.

b. Reliability and Quality Assurance

In assessing the reliability achieved, emphasis will be placed on a sound scientific (including statistical methods) approach which verifies the design and all loads, assumptions, analyses, failure modes, design data and predictions by experiment and test. At least at the part, component and subsystem level, extended limits and tests to failure shall be emphasized. Demonstration purely by attribute (go, no-go) testing is not required. Nevertheless, all attibute data obtained will be recorded and analyzed so that the currently demonstrated relability and confidence level shall be available at all times. For this purpose, component, subsystem and system data will be combined to the extent that sound judgment permits. In addition to overall engine reliability, parameters necessary to demonstrate the safety characteristics of the system shall be emphasized, e.g., failure rate at steady state during each cycle, the ratio of failures during startup and shutdown to those during steady state, the fraction of failures which would result in a hazardous situation vs. those which would not.

NPC 250-1, Reliability Program Provisions for Space Systems Contractors; NPC 200-2, Quality Program Provisions for Space System Contractors; and NPC 200-3 Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services, or elements thereof, provide the requirements to be satisfied in the preparation of reliability and quality program plans. Accordingly, reliability and quality plans shall be prepared by the contractor which reflect requirements imposed, and are tailored to meet the needs of the special nature of the program. When contractor reliability and quality plans are approved by SNPO they will serve as the basis for implementation of reliability and quality requirements through the contractors activities.

Reliability and Quality Program Plans shall be developed by the prime and principal subcontractors. The prime contractor shall coordinate and monitor quality efforts in order to provide uniform Reliability and Quality Assurance programs. The programs shall include:

(1) Trend Data Program

The purpose of this requirement is to provide a documented history of each component's critical characteristics from procurement of raw materials and fabrication through end-of-life to identify deterioration as one assessment of readiness to perform adequately and also to detect changes in processes and procedures.

This requirement can be satisfied by the generation, implementation, and completion of a program which incorporates the features described below. This program plan for each component will be part of the R&QA plan.

The required features of the Trend Data Program shall be incorporated into the component engineering data packages and shall include the following:

(a) Identifying measurements required to establish trends such as deterioration, wear, or other factors which if measured would indicate incipient deviations from specified tolerances.

(b) Collection and collation of pertinent data.

(c) Trend analyses.

(d) Verification of the validity of trends.

(e) Assessment of degree of deterioration.

(f) Enforcement throughout development, qualification, and production phases.

(2) Selection and certification of hardware for qualification or delivery.

Hardware designated for qualification testing or assembly to an engine (other than a development engine) shall be selected by a review procedure first by the contractor and then by the Government. Criteria for disapproval for the above uses shall include:

(a) History of unexplained transient non-recurring malfunctions.

(b) Excessive operating run time and/or hot fire cycles.

(c) The failure history of the part/component/assembly indicates a marginal or degraded reliability condition.

(d) The part, component or assembly had excessive rework and repair during fabrication and/or acceptance.

(e) The supporting documentation is incomplete, lacks inspection verification, or does not reflect adequate corrective action and/or acceptance rework.

(f) The part, component, or assembly has a history or performance data that indicates marginal operation which is outside the acceptable limits.

(g) The part, component, or assembly is below the authorized minimum or base line configuration disposition.

(h) Other factors which in the judgment of the reviewers constitute a basis for disapproval.

(3) Malfunction/Failure Reporting, Analysis, and Resolution Boards:

(a) The engine contractor and nuclear subsystem (NSS) contractor shall each establish a top level malfunction/failure reporting, analysis and resolution board.

(b) The board(s) will review at regular and frequent intervals the total engine and/or reactor program malfunction/failure history and institute corrective action.

(c) Constitution of the boards:

<u>Engine Contractor:</u>

Manager, NRO

Programs Senior Reliability Supervisor

Programs Senior Quality Assurance Supervisor

Programs Senior Supervisory Component Engineer

Programs Senior Supervisory System Engineer

Project Management and Planning Supervisors

Government Observer

NSS Contractor Observer

NSS Contractor

The NSS contractor's board shall include personnel of the same level of responsibility and authority as those listed for the engine contractor and will also include Government and prime contractor observers.

(d) Board Reports

The records of the boards' meetings and actions shall be made available promptly to the Government and to opposite board's chairman.

c. Safety

An effective NERVA systems safety program shall be conducted which meets the requirements of NASA Safety Manual NHB 1700 (As interpreted by the NERVA Program Safety Plan (Appendix __)). The contractor shall submit and execute a NERVA Safety Engineering Plan per paragraph 1.2.2., Section III, NHB 1700.1.

9. Preferred Parts

All electric-electronic parts used in qualification and subsequent hardware will conform to "high reliability standards" in accordance with specification (tbd) in the overall engine operating environments.

10. MILA Environment, Moisture and Fungus Resistance and Corrosion of Metal Parts

The engine shall be designed to withstand the regional and seasonal environment of the Merrit Island Launch Area, Cape Kennedy, Florida. Minimum requirements will be the applicable portions of Military Specifications: MIL-STD-810, MIL-STD-33586 and MIL-F-7179. 3

C. Engine Test Program Guidelines

1. Purpose of Guidelines

The purpose of the guideline information in this section is as follows:

a. To set forth definitions of tests and concepts in order that common understanding will prevail as to the Government's intent;

b. To indicate the Government's general objectives regarding the testing of reactor and engine builds in order that further test details can be developed on a common basis; and

c. To specify a basis for component and subsystem testing consistent with the overall objectives of the engine development program.

2. Definitions

a. Rated Performance

Rated performance means the capability of an item (component, subsystem, system) to function as designed under the specified normal parameters (environments and loads). For the engine system, certain of these normal parameters are specified as "Rated Conditions" in Sections IIIB1a (full thrust steady state conditions), IIIB1c (throttling of thrust) and IIIB1d (startup and shutdown transients).

b. Specification Extreme Performance

Specification Extreme Performance means the capability of an item to function as designed under normal parameters plus an increment to cover probable imprecision in the measurement, analysis or control of such parameters. Hence, the magnitude of any test parameter used to evaluate Specification Extreme Performance shall equal the nominal value of that test parameter plus the statistical sum of the imprecision in all other parameters which affect the test parameter. In general, such imprecision in the value of each parameter shall be expressed as the three-standard-deviation ("three sigma") value.

For the engine system, major parameters related to Specification Extreme Performance include: engine thrust, reactor power, chamber temperature, specific impulse, chamber pressure, propellant flow rate, core pressure drop, rate of change of chamber temperature (increasing and decreasing, including emergency shutdown), stem temperature, duration and cycles. The design practices called for in Section 8a shall result in a detailed Specification Extreme Performance description for each item.

c. Design Performance.

Design Performance means the capability of an item to function as designed under parameters which reflect the Specification Extreme magnitude plus the margin applied to each parameter in the design of that item. The design practices called for in Section 8a shall result in a detailed Design Performance description for each item.

d. Development Tests

Development tests include those tests and evaluations necessary to acquire engineering data for the direct support of 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 components to natural or simulated loads and environments.

Development testing will be accomplished on any of the items involved in NERVA, up to and including the complete engine. Development testing shall include Design Performance demonstration. The design practices of Section 8a shall call out the features of such testing. Where the parameters of duration and progressive damage are important in an item, Design Performance of those parameters shall be demonstrated by development testing.

These development tests will establish the basis for confidence in the design (including its margins, safety factors and reliability), in fabrication processes and in operational techniques for the item under test, for release of the item to Preliminary Qualification and to the Formal Qualification test programs.

e. Preliminary Qualification Tests

The Preliminary Qualification testing of an item (up to and including the complete engine) involves tests to demonstrate that the item functions as designed. Hence, Preliminary Qualification tests shall include demonstration of Design Performance, as defined above. The level of major parameters involved in Category II[1] Preliminary Qualification tests shall result from the design practices called for in Section 8a and from the results of Category I[1] development and Preliminary Qualification testing.

Successful completion of the Preliminary Qualification tests will be the basis for the incorporation of items

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[1] Defined in Sections i and j.

in the next higher assembly item Preliminary Qualification test program and will indicate that the item is suitable for release to Formal Qualification tests. In the latter case the release to Formal Qualification may be additionally supported by development tests that provide test data on features not demonstrated in the Preliminary Qualification tests. Preliminary Qualification testing shall include, but not be limited to, all items designated CEI and ECC.

f. Formal Qualification Tests

The Formal Qualification test of an item (up to and including the complete engine) involves tests designed to demonstrate that the item satisfactorily meets the requirements of flight. Hence, Formal Qualification tests shall include demonstration of Specification Extreme Performance for the flight durations and cycles set forth in Section IIIB1b(3). Successful completion of the Formal Qualification testing shall be the basis for the incorporation of items in the next higher assembly item Formal Qualification program and will indicate that the item has completed its design and development phase. Formal Qualification shall include, but not be limited to, all items designated CEI and ECC.

g. Reliability Tests and Analysis

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. The design practices called for in Section 8a will call out the features of reliability test programs on any item.

h. Quality Assurance and Acceptance Tests

Quality assurance testing includes all those non-destructive tests, inspections and measurements of an item and those destructive tests of similar items applied for the purpose of release from vendors, fabrication, assembly or inventory. Acceptance tests of an item are conducted subsequent to such inspection to demonstrate functional characteristics that are demonstrable only during the operation or simulated operation of the item. These tests are intended to verify that the item is in accordance with specification and is acceptable for delivery to inventory or use in accordance with the qualification rating of that item.

i. Category I Tests of an Item

Tests on an item are considered to be Category I tests if the item is tested with equipment simulating the parameters and interface without the incorporation of other items. Under such tests, the item is developed and qualified in accordance with design and/or specification using only test support equipment.

j. Category II Tests

If any feature of an item cannot be adequately demonstrated by the use of simulated parameters and interfaces, and if the actual development parameters and interfaces can only be achieved by the incorporation of other items, that 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 design or specification will require some demonstrations in the Category I and some in Category II type tests. Other items might be fully qualified only by means of Category II testing. The design practices described in Section 8a will define the category of testing required in the course of developing each item.

k. 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 an item that are required to be demonstrated for Formal Qualification of the item and which can only be demonstrated in conjunction with an engine or reactor test shall be considered to be demonstrated in Category II tests as a part of the engine or reactor. However, any item in any engine or reactor assembly will have first successfully completed specified Category I.

b. The component development program shall be conducted to provide suitably qualified components for use in the guideline engine test program. The component development 6 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 development tested prior to incorporation into the E-1 assembly.

c. Features of the engine and reactor that are required to be demonstrated in the engine and reactor development, Primary Qualification, and Formal Qualification test series have been tentatively assigned to specific engines and reactors to divide the acquisition of demonstration data among a fixed number of engines and reactors, 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 guidelines distribution of the data acquisition plan relative to reactor number and Table 3 summarizes similar information relative to engine number. The engines and reactors are also grouped relative to the kinds of test plans.

(1) Reactors R-1 and R-2 are assigned to nuclear subsystem 6
development testing. The primcipal objectives of this testing shall be:

(a) To demonstrate Design Performance of the nuclear subsystem;

(b) To establish the locus of reactor map constraints;

(c) To demonstrate controllability; and

(d) To determine duration and cycling capability for 6
300 minutes or greater (30 cycles or greater) during the achievement of objectives (a) through (c) in R-1; to determine duration and cycling capability for 600 minutes or greater (60 cycles or greater) during the achievement of objectives (a) through (c) in R-2.

Other objectives are set forth in Table 2. Items delivered for assembly into R-1 and R-2 shall have completed the specified Category I Preliminary Qualification testing related to R-1 and R-2; that is, the Preliminary 6
Qualification of each component shall show satisfactory completion of testing, demonstrating that the component is capable of operating under R-1 and R-2 conditions.

(2) Reactor R-3 is assigned to nuclear subsystem Preliminary Qualification and will serve as Category I Preliminary Qualification testing of the nuclear subsystem. The Category II Preliminary 6
Qualification Test of the nuclear subsystem will be performed on the R-2 test article. The principal objectives of this testing shall be:

(a) To demonstrate Design Performance;
(b) To confirm the locus of reactor-map constraints;
(c) To confirm controllability;
(d) To confirm duration and cycling capability for 600 minutes of cycled operation during the 6
achievement of objectives (a) through (c).

Other objectives are set forth in Table 2. All nuclear subsystem components delivered for assembly into R-3 shall have successfully completed Formal Qualification in appropriate Category I or Category II tests. All other test article components (e.g., nozzle, pressure vessel) shall complete the Preliminary 6
Qualification and Formal Qualification tests via Category I tests prior to assembly into R-3.

(3) Reactors R-4 and R-5 are assigned to Formal Qualification of the nuclear subsystem, and shall contain all of the items making up that subsystem. The principal objective of these tests shall be: 6

(a) To accomplish Formal Qualification under conditions of Specification Extreme Performance for the full endurance specification. 6

(b) To achieve Formal Qualification by reactor disassembly and evaluation of reactor components. Other objectives are set forth in Table 2. All components that are separately qualified and delivered for assembly into R-4/R-5 shall have successfully completed Formal Qualification by means of Category I or Category II tests. 6

(4) Three weight and envelope mockups (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. These three mockups shall support studies as required at WANL, AGC, NRDS and at vehicle

development sites. The WEMU's 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 in ETS-1. They shall also aid in developing and demonstrating engine features involved during the development phase to meet the requirements for engine maintainability. This program shall be completed prior to the testing of E-2.

(5) The program shall also provide for an engine simulator capable of performing checkout tests in ETS-1 prior to the power test of E-1. The unit shall be driven 6

by facility-supplied cold hydrogen gas and be capable of delivering the engine full-power flow rate.

(6) The engine E-1 shall be assigned to engine development testing. The objective of this test is to investigate engine dynamics, controllability and mapping. Items delivered for assembly into E-1, with the exception of the Electronic Power Instrumentation Control (EPIC), the Anti-Criticality Poison System (ACPS), Nozzle Extension and Nuclear Subsystem, shall have completed the specified Preliminary Qualification Test related to E-1; i.e., the Preliminary Qualification Test of the item shall have demonstrated that the item 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. 6

(7) Engines E-2, E-3, and E-4 shall be assigned to Preliminary Qualification testing. The objectives of these tests include Design Performance operation for the full duration. Other objectives are listed in Table 3. All component models delivered for assembly into E-2 shall have successfully 6

completed the Category I Formal Qualification
Test program for the component, with the
exception of the Electronic Power Instrumentation
Controls (EPIC), the Anti-Criticality Poison
System (ACPS), Nozzle Extension and Nuclear
Subsystem. As shown in Table 4, the principal
EPIC system development tests shall be conducted
as Category II tests in conjunction with E-2;
Preliminary Qualification with E-3 and E-4;
and Formal Qualification with E-5, E-6 and E-8.
The Nozzle Extension shall, because of facility
limitations, be omitted from engine tests
(E-1 through E-8). Engine E-2 and beyond shall 6
contain all engine systems except the Anti-
Criticality Poison System extraction device
(and the Nozzle Extension). The Anti-Criticality
Poison System extraction device shall be provided
for in engines beginning with E-3, and its
Preliminary Qualification shall be conducted
in conjunction with the testing of E-4. Test
Stand ETS-1 (as modified) shall be checked out
with the aid of the Weight-and-Envelope Mockup
prior to the installation and testing of E-1.

(8) Engines E-5, E-6 and E-8 shall be assigned to Formal Qualification testing. The objectives of these tests shall be Specification Extreme Performance for the full endurance specification. 6 Formal Qualification of the Anticriticality Poison System will be conducted in conjunction with E-5 assembly in E-MAD and utilizes subsequent E-5 performance data.

(9) 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.

(10) 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 System (ACPS) extraction device Formal Qualification test requirements.

(11) Limited reliability tests 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.

(12) 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.

TABLE 2: NERVA GUIDELINE REACTOR ASSEMBLY TEST PROGRAM

6

Data to be Acquired	Reactor Assembly Designation				
	R-1	R-2	R-3	R-4	R-5
I. General					
1. Weight, CG, Moment of Inertia	D	D	PQ	Q	Q
2. GSE Compatibility	D	D	PQ	Q	Q
3. Facility Proof (Test Cell C & Control Point)	PQ	PQ	Q	-	-
4. Tank/Engine Interactions	-	-	-	-	-
5. Interface Compatibility	D	D	PQ	PQ	Q
6. Hardware Verification	D	D	PQ	PQ	Q
II. Checkout & Maintenance					
1. Transportability (Reactor Subassembly)	D	D	PQ	PQ	Q
2. Acceptance Test	D	D	PQ	PQ	Q
3. Leak Test	D	D	PQ	PQ	Q
4. Purge Capability	D	D	PQ	PQ	Q
5. Maintainability	D	D	PQ	PQ	Q
6. Facility Proof (E-MAD)	PQ	PQ	Q	-	-
7. Shielding	D	D	D	D	D
III. Environment					
1. Environment Extremes	D	D	PQ	PQ	-
2. EMI	D	D	PQ	PQ	-
3. Radiation Characteristics	D	D	PQ	PQ	-
4. Vibration	D	D	PQ	PQ	Q
IV. Operational Performance					
1. Cold Flow	D	D	-	-	-
2. Specification Extreme Performance	-	-	-	Q	Q
3. Design Performance	D	D	PQ	-	-
4. Endurance	D	D	PQ	Q	Q
5. Performance Mapping	D	D	D	-	-
6. Reproducibility	D	D	PQ	Q	Q
V. Operational Control					
1. Dynamics (Reactor)	D	D	D	-	-
2. Start, Stop, Aftercool, Restart	D	D	PQ	Q	Q
3. Flight Controller	-	-	-	-	-
4. Thrust Vector Control	-	-	-	-	-

TABLE 2: NERVA GUIDELINE REACTOR ASSEMBLY TEST PROGRAM (Cont'd)

6

Data to be Acquired	Reactor Assembly Designation				
	R-1	R-2	R-3	R-4	R-5
VI. Post Mortem Evaluation	D	D	PQ	Q	Q
VII. Manned Reliability and Safety					
1. Malfunction Detection	D	D	D	-	-
2. Malfunctions	D	D	D	-	-
3. Emergency Cooling	D	D	-	-	-
4. Anticriticality	D	D	PQ	Q	-

TABLE 3: NERVA ENGINE - OUTLINE TEST PROGRAM

Engine Requirements or Data	E1	W1	W2	E2	E3	E4	E5	E6	E8	EC	EX
I. General											
1. Weight, CG, Moment of Inertia	-	D	D	PQ	-	PQ	Q	-	-		
2. GSE Compatibility	D	D	-	PQ	-	PQ	Q	-	-		
3. Tank/Engine Interaction[1]	-	-	-	PQ	PQ	PQ	Q	Q	Q		
4. Interface Compatibility	D	D	D	PQ	-	PQ	Q	Q	Q		
5. Electrical Continuity	D	-	-	PQ	PQ	PQ	Q	Q	Q		
6. Trend Data Program Measurements	D	D	D	PQ	PQ	PQ	Q	Q	Q		
II. Checkout and Maintenance											
1. Transportability	D	D	D	-	-	-	-	-	-	Q	
2. Acceptance Test	-	-	-	PQ	PQ	PQ	Q	Q	Q		
3. Leakage Test	D	-	-	PQ	PQ	PQ	Q	Q	Q		
4. Purge Capability	D	D	D	PQ	-	PQ	Q	-	Q		
5. Maintainability	-	D	D	PQ	-	-	Q	-	-	Q	
6. Interchangeability	-	D	D	PQ	-	PQ	-	Q	-	Q	
7. Shielding	PQ	-	-	PQ	PQ	PQ	Q	Q	Q	-	
8. Facility Proof (ETS-1)	PQ	-	-	Q	-	-	-	-	-	-	
III. Environment											
1. Environment Extremes	-	-	-	PQ	PQ	-	Q	-	Q	-	
2. EMI	-	-	-	PQ	PQ	PQ	-	Q	-	Q	
3. Radiation Characteristics	D	-	-	PQ	PQ	PQ	Q	Q	Q		
4. Vibration	D	-	-	-	-	-	-	Q	-	PQ	Q
5. Space Storage	-	-	-	-	-	-	-	-	-	PQ	Q
6. Ground Storage	-	-	-	-	-	-	-	-	-	Q	Q
7. Acoustics	D	-	-	PQ	-	PQ	Q	-	Q		
IV. Operational Performance											
1. Cold Flow	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
2. Specification Extreme Performance	-	-	-	-	-	-	Q	Q	Q	-	-
3. Design Performance	-	-	-	PQ	PQ	PQ	-	-	-	-	-
4. Endurance	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
5. Performance Mapping	D	-	-	D	-	-	-	-	-	-	-
6. Reproducibility	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
V. Operational Control											
1. Dynamics	D	-	-	D	-	-	-	-	-		
2. Start, Stop, Aftercool, Restart	D	-	-	PQ	PQ	PQ	Q	Q	Q		
3. EPIC Demonstration	-	-	-	D	PQ	PQ	Q	Q	Q		
4. Thrust Vector Control	-	D	D	PQ	-	PQ	Q	-	Q		

TABLE 3: NERVA ENGINE - OUTLINE TEST PROGRAM (Cont'd)

Engine Requirements or Data	E1	W1	W2	E2	E3	E4	E5	E6	E8	EC	EX
V. Operational Control (Contd)											
5. Thrust Spoilers	-	D	D	-	-	PQ	-	-	Q		
6. Throttling	D	-	-	-	PQ	-	Q	-	Q		
7. Controllability	D	-	-	PQ	-	PQ	-	Q	-		
VI. Reliability and Safety											
1. Malfunction Detection	-	-	-	PQ	PQ	PQ	Q	Q	Q		
2. Malfunctions	-	-	-	PQ	PQ	PQ	Q	Q	Q		
3. Anticriticality	-	D	D	-	-	PQ	Q	Q	Q		
4. Thrust Integrity	D	-	-	PQ	-	PQ	Q	Q	Q		
5. Stable Operations	D	-	-	PQ	PQ	PQ	Q	Q	Q		
6. Engine Programmer Override	-	-	-	-	PQ	-	Q	Q	Q		
7. Detection Instrumentation	D	-	-	PQ	PQ	PQ	Q	Q	Q		
8. Specific Reliability Tests	-	-	-	R	R	R	R	R	R		
9. Human Functions	D	-	-	-	-	PQ	-	Q	-		

Data Code and Abbreviations

PQ - Preliminary Qualification
- Formal Qualification
W - Weight and Envelope Mockup (WEMU)
D - Development
R - Reliability

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[1] Only those items whose performance is not dependent upon close coupling.

TABLE 4

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

COMPONENT	DEVELOPMENT	COMPONENT TEST DATA TYPE	
		PRELIMINARY QUALIFICATION	FORMAL QUALIFICATION
Electronic Power Instrumentation and Controls (EPIC)	Laboratory and E-2.	Laboratory and E-3, E-4.	Laboratory and E-5, E-6, E-8.
Nozzle **	Technology Data	R-1 - R-3	R-4 and R-5
Nozzle Extension** (Full-Scale)	Laboratory	Laboratory and E-2 for attachment. R-(tbd)	Laboratory and E-5 for attachment. R-(tbd)
Anticriticality Poison System	Laboratory at AGC and WANL	E-4 cold tests in E-MAD	E-5 cold tests in E-MAD

* "Laboratory" means facilities other than NRDS reactor test cells or engine test stands.

** "Nozzle", as used in this Table, means only the regeneratively-cooled nozzle; "nozzle extension" means the extension between the regeneratively-cooled nozzle exit plane and the overall nozzle exit plane.

IV. Programmatic Requirements

A. Aerospace Ground Equipment

An Aerospace Ground Equipment Plan (including Operational Ground
Equipment, OGE, Maintenance Ground Equipment, MGE, and Test
Support Equipment, TSE) describing the systematic process as 2
utilized to develop AGE requirements in accordance with AFSCM
375-5, shall be prepared by the Contractor. Upon approval, the
plan will form the basis for providing the necessary Aerospace
Ground Equipment.

Aerospace Ground Equipment will be provided in accordance with the procedures established, in AFSCM 375 series manuals and AFSCM 310-1/AFLCM 310-1, for engineering critical components.

B. Facilities and Ground Support Equipment

1. General

To the maximum extent possible existing facilities and equipment will be utilized as is or modified to perform the fabrication, assembly, and testing of NERVA parts, components, subsystems, systems, and engine in accordance with the requirements of this document.

2. Available Facilities and Equipment

a. Government/Contractor facilities and special test equipment in California.

b. Government/Contractor facilities and special test equipment at Cheswick, Pennsylvania; Large, Pennsylvania; and Waltz Mills, Pennsylvania.

c. Government facilities at the Nuclear Rocket Development Station (NRDS) Jackass Flats, Nevada, particularly Engine

Test Stand #1, Reactor Test Cell "C", and the Engine Maintenance Assembly and Disassembly Building.

d. Government owned and operated support facilities and systems at the NRDS, such as the Radioactive Material Storage Facility, Technical Service Shops, Maintenance Shops and the Administration and Engineering Building.

3. Management Control of Facilities and Equipment

Facilities, special test equipment, and support equipment utilized in the NERVA qualification programs and addition to and modifications of existing facilities and equipment will be accomplished in general accordance with requirements of the AFSCM 375 series and AFSCM 310-1/AFLCM 310-1 as specified in the approved NERVA Management Plan and appropriate end item specifications.

a. To the maximum practicable extent, new facilities shall be designed and existing facilities modified to be available as required to meet the test schedule with all essential features calibrated and working properly and so that no single failure or credible combination of errors, malfunctions or accidents can cause personnel injury, and/or facility destruction, facility damage, test article or test data loss, in that order of priority.

b. All facilities defined above will be analyzed to determine their ability to meet these availability and reliability requirements and modifications made where deficiencies are found.

C. Logistic Plan

A program logistics requirements plan; to provide minimum inventory required during the various phases of the program, shall be developed. Upon approval this plan will form the basis for providing inventories at various points in the program.

D. Data and Document Management Plan

A NERVA Program Data/Document Control Plan shall be developed. Upon approval the plan will be the basis for data and document control throughout the program. NPC 500-6, DM 001.000-1 may be used as a guide in developing this program.

E. Configuration Management Plan

A NERVA Program Configuration Management Plan shall be developed. Upon approval the plan will be the basis for the configuration management of the items provided under this program. The Configuration Plan and Management shall be in accordance with the AFSCM 375 series and AFSCM 310-1/AFLCM 310-1.

F. NERVA Management Plan

A NERVA Program Management Plan shall be developed by the contractor. Upon approval this plan will form the basis for the execution of the program.

In addition to the standard management practices the contractor's Management Plan required by the AFSCM 310-1/AFLCM 310-1 data item M-1-14 will include a detailed description of the procedures for an integrated management process. This set of procedures will be based on a functional analysis approach, and shall be derived from a model containing a responsibility matrix to control the processes involved in program operations and shall explicitly define the methods used to verify the effectiveness of the process.

The requirement is to establish a system oriented management procedure directed toward functional responsibilities rather than organizational responsibilities. It is required that these functional procedures specifically include, but not be restricted to the following activities:

Contract Administration	Quality Assurance	
Plans and Programs	Reliability	
Engineering	Facilities	
Safety	Maintainability	6
Procurement	Logistics	
Manufacturing (Production)	Data Management	
Test Operations	Configuration Management	

Functional responsibilities shall be shown in relationship to the above listed activities. A form functional flow diagram shall be included to describe the program management interrelationships and controls to assure effective management of the NERVA engine development program.

The documents, reports, and exhibits shown in Appendix ___ "System Management Documents and Exhibits" form the minimum data items to be provided under this program. The form or content of the document may be revised to suit the needs of this program. However, the intent is that the basic information required will be in accord with the AFSCM 375 series. AFSCM 310-1/AFLCM 310-1, AEC Manual, pertinent NASA documents, and the SNPO Manual of Regulations.

G. NERVA Engine System Program Requirements Schedule

Appendix C, attached, contains the programs controlled milestones. Additional Government controlled milestones will be established by the Government office directly responsible for individual contracts.

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

Date: July 1, 1969

REFERENCE MISSIONS FOR NERVA SYSTEM ENGINEERING

The missions described in this Appendix are considered representative of the classes of near term missions for which the use of nuclear propulsion would be suitable and advantageous. These missions are to be utilized in the identification of NERVA requirements and in the determination of engine design solutions which will result in maximum mission payloads consistent with reliability, flight safety and minimum engine thrust and specific impulse requirements.

It shall be assumed that all launches occur from Complex 39 at the Kennedy Space Center. The launch vehicle to be assumed for all missions is a two-stage version of the projected Saturn V SA 520 (INT-21), as described in NASA TMX-53684, except as modified to accept a nuclear third stage. For NERVA reference mission purposes this shall be assumed to imply a restartable S-II Stage. 6

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION A

Reusable Interorbit Shuttle Mission

6

The purpose of this mission is to shuttle men and materials between low Earth orbit and lunar or geosynchronous orbit. Multiple round trips shall be assumed for engine functional analysis, although engine lifetime requirements are treated separately.

The reusable nuclear vehicle is launched into a 262-NM, 55^{o}-inclination, circular Earth orbit by an INT-21 (SIC/SII) launch vehicle launched from KSC. The nuclear vehicle propellant capacity is nominally 300,000 lb., and the tank is off loaded during launch as required. The nuclear vehicle is docked to an orbiting propellant depot (which also has check-out and maintenance capability) by means of its chemical reaction control system (RCS) and made ready for the initial round trip mission.

At the time dictated by targeting considerations, the nuclear vehicle is separated from the propellant depot; the engine is started on the standard ramp, operated first at full power, and then at full-temperature part-power for (TBD) time, shut down in the standard manner, and cooled without thrust nulling so as to place the vehicle in the proper transfer ellipse.

The nuclear vehicle is assumed to rendezvous with a space station in the destination orbit, although the nuclear vehicle may also be used initially to place the station in its orbit. The lunar station is in a lunar polar orbit, and the geosynchronous station is in an Earth equatorial orbit. Lunar orbit may be achieved directly, with a single thrust period. However, safety considerations may dictate that the NERVA engine be operated three time so as to (1) enter an elliptical lunar-equatorial orbit (eccentricity TBD), (2) change the plane to polar orientation and (3) circularize at 60NM altitude. Geosynchronous orbit is achieved with a single engine operation, as previously described for low-orbit departure. In either case, the nuclear vehicle achieves gross rendezvous with the space station following a (TBD) aftercooling period, during which the aftercooling thrust is utilized for final-velocity attainment.

The nuclear vehicle then enters the thrust-nulling mode, using the (TBD) concept, during which the nuclear vehicle performs terminal rendezvous and is docked to the space station by means of the nuclear-vehicle RCS. It remains docked for up to 30 days.

Following the operations in destination orbit, the nuclear vehicle is disengaged from the space station. The NERVA engine is restarted and operated as required to place the nuclear vehicle on a transfer ellipse to the initial low-altitude Earth orbit (262 NM, 55°). In order to depart lunar polar orbit at any time, the nuclear vehicle must be capable of performing a three-impulse maneuver similar to that used for lunar-orbit attainment.

Mission A (Continued)

Near perigee the nuclear vehicle is operated again so that following a (TBD) aftercooling period the vehicle is in an orbit suitable for terminal rendezvous with the propellant depot. Thrust nulling is used as required to permit docking with the propellant depot by means of the vehicle RCS.

Following each round trip, the nuclear vehicle is checked out, maintained
(if necessary), reloaded with expendables and payload, and used for a
subsequent round trip. The maximum turnaround time is (TBD). Upon comple-
tion of the hardware lifetime, the nuclear vehicle either attains a long- 7
lived, non-interference Earth orbit or, perhaps, flies an expendable
deep-space mission with an automated payload.

Maximum benefit will be taken of the low structural loads and the configuration freedom associated with space operation. For example, techniques will be evaluated for jettisonning hardware not needed after launch. Length and diameter optimization will be based on space operations to the extent allowed by initial-launch considerations (VAB hook height, space shuttle cargo hold dimensions, etc.). Propellant tank insulation will be based on single round trip duration (i.e., 30-40 days) and meteoroid protection will be based on a one-year exposure. Crew shielding will be sufficient to limit the engine dose per round trip to 10 rem at the location of each passenger and 3 rem at the location of each flight crew member (excluding dose during post-shutdown periods).

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION B

(DELETED) 6

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION C

Unmanned Deep-Space Injection Mission

6

The purpose of this mission is to place a large, unmanned payload on a deep-space trajectory using the reusable nuclear vehicle for acceleration from an initial low-altitude orbit to an energy adequate for mission accomplishment or staging. The nuclear vehicle would then return to the initial orbit for reuse.

The nuclear vehicle is launched as described in Mission A or is available between roundtrips to synchronous or lunar orbit. The automated payload is assembled to the nuclear vehicle in the initial (262-NM, 55° circular orbit of the propellant depot, and the system is checked out for the mission. The nuclear vehicle capacity and other characteristics are determined by the requirements of Mission A. The resulting capability will be a variation of payload with staging velocity.

At the time dictated by targeting considerations, the nuclear vehicle is separated from the propellant depot; the engine is started on the standard ramp, operated first at full power and then at full-temperature part-power for (TBD) time, shut down in the standard manner, and cooled without thrust nulling so as to place the vehicle on proper trajectory. Depending upon mission requirements, this trajectory may be that desired for the automated payload, in which case the payload is separated from the nuclear vehicle as described below, or it may be an intermediate ellipse. In the latter case the operating sequence is repeated once or twice more (near the next perigee or at apogee and near the next perigee) to achieve the desired trajectory for payload separation. Multi-impulse injection would be used for either efficiency (2-impulse) or orbit-plane change (3-impulse).

When the desired separation point is reached, the automated payload either enters a coast phase or is propelled further by a separate propulsion system. The nuclear vehicle will be rotated for retro-thrust. The NERVA engine will be started, operated at full power, and shut down so as to attain an elliptic Earth orbit. Return to the orbiting propellant depot will be accomplished with one or two additional nuclear thrust periods, timed for efficient rendezvous.

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION E

EMERGENCY MISSION

Deleted - 7

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION R

REACTOR GROUND TEST

(TO BE PROVIDED)

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION X

ENGINE GROUND TEST

(TO BE PROVIDED)

TITLE: NERVA PROGRAM REQUIREMENTS DOCUMENT

RELEASE AND CHANGE CONTROL RECORD

RELEASE	DATE	REPLACE PAGE NUMBERS	PAGE ADDITIONS
1	June 5, 1968	1 through 50 (initial issue)	--
2	March 17, 1969	46	--
3	May 12, 1969	3, 6, 7, 8, 9, 10, 11, 18, 19 and 25	--
4	June 5, 1969	36, 37, 38 and 45	--
5	July 1, 1969	Original Appendix B (System Engineering Requirements Document)	Appendix B (1 through 9)
6	Nov. 21, 1969	(i and iii), 2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 17, 32, 34, 35, 36, 37, 38, 39, 41, 42, 43, 45 and 49. Appendix B - 1, 2, 3, 4, 5, 6, 7, 8 and 9	10
7	Jan. 19, 1970	i, 10, 11, 12, 13, 14 and 18. Appendix B - 4 and 8	--
8	Aug. 31, 1970	i, ii, and 1 through 25 (Note: Replace 1 through 25 with 1 through 18.)	--
9	Oct. 29, 1970	i, ii, iii, and 26 through 50 (Note: Replace 26 through 50 with 18 through 34.) (Note: Replace Appendix B.)	--
10	Feb. 18, 1971	2	--

MILTON KLEIN
Manager
Space Nuclear Systems Office

R. W. SCHROEDER
Chief
Space Nuclear Systems Office
Cleveland Extension

(4) Nominal Specific Impulse, I_{sp} — 825 sec.

(5) Minimum Specific Impulse, I_{sp} — (tbd) sec.

(6) Engine Weight Without External Shield Maximum — (tbd) lb.

(7) Engine Weight With External Shield Maximum — (tbd) lb.

Rated inlet conditions for the propellant feed system during the normal engine operating mode at rated thrust are shown in Figure 1. In the event of a failure of one leg of a multiple turbopump system, i.e , PFS (propellant feed system) malfunction mode these same conditions apply but the engine thrust requirement is reduced to 80% of rated thrust.

The propellant feed system shall be designed to operate in the normal engine operating mode at rated thrust with saturated propellant at 28 psia (having zero percent vapor) at the tank outlet. (Zero tank NPSP.) As a goal the outlet propellant tank saturation pressure for this requirement is 26 psia.

The reactor and nozzle design will incorporate such features as necessary (exclusive of fuel element features) to allow growth, as shown by analysis, to operation at 4500° R nominal mixed mean chamber temperature for two hours' duration (12 cycles) at (tbd) thrust.

b. Endurance

The operating time shall be utilizable in multiple cycles, up to 60, of varying lengths totaling a minimum of 600 minutes (10 hours). The durations at rated conditions for single burns shall be one hour. All operations at rated temperatures shall be considered as part of the 600 minute endurance. This rated endurance is not to be construed as the limit of life of all components. Rather, the endurance of such components (except fuel elements) shall be greater than 600 minutes and shall be established by reliability, maintainability, performance, weight, manufacturing and cost considerations.

c. Throttling

The engine shall be capable of throttling at rated chamber temperature from the rated engine condition of 450 psia chamber pressure to a chamber pressure of 293 psia at a normal rate of 50 psi/second for a duration of 200 seconds per thrust period, to allow optimum removal of delayed neutron power production at rated chamber temperature. 10

TITLE: NERVA PROGRAM REQUIREMENTS DOCUMENT

RELEASE AND CHANGE CONTROL RECORD

RELEASE	DATE	REPLACE PAGE NUMBERS	PAGE ADDITIONS
1	June 5, 1968	1 through 50 (initial issue)	--
2	March 17, 1969	46	--
3	May 12, 1969	3, 6, 7, 8, 9, 10, 11, 18, 19 and 25	--
4	June 5, 1969	36, 37, 38 and 45	--
5	July 1, 1969	Original Appendix B (System Engineering Requirements Document)	Appendix B (1 through 9)
6	Nov. 21, 1969	i, iii, 2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 17, 32, 34, 35, 36, 37, 38, 39, 41, 42, 43, 45 and 49. Appendix B - 1, 2, 3, 4, 5, 6, 7, 8 and 9	10
7	Jan. 19, 1970	i, 10, 11, 12, 13, 14 and 18. Appendix B - 4 and 8	--
8	Aug. 31, 1970	i, ii, and 1 through 25 (Note: Replace 1 through 25 with 1 through 18.)	--
9	Oct. 29, 1970	i, ii, iii, and 26 through 50. (Note: Replace 26 through 50 with 18 through 34.) (Note: Replace Appendix B.)	--
10	Feb. 18, 1971	2	--
11	Feb. 19, 1971	8, 12 and 34	--

David S. Gabriel

MILTON KLEIN
Manager
Space Nuclear Systems Office

for R. W. SCHROEDER
Chief
Space Nuclear Systems Office
Cleveland Extension

(2) Physical, including mechanical assembly and spatial relationship of parts at the interface. Such parts include electrical connectors, fluid line couplings and structural attachments.

(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrain end item design. These constraints include assembly, disassembly, alignment, maintenance and safety (310 documentation).

o. <u>Engine Interface With Orbiting Propellant Depot and Space Station</u>

The engine interfaces with the Orbiting Propellant Depot and with the Space Station shall be defined by the Interface Control Document approved by SNPO. This Document will define the following characteristics:

(1) Functional, particularly engine component maintenance, checkout, logistics and disposal.

(2) Physical, including mechanical connections, spatial relations, shielding, etc.

(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrains end item design. These constraints include maintenance, safety and checkout.

(4) A record of engine requirements allocated to the Orbiting Propellant Depot and to the Space Station shall be maintained as part of the NERVA systems engineering.

p. <u>Emergency Detection and Operation</u>

Maximum effort shall be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the completion of the mission, the flight crew, the launch crew or the general public.

In the event the planned mission must be abandoned the effect of each mode of failure on engine performance must be minimized so as to make the optimum use of remaining propellant and at the minimum to provide an integrated engine performance of:

(1) 30,000 pounds thrust 11

(2) 500 seconds specific impulse 11

(3) 10^8 pound-seconds total impulse including cooldown propellant with the total impulse controllable up to a maximum of 10^8 pound-seconds.

5. Cleanliness

The engine shall be designed to handle any unlimited flow (rate) of 600 micron or less particles throughout its operating life. The estimated weight to be handled is 220 grams of materials with the density of aluminum.

A NERVA Program Contamination and Corrosion Control Plan shall be developed. Upon approval the plan will be the basis for design and construction requirements for parts, components, subsys- 11
tems, and systems provided during the program life-cycle. The plan shall be prepared in accordance with NERVA Data Item Description S-021.

6. Electromagnetic Interference

The engine shall be designed and tested to satisfy the requirements of military specification MIL-E-6051-D and others.

7. Interchangeability

All qualification hardware shall be interchangeable down to the component level.

8. Man Rating, Reliability, Quality Assurance, and Safety

a. Man Rating

(1) The NERVA engine shall be man rated. Equipment is man rated when its utilization in manned space vehicles provides for and protects the crew's well being and utilizes man's ability to control and repair. It follows that man-rated equipment, and especially propulsion, must be highly reliable. Man rating is not attained solely by compliance with some particular specification or rule. As a minimum, the requirements of SNPO-C-1 stress specification and SNPO-C loads and environment specifications will be met. However, compliance with these requirements alone does not insure achievement of the required reliability of man rating. Rather it results from that fastidious approach to the total effort from concept to final disposition in flight which takes every reasonable step to assure the safety of the astronauts, the launch crew, and the general public. Special steps are required to assure the elimination of errors and, in particular, errors caused by the use of "engineering judgment" by individuals during design, test or fabrication. To give visibility to the use of judgment special procedures and approaches will be devised to assure that the judgments do not stand unreviewed.

The practice of man rating begins with a study of the functional flow diagrams for representative missions coupled with a recognition of undesirable stresses and dangerous situations for the

b. All facilities defined above will be analyzed to deterime their ability to meet these availability and reliability requirements and modifications made where deficiences are found.

C. Logistics Plan

A program logistics requirements plan; to provide minimum inventory required during the various phases of the program, shall be developed. Upon approval this plan will form the basis for providing inventories at various points in the program.

D. Data and Document Management Plan

A NERVA Program Data/Document Control Plan shall be developed. Upon approval the plan will be the basis for data and document control throughout the program. NPC 500-6, DM 001.00-1 may be used as a guide in developing this program.

E. Configuration Management Plan

A NERVA Program Configuration Management Plan shall be
developed. Upon approval the plan will be the basis for the con- 11
figuration management of the items provided under this program. The
plan shall be prepared in accordance with NERVA Data Item Description
C-018."

F. NERVA Management Plan

A NERVA Management Plan shall be developed by the contractor in accordance with NERVA Data Item Description M-001.

G. NERVA Engine System Program Requirements Schedule

Appendix C (tbd), attached, contains the programs controlled milestones. Additional Government controlled milestones will be established by the Government office directly responsible for individual contracts.

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MILTON KLEIN
Manager
Space Nuclear Propulsion Office

R. W. SCHROEDER
Chief
Space Nuclear Propulsion Office
Cleveland Extension

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I. Scope

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

The NERVA Propulsion and Test Systems includes the engine assembly, engine and component test and qualification facilities, aerospace ground equipment, and supporting systems and services.

II. Authorized Documents

The procedures and requirements of the documents listed in Appendix A, "NERVA Authorized Documents List", are applicable to the NERVA Program, except as modified by this document. The interpretation and application of the contents of the documents listed in Appendix A shall be in accordance with the NERVA Management Plan, M-001.

III. Technical Performance Requirements

A. Reference Missions

The engine shall be designed for multiple missions as described in the Reference Missions for System Engineering, Appendix B, attached hereto.

B. Engine Performance Requirements

1. Functional Characteristics

a. Performance Requirements at Rated Conditions

Rated conditions shall be based on steady state operation of the vehicle tankage (i.e., after startup pressurization transient) as follows: MSFC Specification 356A (liquid) hydrogen, delivered at the tank outlet (upstream of the main propellant shutoff valve (PSOV), with the engine at zero ambient pressure; zero gimbal angle; and single module (engine) operation, utilizing a full flow cycle to drive the turbopump(s) and assuming a contoured nozzle expansion ratio of 100:1. The engine shall be capable of performing as specified herein:

(1) Thrust, F	75,000 ±2,000 lbs.
(2) Nominal Mixed Mean Chamber Inlet Temperature, T_c	4250° R
(3) Nominal Chamber Pressure, P_c	450 psia

(4) Nominal Specific Impulse, I_{sp} — 825 sec.

(5) Minimum Specific Impulse, I_{sp} — (tbd) sec.

(6) Engine Weight Without External Shield Maximum — (tbd) lb.

(7) Engine Weight With External Shield Maximum — (tbd) lb.

Rated inlet conditions for the propellant feed system during the normal engine operating mode at rated thrust are shown in Figure 1. In the event of a failure of one leg of a multiple turbopump system, i.e., PFS (propellant feed system) malfunction mode these same conditions apply but the engine thrust requirement is reduced to 80% of rated thrust.

The propellant feed system shall be designed to operate in the normal engine operating mode at rated thrust with saturated propellant at 28 psia (having zero percent vapor) at the tank outlet. (Zero tank NPSP.) As a goal the outlet propellant tank saturation pressure for this requirement is 26 psia.

The reactor and nozzle design will incorporate such features as necessary (exclusive of fuel element features) to allow growth, as shown by analysis, to operation at 4500° R nominal mixed mean chamber temperature for two hours' duration (12 cycles) at (tbd) thrust.

b. Endurance

The operating time shall be utilizable in multiple cycles, up to 60, of varying lengths totaling a minimum of 600 minutes (10 hours). The durations at rated conditions for single burns shall be one hour. All operations at rated temperatures shall be considered as part of the 600 minute endurance. This rated endurance is not to be construed as the limit of life of all components. Rather, the endurance of such components (except fuel elements) shall be greater than 600 minutes and shall be established by reliability, maintainability, performance, weight, manufacturing and cost considerations.

c. Throttling

The engine shall be capable of throttling at rated chamber temperature from the rated engine condition of 450 psia chamber pressure to a chamber pressure of 293 psia at a normal rate of 50 psi/second for a duration of (tbd) minutes per thrust period, to allow optimum removal of delayed neutron power production at rated chamber temperature.

d. Startup and Shutdown

(1) Operating Ramp Rates

Bootstrap startup shall provide the highest possible integrated specific impulse within the (thermal) stress limitations of the reactor structure(s) during the starting transient. The operating line so defined shall pass through the throttle point (4250^{o} T_c R - 293 P_c psia), following the high specific impulse locus to the throttle point, and shall maintain rated I_{sp} from the throttle point to rated conditions. During the major portion of the transient ramps the engine shall have the capability and controllability of 150^{o} R/sec. ($T_c \leq 4250^{o}$ R) chamber temperature rate and 50 psia/sec. ($P_c \geq 293$ psia) chamber pressure rate.

(2) Startup Conditions

The engine in the normal engine operating mode shall be capable of bootstrap starting and restarting with saturated propellant at the tank outlet at any time and at any pressure within the venting range of the propellant tank and accelerating to rated thrust within (tbd) seconds. The venting range of the propellant tank will be (tbd) to 30 psia. In the PFS malfunction mode acceleration to 80% rated thrust is required with (tbd) seconds. Engine bootstrap characteristics shall be designed to be relatively insenitive to back pressure between vacuum and the exhaust duct pressure to be provided in the engine test facilities.

(3) Cooldown

Cooldown thrust following pump tailoff shall be delivered at the highest possible specific impulse consistent with the requirements for controllability of total impulse, and the average specific impulse shall be no less than 400 seconds. The minimum thrust during cooldown shall be at least 30 pounds.

Provisions shall be made to provide for those internal design features which could permit the addition of an engine thrust nulling system at a later date, should it be required.

e. Propellant Tank Pressurization Gas

The engine shall be capable of providing hydrogen pressurizing gas to the propellant tank during startup, steady state, and shutdown operations in the quantities and on schedule shown in Figure (tbd).

FEED SYSTEM INLET CONDITIONS

(MEASURED @ TANK OUTLET)

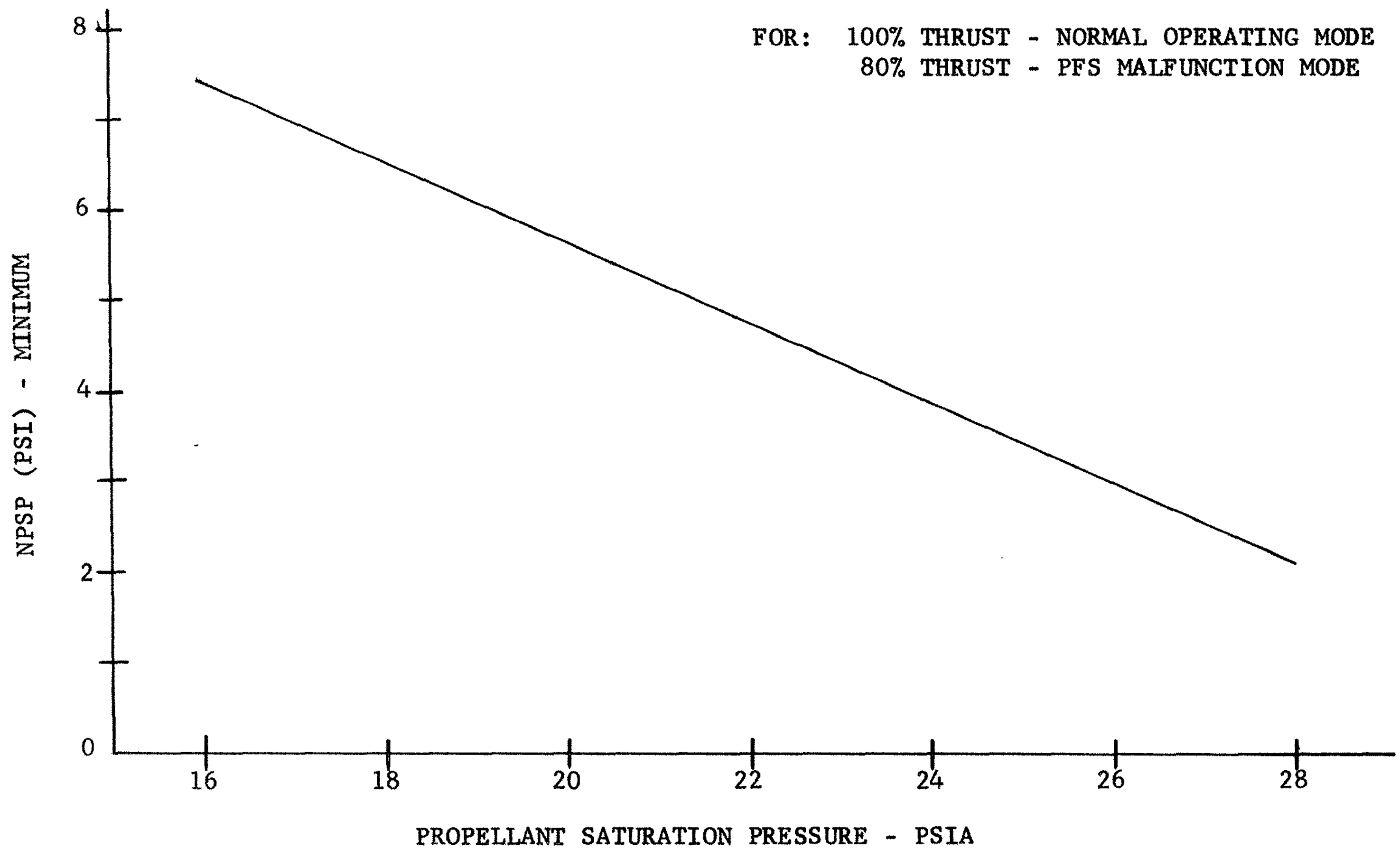

FIGURE 1.

FIGURE 1.

f. Controllability

The control system shall provide sufficient precision and accuracy for the range of propellant conditions specified in Section III.B.1.a to control the operations in such a manner that the missions outlined in the Reference Missions for System Engineering (Appendix B) may be planned and executed successfully. In the various modes of operation the performance shall be controlled within the following 3 sigma limits:

(1) Startup to Rated Thrust

(a) Total Impulse ± (tbd)

(b) Time ± (tbd)

(c) Propellant Consumption ± (tbd)
(including childown prop.)

(2) Steady State (nominal rated conditions)

(a) Specific Impulse ± 0.75%

(b) Thrust ± 2.0%

The specific impulse controllability requirement set forth above assumes an Isp trim signal from the vehicle.

(c) Shutdown and Cooldown

1 Total Impulse ± 20,000 lb-sec

2 Time ± 15 sec.

3 Propellant Consumption ± (tbd)
(including cooldown prop.)

The total impulse controllability requirements set forth above apply during the period which starts with departure of engine operation from the rated chamber-temperature point and which ends with termination of thrust for a given engine cycle. The time controllability requirement applies over this same period.

g. Thrust Vector Control

The thrust vector control system shall provide a gimballed engine system having a displacement of at least 3.0° in any direction at a maximum rate of 0.25°/sec. with a maximum acceleration of 0.5°/sec.^{2}.

h. Leakage

To minimize leakage the engine shall be designed to minimize joints where leakage may occur. Furthermore, maintainability and reliability shall not be compromised. Maximum leakage during all non-operating periods shall not exceed 400 standard cubic inches of hydrogen per minute. The engine design shall be capable of handling leakage without problems such as ice, including solidified hydrogen, forming in any place in the engine or engine valving. It shall also dispose of all leakage in a safe manner.

i. Reliability

The reliability requirement for the NERVA engine shall be 0.995, i.e., the probability at 90% confidence level that the engine shall successfully fulfill the endurance requirements set forth in Section "b" at rated operation while meeting all mission related requirements of this document shall be 0.995 or greater. Confidence level need not be established by attribute testing.

j. Radiation Shielding

(1) The engine shall include radiation shielding which protect components from radiation degradation of reliability, performance or endurance beyond the limits specified elsewhere herein.

(2) The radiation shielding shall also provide propellant tank protection such that the combined effects of heating, temperature gradient, and/or vapor content will not degrade engine performance beyond the limits specified elsewhere herein or unduly reduce the payload.

(3) Provision shall be made for additional engine-mounted external disk crew radiation shielding, and installation thereof, to reduce the dose due to engine radiations per round-trip to 10 rem at the location of each passenger and 3 rem at the location of each flight crew member in the spacecraft for nuclear-shuttle operations. The additional engine-mounted crew radiation shielding shall be removable and replaceable in space based on mission requirements.

An additional design objective will be to allow reductions in the crew shielding with minimum redesign should mission requirements permit.

(4) The overall engine design, including reactor, lines and nozzle shall be such as to minimize the penalty for crew radiation protection.

k. Environment

The engine shall be capable of meeting all performance and endurance requirements after being subjected to all ground, launch, and flight environments. Environmental guidelines are provided in SNPO-C-6.

l. Nozzle

The nozzle length and area ratio shall be optimized, compatible with engine specific impulse requirements and payload trade-off studies.

m. Storage

The engine shall be capable of operating without degradation of reliability, performance, and endurance under the following storage conditions:

(1) Five years on the ground in a suitable container.

(2) Three years in space, operating and non-operating.

(3) Six (6) months under pad environment.

n. Engine to Stage Interfaces

In general, special provisions for ground testing, data acquisition, and control will be incorporated. These features may be eliminated in the deliverable engines (and stages) and will be designed so that their elimination from deliverable flight test engines (and stages) shall not affect the validity of the qualification program or the engine (and stage) reliability.

The engine interfaces with the stage and the test stand shall be defined by the Interface Control Document approved by SNPO. The Interface Document will define the following characteristics:

(1) Functional, including structural loads, induced environments, fluid flows, electrical circuit characteristics and pin functions designations.

(2) Physical, including mechanical assembly and spatial relationship of parts at the interface. Such parts include electrical connectors, fluid line couplings and structural attachments.

(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrain end item design. These constraints include assembly, disassembly, alignment, maintenance and safety (310 documentation).

o. Engine Interface With Orbiting Propellant Depot and Space Station

The engine interfaces with the Orbiting Propellant Depot and with the Space Station shall be defined by the Interface Control Document approved by SNPO. This Document will define the following characteristics:

(1) Functional, particularly engine component maintenance, checkout, logistics and disposal.

(2) Physical, including mechanical connections, spatial relations, shielding, etc.

(3) Procedural, including only procedures resulting from operation sequence, human factors or maintenance requirements that constrains end item design. These constraints include maintenance, safety and checkout.

(4) A record of engine requirements allocated to the Orbiting Propellant Depot and to the Space Station shall be maintained as part of the NERVA systems engineering.

p. Emergency Detection and Operation

Maximum effort shall be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the completion of the mission, the flight crew, the launch crew or the general public.

In the event the planned mission must be abandoned the effect of each mode of failure on engine performance must be minimized so as to make the optimum use of remaining propellant and at the minimum to provide an integrated engine performance of:

(1) 30,000 pounds thrust (to be verified)

(2) 500 seconds specific impulse (to be verified)

(3) 10^8 pound-seconds total impulse including cooldown propellant with the total impulse controllable up to a maximum of 10^8 pound-seconds.

These requirements shall be provided by a single engine cycle in the degraded state. Operation in an emergency mode must be attainable from all operating modes of the engine cycle including all shutdown modes and coast phases. If mission abandonment is required during the normal steady state operation immediate retreat to an emergency mode shall be made. If the malfunction occurs during engine modes following the steady state power modes, provision shall be made for cooling up to five hours prior to entering an emergency mode. Ramps from the normal operational modes to an emergency mode are TBD. Shutdown ramps from the emergency modes are TBD. Final cooling shall preclude engine disassembly and, if it can be done at no additional risk to population, passengers or crew, preserve the engine in a restartable condition.

The required total impulse must be provided in a sustained emergency mode at any of the points above the required minimum and within the normal operating map. The operating point selected after the failure has occurred will be determined by the nature of the failure and the reliability of retreating to and operating at the emergency mode operating point.

Potential failure modes that would preclude attainment of these requirements shall be identified and presented to the Government for review with justification for retention.

A Contingency Analysis and Planning Process shall be continuously conducted to ensure that these requirements are met.

In addition, the NERVA engine shall incorporate the following features:

(1) Means of preventing accidental criticality during all ground and space operations. An anticriticality destruct system shall be provided for launch and ascent.

(2) Throughout the mission means shall be provided for preventing credible core vaporization, disintegration or violation of the thrust/load path to the payload.

(3) Judicious selection of diagnostic instrumentation adequate to detect the approach of a failure or and event which could injure the crew or damage the spacecraft directly and provisions to preclude such an event.

(4) Judicious selection of diagnostic instrumentation adequate to detect deteriorating situations or incipient failures.

(5) Ability to override the engine programmer remotely by the crew and ground control, the ability for remote thrust cutdown independent of the engine program. In addition, the engine control system shall have the ability to preclude excessive or damaging deviations from programmed power and ramp rates.

q. Man-rating

The engine system shall be man-rated (see Paragraph 8

2. Transportability

The assembled engine or major subassemblies when protected by packaging shall be transportable in any attitude by land, sea, or air without degradation.

The complete engine assembly shall be transportable after final checkout.

The engine shall be transportable either vertically or horizontally when assembled to the propellant tank.

Suitable handling points and devices shall be provided to permit assembly to the propellant tank in both the vertical and horizontal attitudes.

The requirements of Air Force Specification (tbd), "Transportability Demonstration" and SNPO-C loads and environmental specifications shall be satisfied before shipment of the engine or any of its subassemblies.

3. Maintainability

(a) The engine shall be designed and constructed to meet the following requirements:

(1) All mission-critical components external to the reactor pressure vessel and nozzle will be maintainable by repair, replacement or substitution (switching or redundancy) before and after operations. Trade studies will be conducted to investigate: (a) the extent to which modular versus individual-component designs affect reliability, maintainability and performance (including weight): and, (b) the extent to which remote or direct maintainability will be employed.

(2) Such maintenance will be achievable during non-operating periods in the mission.

(3) All mission-critical components will be capable of functional and electrical checks remotely after engine assembly or engine maintenance.

(4) It will be possible to purge the engine by an external source of inert gas prior to ground operation or launch.

(5) The engine will be remotely installed and removed from engine test facilities (listed elsewhere herein).

(6) After space operations, manual maintenance will not be required in excessive radiation environments.

(7) For the storage periods previously specified, no periodic routine engine maintenance will be required.

(b) Trade-off studies, concurred in by SNPO, will determine the advisability of designing and constructing the engine such that it is replaceable on the stage; or that the reactor/pressure-vessel/nozzle assembly is replaceable on the engine. The trade-off studies shall also address themselves to the question of disposal of these assemblies.

(c) A maintainability program and program plan shall be provided in accordance with AFSCM 310-1 and AFLCM 310-1. This program and plan shall also be in accordance with the following sections of this NPRD:

(1) Page 9, Section (3) and Page 9, Section (4):

diagnostic instrumentation for failure detection and display of information in-flight;

(2) Page 15, Section (1): trend-data program; and

(3) Page 15, Section (2): certification of deliverable hardware.

The plan shall consider, in addition, the logistical requirements of engine maintenance for the mission modes of Appendix B.

(d) Utilization of maintainability concepts may be necessary to achieve the required reliability over the endurance stated in Section II.B.1.b. However, maintainability will not be used as a substitute for reliable design. The maintainability program will be developed to extend the results of the reliability design process described in Section III.B.8 to aid, where necessary, in achieving the reliability requirement.

4. Acceptance

The engine assembly will be accepted on the basis of successful functional and cold flow tests, together with a review of the production and test history of those components in the assembly and all other related components in the program.

Some additional criteria for acceptance are provided in paragraph 8, "Quality Assurance."

5. Cleanliness

The engine shall be designed to handle any unlimited flow (rate) of 600 micron or less particles throughout its operating life. The estimated weight to be handled is 220 grams of materials with the density of aluminum.

The design and construction of parts, components, subsystems, and systems shall satisfy the requirements of AFSCM 310-1/AFLCM 310-1 S-21-17, "Contamination Control." The above requirements are also applicable to self-contamination.

6. Electromagnetic Interference

The engine shall be designed and tested to satisfy the requirements of military specification MIL-E-6051-D and others.

7. Interchangeability

All qualification hardware shall be interchangeable down to the component level.

8. Man Rating, Reliability, Quality Assurance, and Safety

a. Man Rating

(1) The NERVA engine shall be man rated. Equipment is man rated when its utilization in manned space vehicles provides for and protects the crew's well being and utilizes man's ability to control and repair. It follows that man-rated equipment, and especially propulsion, must be highly reliable. Man rating is not attained solely by compliance with some particular specification or rule. As a minimum, the requirements of SNPO-C-1 stress specification and SNPO-C loads and environment specifications will be met. However, compliance with these requirements alone does not insure achievement of the required reliability of man rating. Rather it results from that fastidious approach to the total effort from concept to final disposition in flight which takes every reasonable step to assure the safety of the astronauts, the launch crew, and the general public. Special steps are required to assure the elimination of errors and, in particular, errors caused by the use of "engineering judgment" by individuals during design, test or fabrication. To give visibility to the use of judgment special procedures and approaches will be devised to assure that the judgments do not stand unreviewed.

The practice of man rating begins with a study of the functional flow diagrams for representative missions coupled with a recognition of undesirable stresses and dangerous situations for the crew. A thorough, analysis (Fault tree analysis, for example) must then be conducted (and continuously updated) to determine ways in which normal operation, single failures or credible combinations of failures can result in these undesirable circumstances. A contingency plan must then be prepared (also continuously updated). From these analyses, requirements must be established, using Requirements Allocation Sheets as appropriate, and included in all component, subsystem, and system specifications.

(2) The reliability and safety goals previously stated are to be achieved through inherent design whenever possible. In particular, maximum effort should be placed on a design which eliminates single failures or credible combinations of errors and/or failures which could jeopardize the completion of the mission, endanger the flight crew, launch crew or the general public. If that proves impossible or results in an excessive penalty, redundancies internal to the component in question will be incorporated. If that is impossible, ways in which other component can compensate will be explored. If cases occur where no practical solution can be found by inherent design and where credible single or multiple failures can jeopardize crew and/or population safety, then countermeasures must be provided and/or techniques such as maintainability and alternate operating modes must be employed.

The nature of nuclear rockets is such that man rating and reliability must be obtained primarily through consistent, thorough, rigorous design practices applied throughout the programs. Design practice standards cover principles, philosophy, procedures or criteria governing the requirements of space hardware or the conditions to which space hardware shall be designed. These design practice standards shall be summarized for each component on design practice standards sheets. They also give detailed requirements to which a particular system, subsystem or item shall be designed. These design practice standards shall be prepared by the contractor(s) and approved by the Government.

These design practice standards shall include the following:

(a) The compilation of a complete statement of the environment which the component will see during inspection, storage, transportation, checkout, ground test, and flight.

(b) A complete listing and analysis of imposed loads of all kinds.

(c) A complete listing and analysis of all input data utilized in the design including an analysis of the variation and uncertainties of these data.

(d) Complete stress, thermal, vibration, and other special analyses as required.

(e) A thorough failure modes, effects, and criticality analysis.

(f) A reliability prediction based on the above analyses in addition to one based on historical data of similar components.

(g) A carefully considered plan to provide experimental verification of all the above factors.

All of these steps shall be recorded by the designer, carefully reviewed within the contractor organization, and furnished SNPO for further review and appropriate action.

(3) The process of review of requirements, analysis, design, redesign, prediction and verification described above must be periodically and formally reiterated and updated so that improvements can be made, new information and requirements incorporated, and changes accounted for and documented.

b. Reliability and Quality Assurance

In assessing the reliability achieved, emphasis will be placed on a sound scientific (including statistical methods) approach which verifies the design and all loads, assumptions, analyses, failure modes, design data and predictions by experiment and test. At least at the part, component and subsystem level, extended limits and tests to failure shall be emphasized. Demonstation purely by attribute (go, no-go) testing is not required. Nevertheless, all attribute data obtained will be recorded and analyzed so that the currently demonstrated reliability and confidence level shall be available at all times. For this purpose, component, subsystem and system data will be combined to the extent that sound judgment permits. In addition to overall engine reliability, parameters necessary to demonstrate the safety characteristics of the system shall be emphasized, e.g., failure modes and effects during each operational phase, the criticality of each engine effect, and failure rates for each mode of failure.

NPC 250-1, Reliability Program Provisions for Space System Contractors; NPC 200-2, Quality Program Provisions for Space System Contractors; and NPC 200-2 Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services, or elements thereof, provide the requirements to be satisfied in the preparation of reliability and quality program plans. Accordingly, reliability and quality plans shall be prepared by the contractor which reflect requirements imposed, and are tailored to meet the needs of the special nature of the program. When contractor reliability and quality plans are approved by SNPO they will serve as the basis for implementation of reliability and quality requirements through the contractors activities.

Reliability and Quality Program Plans shall be developed by the prime and principal subcontractors. The prime contractor shall coordinate and monitor quality efforts in order to provide uniform Reliability and Quality Assurance programs. The programs shall include:

(1) Trend Data Program

The purpose of this requirement is to provide a documented history of each component's critical characteristics from procurement of raw materials and fabrication through end-of-life to identify deterioration as one assessment of readiness to perform adequately and also to detect changes in processes and procedures.

The required features of the Trend Data Program shall be incorporated into the component engineering data packages and shall include the following:

(a) Identifying measurements required to establish trends such as deterioration, wear, or other factors which if measured would indicate incipient deviations from specified tolerances.

(b) Collection and collation of pertient data.

(c) Trend analyses.

(d) Verification of the validity of trends.

(e) Assessment of degree of deterioration.

(f) Enforcement throughout development, qualification, and production phases.

(2) Selection and certification of hardware for qualification or delivery.

Hardware designated for qualification testing or assembly to an engine (other than a development engine) shall be selected by a review procedure first by the contractor and then by the Government. Criteria for disapproval for the above uses shall include:

(a) History of unexplained transient non-recurring malfunctions.

(b) Excessive operating run time and/or hot fire cycles.

(c) The failure history of the part/component/ assembly indicates a marginal or degraded reliability condition.

(d) The part, component or assembly had excessive rework and repair during fabrication and/or acceptance.

(e) The supporting documentation is incomplete, lacks inspection verification, or does not reflect adequate corrective action and/or acceptance rework.

(f) The part, component, or assembly has a history or performance data that indicates marginal operation which is outside the acceptable limits.

(g) The part, component, or assembly is below the authorized minimum or base line configuration disposition.

(h) Other factors which in the judgment of the reviewers constitute a basis for disapproval.

(3) Malfunction/Failure Reporting, Analysis, and Resolution Boards:

(a) The engine contractor and nuclear subsystem (NSS) contractor shall each establish a top level malfunction/failure reporting, analysis and resolution board.

(b) The board(s) will review at regular and frequent intervals the total engine and/or reactor program malfunction/failure history and institute corrective action.

(c) The engine contractor's board shall consist of:

<u>Engine Contractor</u>:

NERVA Program Director, Chairman

a programs senior reliability supervisor

a programs senior quality assurance supervisor

a programs senior supervisory component engineer

a programs senior supervisory system engineer a project management and planning supervisor

a Government observer

a representative of the principal subcontractor

(d) NSS Contractor

The NSS contractor's board shall include personnel of the same level of responsibility and authority as those listed for the engine contractor and will also include Government and prime contractor observers.

(e) Board Reports

The records of the boards' meetings and actions shall be made available promptly to the Government to opposite board's chairman.

c. Safety

The contractor shall submit and execute a comprehensive NERVA Safety Plan, S 019, which defines a total integrated approach to safety.

9. Preferred Parts

All electric-electronic parts used in qualification and subsequent hardware will conform to "high reliability standards" in accordance with specification (tbd) in the overall engine operating environments.

10. MILA Environment, Moisture and Fungus Resistance and Corrosion of Metal Parts

The engine shall be designed to withstand the regional and seasonal environment of the Merrit Island Launch Area, Cape Kennedy, Florida. Minimum requirements will be the applicable portions of Military Specifications:

MIL-STD-810, MIL-STD-33586 and MIL-F-7179

C. Engine Test Program Guidelines

1. The purpose of the guideline information in this section is as follows:

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a. To set forth definitions of tests and concepts in order that common understanding will prevail as to the Government's intent;

b. To indicate the Government's general objectives regarding the testing of reactor and engine test articles in order that further test details can be developed on a common basis; and

c. To specify a basis for component and subsystem testing consistent with the overall objectives of the engine development program.

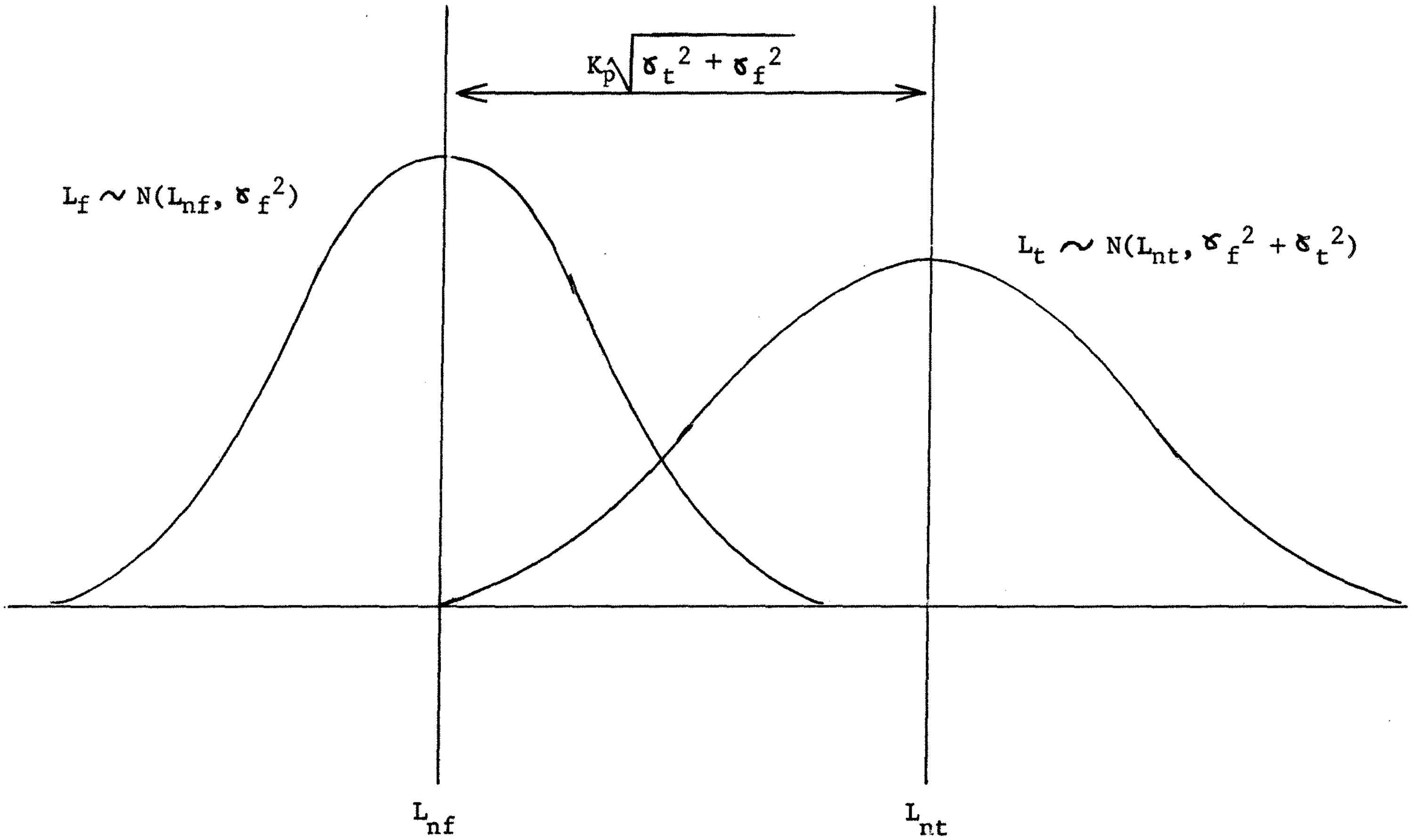
2. Definitions

a. Rated Performance

Rated Performance means the capability of an item (component, subsystem, engine system) to function as designed under the specified nominal operating parameters in the flight environment. For the engine system, certain of these nominal parameters are specified in Sections III.B.1.a (Performance Requirements at Rated Conditions), III.B.1.c (Throttling), and III.B.1.d (Startup and Shutdown).

b. Specification Extreme Performance

Specification Extreme Performance means the capability of the engine, subsystem or components to function at parameter extremes which could occur in flight due to variability in the measurement, analysis and control of such parameters. Testing at Specification Extreme conditions will be planned such that there is a 99% probability that the randomly distributed values of the applicable flight parameter are equalled or exceeded. This involves statistically combining the estimated flight engine parameter variability and the estimated test stand variability. By the way of illustration, nominal Specification Extreme Performance test condition equals nominal flight condition + $K_p \sqrt{\sigma_f^2 + \sigma_t^2}$ where σ_t = the estimated test stand variability and $\sigma_f \doteq$ estimated flight condition variability. Where possible, the 99% probability will be established at a confidence of 95%. The parameter selected for Specification Extreme Performance Testing shall be established judiciously considering the type of assembly considered and its control system. In the case of reactor or engine testing, chamber pressure and chamber temperature are pertinent parameters. For each such Specification Extreme Performance test, the failure probability of each item shall be reviewed to ensure that unacceptable risks are not inherent in such test. Such risk assessment must be conducted singularly for each such test. The acceptable risk level will vary with the assembly and the consequences of failure. A higher risk will be acceptable for smaller components than larger components, subsystems and the engine system. The detailed Specification Extreme Performance description for the engine, subsystem, or component item shall be displayed in each appropriate section of the data item report applicable to qualification testing. (See NPRD Figure 2.)



σ_f = STANDARD VARIATION OF FLIGHT LOAD

σ_t = STANDARD VARIATION OF TEST LOAD

L_{nf} = NOMINAL FLIGHT LOAD

L_{nt} = NOMINAL TEST LOAD

K_p = FACTOR IDENTIFIED WITH A 99% PROBABILITY AT A 95% CONFIDENCE

- Figure 2. -

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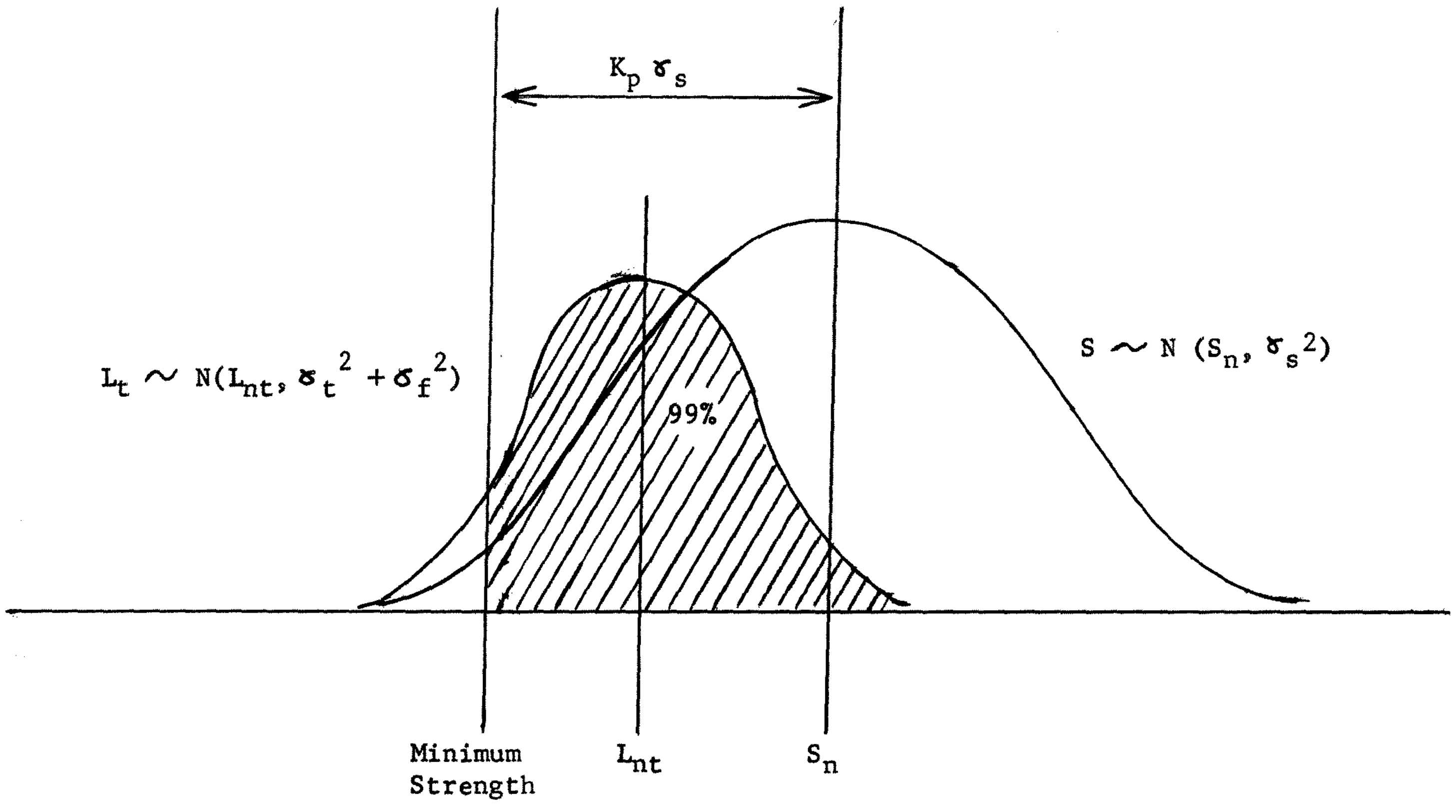
c. Design Performance

During the conduct of design performance verification tests, it will be the objective to stress the limiting part or parts at levels approaching as closely as practicable the minimum material strength. More specifically, design performance verification tests shall be planned such that, for the controlling part or parts, there is a 99% probability (considering instrumentation and control variability) that the minimum strength is equalled or exceeded. Where possible, this 99% probability will be established at a 95% confidence level. For this purpose, minimum strength is defined as the value equalled or exceeded by 99% of the randomly distributed values of the controlling strength parameter (ultimate, yield, creep, etc. as appropriate) at a confidence level of 95%. For each such design performance test, the failure probability of each item shall be reviewed to ensure that unacceptable risks are not inherent in such tests. Such risk assessments must be conducted singularly for each such test. The unacceptable risk level will vary with the assembly and the consequences of failure. A higher risk will be acceptable for smaller components than for larger components, large subsystems, and the engine system. The detailed design performance description for each item shall be displayed in each section of the data item report applicable to preliminary qualification testing. (See NPRD Figure 3.)

DESIGN PERFORMANCE



σ_s = STANDARD VARIATION OF STRENGTH

σ_t = STANDARD VARIATION OF TEST LOAD

σ_f = STANDARD VARIATION OF FLIGHT LOAD

S_n = NOMINAL STRENGTH

L_{nt} = NOMINAL TEST LOAD

K_p = FACTOR IDENTIFIED WITH A 99% PROBABILITY AT A 95% CONFIDENCE

- Figure 3. -

(9)

d. Development Tests

Development tests include those tests and evaluations necessary to acquire engineering data for the direct support of 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 components to natural or simulated loads and environments.

Development testing will be accomplished on any of the items involved in NERVA, up to and including the complete engine. Development testing shall include Design Performance demonstration. The design practices of Section 8a shall call out the features of such testing. Where the parameters of duration and progressive damage are important in an item, design perform- of those parameters shall be demonstrated by development testing.

These Development Tests will establish the basis for confidence in the design (including its margins, safety factors and reliability), in fabrication processes and in operational techniques for the item under test, for release of the item to Preliminary Qualification and to the Formal Qualification test programs.

e. Preliminary Qualification Tests

The Preliminary Qualification Testing of an item (up to and including the complete engine) involves tests to demonstrate that the item functions as designed. Hence, Preliminary Qualification tests shall include demonstration of Design Performance, as defined above. The level of major parameters involved in Category II Preliminary Qualification tests shall result from the design practices called for in Section 8a and from the results of Category I Development and Preliminary Qualification Testing.

Successful completion of the Preliminary Qualification tests will be on the basis for the incorporation of items in the next higher assembly item Preliminary Qualification test program and will indicate that the item is suitable for release to Formal Qualification tests. In the latter case the release to Formal Qualification may be additionally supported by Development Tests that provide test data on features not demonstrated in the Preliminary Qualification tests. Preliminary Qualification testing shall include, but not be limited to, all items designed CEI and ECC.

f. Formal Qualification Tests

The Formal Qualification test of an item (up to and including the complete engine) involves tests designed to demonstrate that the item satisfactorily meets the requirements of flight. Hence, Formal Qualification tests shall include demonstration of Specification Extreme Performance for the flight durations and cycles set forth in Section

IIIB1b. Successful completion of the Formal Qualification testing shall be the basis for the incorporation of items in the next higher assembly item Formal Qualification program and will indicate that the item has completed its design and development phase. Formal Qualification shall include, but not be limited to, all items designated CEI and ECC. 9

g. Reliability Tests and Analysis

The reliability tests 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. The design practices called for in Section 8a will call out the features of reliability test programs on any item.

h. Quality Assurance and Acceptance Tests

Quality assurance testing includes all those non-destructive tests, inspections and measurements of an item and those destructive tests of similar items applied for the purpose of release from vendors, fabrication, assembly or inventory. Acceptance tests of an item are conducted subsequent to such inspection to demonstrate functional characteristics that are demonstrable only during the operation or simulated operation of the item. These tests are intended to verify that the item is in accordance with specification and is acceptable for delivery to inventory or use in accordance with the qualification rating of that item.

i. Category I Tests of an Item

Tests on an item are considered to be Category I tests if the item is tested with equipment simulating the parameters and interface without the incorporation of all interfacing NERVA engine hardware items. Under such tests, the item is developed and qualified in accordance with design and/or specification using test support equipment.

j. Category II Tests

If any feature of an item cannot be adequately demonstrated by the use of simulated parameters and interfaces, and if the actual development parameters and interfaces can only be achieved by the incorporation of all interfacing NERVA engine hardware items, that 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 design or specification will require some demonstrations in the Category I and some in Category II type tests. Other items might be fully qualified only by means of Category II testing. The design practices described in Section 8a will define the category of testing required in the course of developing each item.

k. Category III Tests

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

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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 an item that are required to be demonstrated for Formal Qualification of the item and which can only be demonstrated in conjunction with an engine or reactor test shall be considered to be demonstrated in Category II tests as a part of the engine or reactor. However, any item in any engine or reactor assembly will have first successfully completed specified Category I tests.

b. The component development program shall be conducted to provide suitable qualified components for use in the guideline engine test program. 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 development tested prior to incorporation into the E-1 assembly.

c. Features of the engine and reactor that are required to be demonstrated in the engine and reactor Development, Preliminary Qualification, and Formal Qualification test series have been tentatively assigned to specific engines and reactors to divide the acquisition of demonstration data among a fixed number of engines and reactors, taking into account the expected life, the nature of test, the status development, and the guideline characteristics tentatively planned for NRDS facilities. Table 1 summarizes this tentative guideline distribution of the data acquisition plan relative to reactor number and Table 2 summarizes similar information relative to engine number. The engines and reactors are also grouped according to their assignment in the testing program as a Development, Preliminary Qualification, or Formal Qualification test category item for acquisition of the data for the various requirements listed.

(1) Reactors R-1 and R-2 are assigned to nuclear subsystem development testing. The principal objectives of this testing shall be:

(a) To demonstrate Design Performance of the nuclear subsystem;

(b) To establish the locus of reactor map constraints;

(c) To demonstrate controllability; and

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(d) To determine duration and cycling capability for 300 minutes or greater (30 cycles or greater) during the achievement of objectives (a) through (c) in R-1; to determine duration and cycling capability for 600 minutes or greater (60 cycles or greater) during the achievement of objectives (a) through (c) in R-2.

Other objectives are set forth in Table 1. Items delivered for assembly into R-1 and R-2 shall have completed the specified Category I Preliminary Qualification testing related to R-1 and R-2; that is, the Preliminary Qualification of each component shall show satisfactory completion of testing, demonstrating that the component is capable of operating under R-1 and R-2 conditions.

(2) Reactor R-3 is assigned to nuclear subsystem Preliminary Qualification and will serve as Category I Preliminary Qualification testing of the nuclear subsystem. The Category II Preliminary Qualification tests of the nuclear subsystem will be performed on the E-2 test article. The principal objectives of this testing shall be:

(a) To demonstrate Design Performance;

(b) To confirm the locus of reactor-map constraints;

(c) To confirm controllability;

(d) To confirm duration and cycling capability for 600 minutes of cycled operation during the achievement of objectives (a) through (c).

Other objectives are set forth in Table 1. All nuclear subsystem components delivered for assembly into R-3 shall have successfully completed Formal Qualification in appropriate Category I or Category II tests. All other test article components (e.g., nozzle, pressure vessel) shall complete the Preliminary Qualification and Formal Qualification tests via Category I tests prior to assembly into R-3.

(3) Reactors R-4 and R-5 are assigned to Formal Qualification of the nuclear subsystem, and shall contain all of the items making up that subsystem. The principal objective of these tests shall be:

(a) To accomplish Formal Qualification under conditions of Specification Extreme Performance for the full endurance specification.

(b) To achieve Formal Qualification by reactor disassembly and evaluation of reactor components. Other objectives are set forth in Table 1. All components that are separately qualified and delivered for assembly into R-4/R-5 shall have successfully completed Formal Qualification by means of Category I or Category II tests.

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(4) Three weight and envelope mockups (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. These three mockups shall support studies as required at WANL, AGC, NRDS and at vehicle development sites. The WEMU's shall sufficiently simulate the weight, moments 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 and E/STS-2, 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 the initial test articles in ETS-1 and E/STS-2. They also aid in developing and demonstrating engine features involved during the development phase to meet the requirements for engine maintainability. This program shall be completed prior to the testing of E-2.

(5) The program shall also provide for an engine simulator capable of performing checkout tests in ETS-1 prior to the power test of E-1. This simulator shall be capable of delivering the engine full power flow rate.

(6) The engine E-1 shall be assigned to engine development testing. The objective of this test is to investigate engine dynamics, controllability and mapping. Items delivered for assembly into E-1, with the exception of the Electronic Power Instrumentation Control (EPIC), the Anti-Criticality Poison System (ACPS), Nozzle Extension and Nuclear Subsystem, shall have completed the specified Preliminary Qualification test related to E-1; i.e., the Preliminary Qualification test of the item shall have demonstrated that the item 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.

(7) Engines E-2, E-3, and E-4 shall be assigned to Preliminary Qualification testing. The objectives of these tests include Design Performance operation for the full duration. Other objectives are listed in Table 2. 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 Instrumention Controls (EPIC), the Anti-Criticality Poison System (ACPS), Nozzle Extension and Nuclear Subsystem. As shown in Table 3, the principal EPIC system development tests shall be conducted as Category II tests in conjunction with E-2, Preliminary Qualification with E-3 and E-4, and Formal Qualification with E-5, E-6 and E-8. The Nozzle Extension shall, because of facility limitations, be omitted from engine tests (E-1 through E-8).

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Engine E-2 and beyond shall contain all engine systems except the Anti-Criticality Poison System extraction device (and the Nozzle Extension). The Anti-Criticality Poison System extraction device shall be provided for in engines beginning with E-3, and its Preliminary Qualification shall be conducted in conjunction with the testing of E-4.

(8) Engines E-5, E-6, and E-8 shall be assigned to Formal Qualification testing. The objectives of these tests shall be Specification Extreme Performance for the full endurance. Formal Qualification of the Anticriticality Poison System will be conducted in conjunction with E-5 assembly in E-MAD and utilizes subsequent E-5 performance data.

(9) 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.

(10) 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 System (ACPS) extraction device Formal Qualification test requirements.

(11) Limited reliability tests 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.

(12) 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.

TABLE 1: NERVA GUIDELINE REACTOR ASSEMBLY TEST PROGRAM

	Data to be Acquired	Reactor Assembly Designation				
		R-1	R-2	R-3	R-4	R-5
I.	General					
	1. Weight, CG, Moment of Inertia	D	D	PQ	Q	Q
	2. GSE Compatibility	D	D	PQ	Q	Q
	3. Facility Proof (Test Cell C & Control Point)	PQ	PQ	Q	-	-
	4. Tank/Engine Interactions	-	-	-	-	-
	5. Interface Compatibility	D	D	PQ	PQ	Q
	6. Hardware Verification	D	D	PQ	PQ	Q
II.	Checkout & Maintenance					
	1. Transportability (Reactor Subassembly)	D	D	PQ	PQ	Q
	2. Acceptance Test	D	D	PQ	PQ	Q
	3. Leak Test	D	D	PQ	PQ	Q
	4. Purge Capability	D	D	PQ	PQ	Q
	5. Maintainability	D	D	PQ	PQ	Q
	6. Facility Proof (E-MAD)	PQ	PQ	Q	-	-
	7. Shielding	D	D	D	D	D
III.	Environment					
	1. Environment Extremes	D	D	PQ	PQ	-
	2. EMI	D	D	PQ	PQ	-
	3. Radiation Characteristics	D	D	PQ	PQ	-
	4. Vibration	D	D	PQ	PQ	Q
IV.	Operational Performance					
	1. Cold Flow	D	D	-	-	-
	2. Specification Extreme Performance	-	-	-	Q	Q
	3. Design Performance	D	D	PQ	-	-
	4. Endurance	D	D	PQ	Q	Q
	5. Performance Mapping	D	D	D	-	-
	6. Reproducibility	D	D	PQ	Q	Q
V.	Operational Control					
	1. Dynamics (Reactor)	D	D	D	-	-
	2. Start, Stop, Aftercool, Restart	D	D	PQ	Q	Q
	3. Flight Controller	-	-	-	-	-

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TABLE 1: NERVA GUIDELINE REACTOR ASSEMBLY TEST PROGRAM (Cont'd)

Data to be Acquired	Reactor Assembly Designation				
	R-1	R-2	R-3	R-4	R-5
VI. Post Mortem Evaluation	D	D	PQ	Q	Q
VII. Reliability and Safety					
1. Malfunction Detection	D	D	D	-	-
2. Malfunctions	D	D	D	-	-
3. Emergency Cooling	D	D	-	-	-
4. Anticriticality	D	D	PQ	Q	-

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TABLE 2: NERVA ENGINE - OUTLINE TEST PROGRAM

Engine Requirements or Data	E1	W1	W2	E2	E3	E4	E5	E6	E8	EC	EX
I. General											
1. Weight, CG, Moment of Inertia	-	D	D	PQ	-	PQ	Q	-	-	-	-
2. GSE Compatibility	D	D	-	PQ	-	PQ	Q	-	-	-	-
3. Tank/Engine Interaction[1]	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
4. Interface Compatibility	D	D	D	PQ	-	PQ	Q	Q	Q	-	-
5. Electrical Continuity	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
6. Trend Data Program Measurements	D	D	D	PQ	PQ	PQ	Q	Q	Q	-	-
II. Checkout and Maintenance											
1. Transportability	D	D	D	-	-	-	-	-	-	Q	-
2. Acceptance Test	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
3. Leakage Test	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
4. Purge Capability	D	D	D	PQ	-	PQ	Q	-	Q	-	-
5. Maintainability	-	D	D	PQ	-	-	Q	-	-	Q	-
6. Interchangeability	-	D	D	PQ	-	PQ	-	Q	-	Q	-
7. Shielding	PQ	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
8. Facility Proof (ETS-1)	PQ	-	-	Q	-	-	-	-	-	-	-
III. Environment											
1. Environment Extremes	-	-	-	PQ	PQ	-	Q	-	Q	-	-
2. EMI	-	-	-	PQ	PQ	PQ	-	Q	-	Q	-
3. Radiation Characteristics	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
4. Vibration	D	-	-	-	-	-	-	Q	-	PQ	Q
5. Space Storage	-	-	-	-	-	-	-	-	-	PQ	Q
6. Ground Storage	-	-	-	-	-	-	-	-	-	Q	Q
7. Acoustics	D	-	-	PQ	-	PQ	Q	-	Q	-	-
IV. Operational Performance											
1. Cold Flow	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
2. Specification Extreme Performance	-	-	-	-	-	-	Q	Q	Q	-	-
3. Design Performance	-	-	-	PQ	PQ	PQ	-	-	-	-	-
4. Endurance	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
5. Performance Mapping	D	-	-	D	-	-	-	-	-	-	-
6. Reproducibility	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-

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TABLE 2: NERVA ENGINE - OUTLINE TEST PROGRAM (Cont'd)

Engine Requirements or Data	E1	W1	W2	E2	E3	E4	E5	E6	E8	EC	EX
V. Operational Control											
1. Dynamics	D	-	-	D	-	-	-	-	-	-	-
2. Start, Stop, After-cool, Restart	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
3. EPIC Demonstration	-	-	-	D	PQ	PQ	Q	Q	Q	-	-
4. Thrust Vector Control	-	D	D	PQ	-	PQ	Q	-	Q	-	-
5. Throttling	D	-	-	-	PQ	-	Q	-	Q		
6. Controllability	D	-	-	PQ	-	PQ	-	Q	-	-	-
VI. Reliability and Safety											
1. Malfunction Detection	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
2. Malfunctions	-	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
3. Anticriticality	-	D	D	-	-	PQ	Q	Q	Q	-	-
4. Thrust Integrity	D	-	-	PQ	-	PQ	Q	Q	Q	-	-
5. Stable Operations	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
6. Engine Programmer Override	-	-	-	-	PQ	-	Q	Q	Q	-	-
7. Detection Instrumentation	D	-	-	PQ	PQ	PQ	Q	Q	Q	-	-
8. Specific Reliability Tests	-	-	-	R	R	R	R	R	R	-	-
9. Human Functions	D	-	-	-	-	PQ	-	Q	-	-	-

Data Code and Abbreviations

PQ - Preliminary Qualification
Q - Formal Qualification
W - Weight and Envelope Mockup (WEMU)
D - Development
R - Reliability

[1] Only those items whose performance is not dependent upon close coupling.

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TABLE 3

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

Component	Development	Component Test Data Type	
		Preliminary Qualification	Formal Qualification
Electronic Power Instrumentation and Controls (EPIC)	Laboratory and E-2.	Laboratory and E-3, E-4	Laboratory and E-5, E-6, E-8
Nozzle**	Technology Data	R-1 - R-3	R-4 and R-5
Nozzle Extension** (Full Scale)	Laboratory	Laboratory and E-2 for attachment R-(tbd)	Laboratory and E-5 for attachment.R-(tbd)
Anticriticality Poison System	Laboratory at AGC and WANL	E-4 cold tests in E-MAD	E-5 cold tests in E-MAD

* "Laboratory" means facilities other than NRDS reactor test cells or engine test stands.

** "Nozzle" as used in this Table, means only the regeneratively-cooled nozzle; "Nozzle Extension" means the extension between the regeneratively-cooled nozzle exit plane and the overall nozzle exit plane.

IV. Programmatic Requirements

A. Aerospace Ground Equipment

A Test Support Equipment/Aerospace Ground Equipment Plan (TSE/AGE Plan) shall be prepared by the contractor. Source data for inputs to this plan shall be the data generated by the System Engineering process identified in AFSCM 375-5. The plan will form the basis for providing all the necessary TSE and AGE.

B. Facilities and Ground Support Equipment

1. General

To the maximum extent possible existing facilities and equipment will be utilized as is or modified to perform the fabrication, assembly, and testing of NERVA parts, components, subsystems, systems, and engine in accordance with the requirements of this document.

2. Available Facilities and Equipment

a. Government/Contractor facilities and special test equipment in California.

b. Government/Contractor facilities and special test equipment at Cheswick, Pennsylvania; Large, Pennsylvania; and Waltz Mills, Pennsylvania.

c. Government facilities at the Nuclear Rocket Development Station (NRDS) Jackass Flats, Nevada.

3. Management Control of Facilities and Equipment

Facilities, special test equipment, and support equipment utilized in the NERVA qualification programs and additions to and modifications of existing facilities and equipment will be accomplished in general accordance with requirements of the AFSCM 375 series and AFSCM 310-1/AFLCM 310-1 as specified in the approved NERVA Management Plan and appropriate end item specifications.

a. To the maximum practicable extent, new facilities shall be designed and existing facilities modified to be available as required to meet the test schedule with all essential features calibrated and working properly and so that no single failure or credible combination of errors, malfunctions or accidents can cause personnel injury, and/or facility destruction, facility damage, test article or test data loss, in that order of priority.

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b. All facilities defined above will be analyzed to determine their ability to meet these availability and reliability requirements and modifications made where deficiencies are found.

C. Logistics Plan

A program logistics requirements plan; to provide minimum inventory required during the various phases of the program, shall be developed. Upon approval this plan will form the basis for providing inventories at various points in the program.

D. Data and Document Management Plan

A NERVA Program Data/Document Control Plan shall be developed. Upon approval the plan will be the basis for data and document control throughout the program. NPC 500-6, DM 001.00-1 may be used as a guide in developing this program.

E. Configuration Management Plan

A NERVA Program Configuration Management Plan shall be developed. Upon approval the plan will be the basis for the configuration management of the items provided under this program. The Configuration Plan and Management shall be in accordance with the AFSCM 375 series and AFSCM 310-1/ AFLCM 310-1.

F. NERVA Management Plan

A NERVA Management Plan shall be developed by the contractor in accordance with NERVA Data Item Description M-001.

G. NERVA Engine System Program Requirements Schedule

Appendix C (tbd), attached, contains the programs controlled milestones. Additional Government controlled milestones will be established by the Government office directly responsible for individual contracts.

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

Date: July 1, 1970

REFERENCE MISSIONS FOR NERVA SYSTEM ENGINEERING

The missions described in this Appendix are considered representative of the classes of near term missions for which the use of nuclear propulsion would be suitable and advantageous. These missions are to be utilized in the identification of NERVA requirements and in the determination of engine design solutions which will result in maximum mission payloads consistent with reliability, flight safety, and minimum engine thrust and specific impulse requirements.

It shall be assumed that all launches occur from Complex 39 at the Kennedy Space Center. The launch vehicle to be assumed for all missions is a two-stage version of the projected Intermediate-21 launch vehicle using a standard J-2 engine as described in Boeing Report, Preliminary Analysis of INT-21 Launch Vehicle, MDAC Space Station Configuration, February 23, 9
1970, except as modified to accept a nuclear third stage.

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MISSION A

Reusable Interorbit Shuttle Mission

The purpose of this mission is to shuttle men and material between low Earth orbit and lunar or geosynchronous orbit. Multiple round trips shall be assumed for engine functional analysis, although engine lifetime requirements are treated separately.

The reusable nuclear vehicle is launched into a 262-NM, 28.5° inclination, circular Earth orbit by an INT-21 (SIC/SII) launch vehicle launched from KSC. The nuclear vehicle propellant capacity is nominally 300,000 lb., and the tank is off loaded during launch as required. The nuclear vehicle is docked to an orbiting propellant depot (which also has check-out and maintenance capability) by means of its chemical reaction control system (RCS) and made ready for the initial round trip mission. 9

At the time dictated by targeting considerations, the nuclear vehicle is separated from the propellant depot; the engine is started on the standard ramp, operated first at full power, and then at full-temperature part-power for (TBD) time, shut down in the standard manner, and cooled without thrust nulling so as to place the vehicle in the proper transfer ellipse. The nuclear vehicle is assumed to rendezvous with a space station in the destination orbit, although the nuclear vehicle may also be used initially to place the station in its orbit. The lunar station is in a lunar polar orbit, and the geosynchronous station is in an Earth equatorial orbit. Lunar orbit may be achieved directly, with a single thrust period. However, safety considerations may dictate that the NERVA engine be operated three times so as to (1) enter an elliptical luncar-equatorial orbit (eccentricity TBD), (2) change the plane to polar orientation and (3) circularize at 60NM altitude. Geosynchronous orbit is achieved with a single engine operation, as previously described for low-orbit departure. In either case, the nuclear vehicle achieves gross rendezvous with the space station following a (TBD) aftercooling period, during which the aftercooling thrust is utilized for final-velocity attainment.

The nuclear vehicle then enters the thrust-nulling mode, using the (TBD) concept, during which the nuclear vehicle performs terminal rendezvous and is docked to the space station by means of the nuclear-vehicle RCS. It remins docked for up to 30 days.

Mission A (Continued)

Following the operations in destination orbit, the nuclear vehicle is disengaged from the space station. The NERVA engine is restarted and operated as required to place the nuclear vehicle on a transfer ellipse to the initial low-altitude Earth orbit (262 NM, 28.5%). In order to depart lunar polar orbit at any time, the nuclear vehicle must be capable of performing a three-impulse maneuver similar to that used for lunar-orbit attainment. 9

Near perigee the nuclear vehicle is operated again so that following a (TBD) aftercooling period the vehicle is in an orbit suitable for terminal rendezous with the propellant depot. Thrust nulling is used as required to permit docking with the propellant depot by means of the vehicle RCS.

Following each round trip, the nuclear vehicle is checked out, maintained (if necessary), reloaded with expendables and payload, and used for a subsequent round trip. The maximum turnaround time is (TBD). Upon completion of the hardware lifetime, the nuclear vehicle either attains a long-lived, non-interference Earth orbit or, perhaps, flies an expendable deep-space mission with an automated payload.

Maximum benefit will be taken of the low structural loads and the configuration freedom associated with space operation. For example, techniques will be evaluated for jettisonning hardware not needed after launch. Length and diameter optimization will be based on space operations to the extent allowed by initial-launch considerations (VAB hook height, space shuttle cargo hold dimensions, etc.). Propellant tank insulation will be based on single round trip duration (i.e., 30-40 days) and meteoroid protection will be based on a one-year exposure. Crew shielding will be sufficient to limit the engine dose per round trip to 10 rem at the location of each passenger and 3 rem at the location of each flight crew member (excluding dose during post-shutdown periods).

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MISSION C

Unmanned Deep-Space Injection Mission

The purpose of this mission is to place a large, unmanned payload on a deep-space trajectory using the reusable nuclear vehicle for acceleration from an initial low-altitude orbit to an energy adequate for mission accomplishment or staging. The nuclear vehicle would then return to the initial orbit for reuse.

The nuclear vehicle is launched as described in Mission A or is available between roundtrips to synchronous or lunar orbit. The automated payload is assembled to the nuclear vehicle in the initial 262-NM,
9 28.5^{o} circular orbit of the propellant depot, and the system is checked out for the mission. The nuclear vehicle capacity and other characteristics are determined by the requirements of Mission A. The resulting capability will be a variation of payload with staging velocity.

At the time dictated by targeting considerations, the nuclear vehicle is separated from the propellant depot; the engine is started on the standard ramp, operated first at full-temperature part-power for (TBD) time, shut down in the standard manner, and cooled without thrust nulling so as to place the vehicle on proper trajectory. Depending upon mission requirements, this trajectory may be that desired for the automated payload, in which case the payload is separated from the nuclear vehicle as described below, or it may be an intermediate ellipse. In the latter case the operating sequence is repeated once or twice more (near the next perigee or at apogee and near the next perigee) to achieve the desired trajectory for payload separation. Multi-impulse injection would be used for either efficiency (2-impulse) or orbit-plane change (3-impulse).

When the desired separation point is reached, the automated payload either enters a coast phase or is propelled further by a separate propulsion system. The nuclear vehicle will be rotated for retro-thrust. The NERVA engine will be started, operated at full power, and shut down so as to tain an illiptic Earth orbit. Return to the orbiting propellant depot will be accomplished with one or two additional nuclear thrust periods, timed for efficient rendezvous.

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MISSION X

Reactor and Engine Ground Test

a. Testing at NRDS

Nuclear Subsystem Modules (NSSM), which consist of a Nuclear Subsystem and Pressure Vessel Assembly, shall be transported to the Nuclear Rocket Development Station (NRDS), Jackass Flats, Nevada. In concert with the above shipment, the non-nuclear components will be transported to NRDS. The Reactor Test Article, which consists of a NSSM, Nozzle, Instrumentation and associated lines and valves, when mated to the Test Car comprises the Reactor Test Assembly. Each Reactor Test Assembly will be assembled in the MAD Facilities, then transferred to Test Cell "C" for testing. After testing, each Reactor Test Assembly will be returned to the MAD Facilities. The Reactor Test Article will be removed from the Test Car and will be disassembled for post-test examination and evaluation in the MAD Facilities.

Each Reactor Test Article will be tested to obtain specific data and to achieve planned goals. Reactor Test Articles will be utilized for Development testing, Preliminary qualification testing and Qualification testing.

The non-nuclear subsystems for engine testing will be transported to NRDS. In the MAD Facilities the non-nuclear subsystems will incorporate associated NSSM's, received from WANL, and be assembled into NERVA Engines. Each of the engines will be transferred from the MAD Facilities to a NRDS Engine Test Stand (ETS-1 or E/STS-2). The applicable test stands readiness for engine emplacement will be verified before the first engine is placed in the test stand. After testing, each engine will be returned from the test stand to MAD Facilities. In MAD Facilities the engines will be disassembled and subjected to post-test examination and evaluation.

Each engine will also be tested to obtain specific data and to achieve planned objectives. Engines will be utilized for Development testing, Preliminary Qualification testing and Qualification tests.

Engine Weight and Envelope Mockups (WEMU) will be used to develop the Test Support Equipment and Aerospace Ground Equipment required

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to handle and transport the engine. The WEMU will also be used to develop engine to stage interface components and to aid in developing and demonstrating engine features that are necessary to meet the requirements for maintainability.

All Reactor Test Article and NERVA Engine development, prequalification and qualification testing shall be in consonance with Section III.C, "Engine Test Program Guidelines" of the basic document.

b. Testing at Other Sites

(tbd)

APPENDIX B

NERVA PROGRAM REQUIREMENTS DOCUMENT

MISSION R

Reactor Ground Test

(TO BE PROVIDED)