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VOLUME I

TECHNICAL DISCUSSION

NCS-211A

For SNP-1, Contract Year 1963

26 November 1962

MASTER

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SECTION I - INTRODUCTION

This volume contains the technical discussion for Sub-Task 1.9, System Irradiation Experiments, ^{and} for those sub-tasks and tasks which have been changed in whole or part by selection of the hot-bleed cycle. It should be noted that a discussion is presented only where there is a difference between the current program and that described in NCS-208.

Tasks and Sub-Tasks discussed in the volume are:

Sub-Task 1.1	Engine System
Sub-Task 1.2	Propellant Feed System
Sub-Task 1.4	Thrust Chamber Assembly
Sub-Task 1.9	System Irradiation Experiments
Task 5.0	Special Test Equipment
Task 6.0	Other Government Property

ENGINE SYSTEM DEVELOPMENT ENGINEERING (Sub-subtask 1.1.0)

1. Purpose

The purpose of this sub-subtask is to maintain overall development cognizance, and to incorporate into the Hot Bleed System layout drawings, the finalized component, subassembly and assembly designs as they are defined. The 30 September 1963 revision of this layout drawing will represent the design freeze for the Block I E-Engine design. This is conceived to be an engine assembly consisting of prototype pressure with B-4 reactor, conical nozzle, skirt, upper and lower thrust structures, lines and valves, pump suction line, and Mark III TPA. The thrust vector, roll control, pneumatic supply, tank pressurization and destruct systems hardware will not be present in the Block I E Configuration; control drum actuators and cooldown fluid as well as venting circuits to handle turbine and actuator exhaust fluids will be supplied by the test facility. Roll control nozzles will be simulated by orifices on venturis to produce turbine back pressure. In contrast, the FX engine will be equipped with the prototype of all hardware systems missing from the E-1 engine; and the TPA will be a Mark IV, having NERVA flight capability. For technical background on the differences between Mark III and IV see Technical Discussion for subtask 1.2.

The preliminary definition and targeted design goal of the Block I E-Engine will be supported by component and sub-assembly design, development evaluation and testing throughout CY 63. As a result of the change in engine cycle special emphasis will be placed on meeting new performance requirements in the following areas:

Hot Bleed Conical Nozzle

Pressure Vessel designed for B-4 KIWI Core

Mark III TPA Assembly

All other propellant feed system valves and lines will be near NERVA prototype.

In addition to the above, this sub-subtask covers the design and fabrication of NRX-A interface gages; design completion of the NTS Test Stand Thrust Structure and adapter; master interfaces gages for the RIFT vehicle - NERVA Engine and Adapter - NTS Test Stand Interfaces. This sub-subtask also provides for a conceptual analysis of a Hot Flow Development Test System.

2. Orientation of Work Effort

Close liaison with the responsible development engineers for the subtasks listed below will be required in order to support the preparation of the Block I E and FX engine system layout drawings.

- 1.2 Propellant Feed System
- 1.3 Reactor Subassembly
- 1.4 Thrust Chamber Assembly
- 1.5 Non-Nuclear Engine Controls
- 1.7 Pneumatic Systems
- 2.1 Remote Handling System
- 2.2 GSE Checkout and Test
- 2.3 GSE Logistics
- 2.4 Diagnostic Instrumentation

As the component, subassembly and assembly designs are proven via their own development programs, they will be incorporated in the engine layout drawing. The CFDTS to be tested last quarter FY 1963 will also include these advances as discussed in sub-subtask 1.1.3.

The subtasks mentioned in the preceding paragraph will be monitored for their effect on the designs for the tool and gage designs previously mentioned.

GENERATION II, SIMULATOR (Sub-Subtask 1.1.1)

1. Purpose and Objective

While the component sub-assembly design, fabrication, and testing for the Block I E-Engines to be tested at NTS will continue throughout FY 63, two basic configurations of simulators employing pre-prototype Block I hardware will be designed, fabricated and tested. Both units simulate mass, flow path areas, reflector, shield and pressure vessel configuration. These units will be utilized to study the starting transients of the conceptual engine system prior to programmed reactor heat output. The only available heat source will be the heat content of the non-nuclear engine system.

2. Configuration (Dwg 261125)

The first unit is identified as the Generation II, Mod I Simulator. Effort on this unit was initiated in CY 62 and tested during October and

November 1962 using FY 62 funds. The propellant flows from the run tank through a 150 foot length of feed line to the TSOV, then through the pump, and pump discharge line into the pressure vessel reflector inlet and up through the reflectors. After passing through the reflectors, the propellant stream is split with the main flow through the discharge line and the smaller portion flowing through the shield. The flow through the shield is tapped off through the pressure vessel's top closure and is fed to the turbopump turbine. A load simulator valve is provided in the discharge line to regulate the plenum chamber pressure during operation of the simulator. Orifices, a venturi, resistance thermometers, pressure transducers, and other instruments are installed. A turbine power control valve and hydrogen feed loop is also provided. See Figures 1 and 2 following the Technical Discussion for subtask 1.1.

Successful conclusion of the simulator tests will have demonstrated chill down rates and bootstrap start capability of the engine and will provide needed data on flow stability, transients, and thermodynamics before reactor power becomes a factor. As a result of the tests the designs of the TPA, TPCV, and TSOV will be reviewed to insure component capability to support specified engine performance; system control criteria relating engine performance capability to reactor power will be established; analog and digital computer techniques will be analyzed and extended to allow deductions concerning systems behaviour after extraction of all latent heat reactor power begins to rise.

The successor to the Gen II, Mod I Simulator is the Gen II, Mod IB Simulator, to be tested from February through May of 1963. In order to approximate the pressure drop existant when regeneratively cooling the nozzle and to more closely approximate the flow path areas the Mod I Simulator will be modified to the Mod IB by installing NERVA development nozzles and simulated nozzle cooling tube assemblies between the pump discharge line and the reflector inlet. The pressure vessel liner will be modified to mate with two NERVA development nozzles having 4.8 and 6.8 in² total coolant tube cross sectional flow path areas. As a comparison with the two nozzles, two simulated nozzle coolant tube assemblies with 6.8 and 8.5 in² total coolant tube flow path areas will also be fabricated and tested on the Mod IB Simulator. This series of tests will permit correlation of data and check the validity of extrapolation of heat transfer calculations and the effect of the different cross sectional flow path areas on the starting transient of the engine. The Mod IB Simulator will also utilize an ejector system on the simulator discharge, thereby permitting evaluation of simulated engine start conditions at altitude. See Figures 3 and 4.

3. Testing, Data and Analysis

Initial testing of both Mod I and Mod IB Simulators will be with gravity flow liquid hydrogen with pressure at the TSOV maintained at 25 psig by pressurization of the run tank in the C-8 Test Area. The reactor load simulator valve (RLSV) in the discharge line and/or the bypass line will be open. The turbine power control valve (TPCV) will be in a partially open position. After obtaining initial heat transfer rates, it is anticipated that the RLSV and TPCV will be utilized as throttles to regulate discharge line back pressure and turbine inlet pressure in subsequent system tests. The RLSV bypass line in these subsequent tests will be orificed to allow limited flow as a safety measure against overspeeding the turbopump.

Pressure, temperature and flow rate profiles at strategic locations throughout the non-nuclear engine will be obtained from the initial chill down tests. The feasibility of bootstrap TPA startup will be demonstrated and necessary data accumulated (breakaway torque, speed vs turbine inlet pressure and flows, TPCV performance, etc).

Analysis of the data from the tests will provide design information and criteria for confirmation of theoretical calculations. System Control variables during start transients will be defined and aid the controls designer in his design of the E-Block System. Heat transfer rates, localized phase changes, and system pressure balance and flow control during startup will be obtained. From the point-time temperature, pressure and flow profiles across the simulated nozzle coolant tubes in the Mod IB Simulator, analysis will support the design of minimum pressure drop nozzle cooling tubes at the maximum permissible temperature of the nozzle wall.

Test data will be analyzed to provide a nozzle design having minimum pressure drop through the coolant tubes without exceeding safe maximum permissible temperatures of the interior nozzle surface.

DEVELOPMENT TEST SYSTEM (Sub-subtask 1.1.2)

1. Purpose and Objective

Subsequent to the testing and analysis of the Generation II, Mod IB Simulator discussed in Sub-subtask 1.1.2, an upgraded simulator termed the Cold Flow Development Test System (CFDTS) will be assembled and tested. Hardware will be as close to the E-Block as permissible. Prototype components and sub-assemblies will be utilized as much as possible. Again as in the case of the Gen. II Simulators this unit will be utilized to study the starting transients of the conceptual engine system prior to programmed reactor heat input. Instead of tapping turbine feed gas off the top of the shield through the top pressure vessel closure, this configuration will tap off from the nozzle convergent entrance section. Testing will be initiated August 1963.

2. Configuration

The proposed configuration (no assembly drawing available 11/62) will interface with the run tank in Test Area H-5. The TPA assembly will have hydrogen lubricated bearings in place of the oil lubrication of the Mod I and Mod IB TPA. Instead of the discharge line and reactor load Simulator valve the configuration will include a depleted KIWI B core, prototype nozzle with simulated hot bleed port to the turbine inlet line, skirt assembly which will be cooled by turbine exhaust gases that will be expelled at the skirt exit plane. The propellant flow path will be: TSOV to pump to nozzle coolant tubes to reflector-across shield-across depleted core to plenum - exhaust from nozzle to ejector system pulling vacuum on the nozzle. The need for an auxiliary hot gas feed system to supplement the propellant tapped off from the convergent entrance section of the nozzle utilized for TPA power will be evaluated. See Figures 5 and 6.

3. Testing, Data and Analysis

Testing and analysis of data will be made in a manner similar to the Mod I and Mod IB Simulator Test Programs described in Sub-Subtask 1.1.1. Details of test parameters, flow rates, and TPA operation will be made as knowledge and design criteria firms during the Gen II, Mod I and Mod IB Simulator Testing.

4. Hot Flow Non-Nuclear Engine Development Test System (HFDTs)

The need for a full or partial non-nuclear engine HFDTs testing program prior to the first Block I E-Engine test at NTS, 4th quarter CY 64, will be analyzed and evaluated during the 1st quarter of CY 63. Conceptual design, feasibility, requirements need, and an ROM Cost Study will be made in conjunction with REON.

The conceptual analysis will investigate the CY 1964 LRP Test Area Capability for Hot Gas Feed and the desirability of testing (even at a low reactor power demand level) the whole or a major segment of the integrated non-nuclear engine. The approach utilized will be to evaluate the thermodynamic balance requirements of the non-nuclear engine system at various reactor power demand levels. As the component, sub-assembly and assembly designs are proven via their own testing programs, their operating characteristics and requirements will be compared with the engine system requirements at various reactor power demand levels. Conceptual HFDTs designs and feasibility of designing, assembling and operating this system during CY 64 at the LRP test area prior to ETS-1 testing in the 4th quarter of CY 64 will be evaluated.

ACCEPTANCE TEST SYSTEMS (Sub-Subtask 1.1.3)

1. General Description

To provide by August 1963, a detailed document evaluating the program requirements for acceptance testing of non-nuclear engine components and sub-assemblies for the various blocks of NERVA engines to be supplied to NTS and elsewhere.

2. Guide to Work Effort

The work effort in this area will involve Engineering Review and mutual agreement with Quality Engineering as to the recommended methods to acceptance test the items listed below. Functional and operating checkouts, hydrotesting, calibrations, continuity checks, system compatibility and dimensional control will be investigated as well as a tentative assignment of a Classification of Defects Designation.

3. Units and Assemblies Considered for Acceptance Testing

TSOV Assembly

TPA Assembly

Check Valves

Thrust Structure

TPCV Assembly

Nozzle

Gimbal Assembly

Nozzle Skirt

Seals

Wiring Harnesses

Pressure Vessel (Reflectors, Shield, Closures, Support Plates and Pressure Vessel Assembly).

Instruments (Resistance thermometers, thermocouples, strain gages, pressure transducers, accelerometers, speed sensors, controllers, etc.).

Lines, fittings, flanges, bosses, etc.

MODIFIED PROTOTYPE NON-NUCLEAR ENGINE MOCK-UPS (Sub-Subtask 1.1.5)

1. Engineering Mock-up

It has become evident that with the Sacramento Plant entering its second year of participation on the NERVA program an engineering mock-up of the current state of the non-nuclear development engine is required. For minimum cost this engineering mock-up will utilize rejected and used components piping, sub-assemblies and assemblies which have satisfied their intended prime use. This mock-up will be upgraded as later design equipment becomes available. This mock-up will be used as a visual aid for ground support equipment design, training of service division personnel, design of thrust structure interface gages for Test - RIFT contractor - NTS - Westinghouse and other personnel. Sectioned areas not interfering with the structural handling requirements of the 10,000 lb. unit may be made for display and information requirements as the program advances.

2. Hard Mock-up

The design layout for a hard mock-up for use at NTS in CY 64 will be finalized by the end of CY 63. It will duplicate the Block I E-engine design and will be suitable for pressurization and COLD FLOW ONLY Checkouts.

GEN II MOD I
FIG. 1

SYSTEM FLOW SCHEMATIC

FIG. 2

NUCLEAR REACTOR ENGINE SIMULATOR
GEN II MOD 1b

(MECHANICAL)

FIG. 3

NUCLEAR REACTOR ENGINE SIMULATOR
GEN II MOD I b

[SYSTEM FLOW SCHEMATIC]

FIG. 4

TEST DIVISION
THRUST RING
ADAPTER

RUN TANK
BOTTOM

TANK SHUTOFF
VALVE

THRUST
STRUCTURE

COOL DOWN BLEED
VALVE

THRUST-
STRUCTURE

TURBOPUMP ASSY
(GAS LUBRICATED BEARING)

TURBINE CONTROL
VALVE

GAS FARM SYS.

CONTROL ROD
ACTUATOR

SELECTOR
VALVE

EXHAUST LINE

CHECK VALVE

PUMP
DISCHARGE
LINE

TITANIUM PRESS
VESSEL

KIWI B-1B
DEPLETED
GRAPHITE
CORE

TURBINE INLET
LINE

5000

23.00

NERVA NOZZLE

SKIRT

HOT BLEED NON-NUCLEAR ENGINE
DEVELOPMENT TEST SYSTEM
(MECHANICAL ASSY)

CFDTS
FIG. 5

202.00
17 FEET

71.00"

HOT BLEED NON-NUCLEAR ENGINE
DEVELOPMENT TEST SYSTEM

(SYSTEM FLOW SCHEMATIC)

CFDTS
FIG. 6

PROPELLANT FEED SYSTEM (Task Item 1.2)

System

The purpose of this effort is to develop a feed system capable of supplying propellant at the required range of flow rates and pressures to the NERVA engine. The normal constraints related to the startup and shutdown of chemical rocket engines must be adhered to in the nuclear rocket; in addition, these are complicated by additional constraints concerned with the interrelationship between the reactor energy release and the liquid-hydrogen flow buildup. These constraints relate two essentially separate systems and require careful programming in order to limit the rate of temperature rise in the reactor core and at the same time prevent liquid hydrogen from entering the reactor.

The cooldown phase of engine operation is similarly constrained, since the energy output of the core does not completely cease upon shutdown of the reactor. The intensity of decay-energy release of the reactor core is a function of the integrated energy output of the reactor; consequently, the cooldown cycle of this reactor depends on the run duration and power level. On the other hand, the nuclear rocket engine is much more flexible than the chemical rocket with respect to the operating thrust range. By appropriate matching of the energy release in the core and the hydrogen flow rate, it can be made to operate over a wide range of steady-state thrust levels. For this reason, a large number of shutdown schedules is possible. In addition, to take advantage of the inherent restart capability of the NERVA engine, the cooldown cycle must be implemented in such a manner that residual heat capacity is available to provide restart energy, since the start depends upon stored thermal energy in the various engine components to bootstrap the turbine power.

The engineering effort during the period prior to October 1962 will provide a preliminary analysis of the operating conditions, including starting and cooldown transients from the NERVA engine. It is contemplated that these original plans will be refined during Contract Year 1963. The refinements will be based on test data from several sources. The most important source, for starting and shutdown transients, will be the KIWI-B tests; the second will be the simulator tests and the non-nuclear engine development test system experiments. These test results will be analyzed, and the refined transient-operating analyses will be based on the data.

These operating data will be reflected in the various component criteria in order that the design may be integrated into a smoothly working propellant feed system (PFS). The various components of the PFS are discussed below. An overall system PERT planning network showing sequences of activities and events is presented in Figure _____. Details of the efforts for Contract Year 1963 are included in Section _____. A test schedule is shown in Figure _____, and hardware schedules are shown in Figure _____.

Turbopump Assembly

The function of the turbopump assembly is to provide the driving energy for the propellant feed system. It accepts liquid hydrogen at low pressure and temperature from the propellant supply tank and delivers it to the system at a high pressure and the required flow rate as determined by engine system analysis. The turbopump assembly includes a single-stage, radial exit flow pump, power transmission with hydrogen-cooled bearings and a three-stage turbine which utilizes high temperature hydrogen-cooled bearings and a three-stage turbine which utilizes high temperature hydrogen as the driving fluid.

The existing Mark III, Mod II configuration was designed in accordance with pump requirements later published as NERVA Design Criteria (NDC-1A) for the heated bleed engine cycle.

The heated bleed concept of a minor redesign of the MR III TPA for the Flight-Experimental (FX) configuration was negated by the change to hot bleed cycle and increased pump performance requirements. The FX configuration TPA is now to be installed on E-3 engine for tests at partial power and on E-5 engine for tests at rated power.

A major redesign to meet the substantially increased (by 45%) pressure requirement of the preliminary FX design criteria for the hot bleed cycle is required. The increased FX design effort will involve the following analyses:

- (1) Thermal - A general thermal analysis of the entire TPA will be made
- (2) Stress - Including disk centrifugal stress analyses using the resulting thermal gradients and a compromise between weight and creep life.
- (3) Critical speed and shaft oscillations. This will be a compromise with disk weight and foil axial clearances.
- (4) Power match between the turbine and pump. This will involve a compromise between pump efficiency, turbine efficiency, and rotor weight.
- (5) Thermal shrinkage and expansion and the resulting effort on shaft and bearing dynamics.
- (6) Coolant requirements associated with bearing energy generation, energy conduction to the power transmission and radiation heating.
- (7) Pressure-area forces associated with rotor thrust within the feasibility of development to bearing capabilities.

Development requirements for the hot bleed cycle TPA configuration include:

- (1) Development of reliable power transmission incorporating LH_2 -cooled bearings
- (2) Impeller backvane development to minimize bearing loads after rotor thrust is documented and after development of a fluid drive system, which results in rotor thrust changes within the limits of bearing capability.
- (3) Inducer development to a result in values of net positive suction pressure with sufficient margin to ensure reliable operation (FX configuration, only).
- (4) Design for remote diagnostic disassembly and handling (FX configuration, only).
- (5) Development of a static seal arrangement that will permit positive control of axial stacking tolerances and shim adjustment for the required impeller clearance, as well as required sealing of dissimilar metals over a wide range of temperatures.
- (6) Development of fits and tolerances and documentation of cool-down requirements for a reliable rotor balance.
- (7) Development of pump diffuser vanes for an efficient pump (FX configuration).
- (8) Development of turbine disks with adequate creep life when exposed to the temperature and stress gradients resulting from the drive fluid and the power transmission cooling flow.
- (9) Development of turbine clearances at operating temperatures to result in a reasonable compromise between reliability and efficiency.

A decision has been made to use the Mark III, Mod II TPA configuration for the E-1 and E-2 engines. This will enable engine system development tests at partial power in the beginning of the E-engine test program.

A study was initiated to determine the feasibility of attaining a minimum of 90% power for E-1 and E-2 engine operation by a minor turbine redesign. This power increase will be attempted by a proposed TPA speed increase to 22,000 rpm by increasing stator passage area and possibly a change in the first stage stator and rotor profiles. Completion of this study is scheduled for January 1963 and a decision will be made at that time, after due consideration of the overall engine system operation, whether to introduce this design change or use the present Mark III, Mod II TPA configuration. The recommended action will be presented in a proposal to SNPO, if additional funding is necessary.

A new TPA design effort will start late in Calendar Year 1962 using the FX design criteria for the hot bleed cycle. Fabrication drawings will be released by the end of Contract Year 1963. With the present schedule of design freeze during the second quarter of 1964, for the FX configuration to be used on the E-3 engine, most development problems must be solved using the E-1 turbopump configuration. Prior to the required increase in pump pressure, and with the FX configuration scheduled for E-11 engine, available time permitted testing in such a manner as to minimize hazarding TPA damage. This cautious approach will not result in the most expedient development. More hardware is required to permit more stringent development without resulting in depletion of hardware in mid-CY 1964 that could have otherwise resulted. Required lead time will not permit avoiding both the cautious approach during

the first three quarters of CY 1963 and hardware depletion during CY 1963. Stringent development for solutions to problems using the E-1 configuration hardware will permit reduced FX configuration development time and use of the FX configuration in the E-3 engine. Applicability of the E-1 configuration development to FX problems is delineated as follows:

The development of the power transmission incorporating LH_2 -cooled bearings was initiated early in the NERVA program. Tests to date have demonstrated satisfactory operation of a cageless roller bearing for an accumulated 41 minutes in LH_2 at 2000 pound radial loads and 16,000 rpm. Armalon cage thrust and roller bearings operated satisfactorily for a continuous 10 minutes at LH_2 at 1200 to 1300 pound axial loads and 2000 pound radial loads, respectively, at 16000 rpm. The bearing development program will continue until attainment of the goal of operation for one hour at rated speed and load. Rated speed will be demonstrated during December 1962. The bearing development program will include both cage and cageless configurations and materials studies and bearing evaluation involving solid lubricants primarily plated on cages. The bearing program will involve procurement of candidate rolling elements and bearing races from commercial sources and AGC design, fabrication and development of cage configurations of non-metallic materials, especially teflon-silicon materials such as Armalong. A materials program to improve corrosion resistance of races and rolling elements is planned. Configuration development will continue with 440C races and rolling elements until a satisfactory corrosion resistant material is developed. The general approach of testing is to subject the candidate bearing configurations to incrementally more severe conditions of load, speed

and run time in the bearing testers. The bearings will be removed from the testers for inspection initially at small time increments to determine the effect of time on service life.

For the required shaft stiffness with the increased component weight associated with the more powerful FX turbopump configuration, bearing size may be increased. However, the solutions to problems solved using bearings of the Mark III size will general apply.

The feasibility of controlling rotor thrust by adjusting backvane configuration has been demonstrated during Contract Year 1962. The rotor thrust, consisting of pump impeller thrust, turbine thrust and power transmission thrust, must be determined for both the E-1 and FX configurations. The pump impeller thrust has been determined for the E-1 configuration, but the turbine and power transmission thrust components remain to be determined. All three thrust components must be determined for the FX configuration. The determination of these thrust data involves a special instrumentation of turbopump assemblies and special TPA tests employing this hardware. Turbine thrust determination involves documentation of interstage pressure during tests at various speeds and turbine pressure ratios.

The effects of turbine stage pressure ratio on stage thrust will be established during Mark III turbopump tests. The net rotor thrust can be adjusted to a minimum at one operating condition. The pump thrust will generally change in proportion to pump discharge pressure, which will change in proportion to speed squared. Turbine thrust, if significant, will not change in the same manner. The effect of fluid stream shocks (which occur at mean stream relative mach numbers above .6) will affect static pressure along the fluid path resulting in thrust. Although, the effect

on static pressure may be small the associated areas are large. Knowledge of these characteristics as established using Mark III hardware will reduce the development time required with an FX configuration.

Upon completion of the thrust determination, the backvane configuration or an otherwise suitable balance piston will be developed to minimize thrust at the worst operating condition to simplify the TPA bearing problem.

A development program is necessary to produce a pump inducer for the FX configuration. This program involves optimization of the number of vanes and the vane angles associated with the design values of Q/N and H/N^2 . The experience gained during the E-1 configuration inducer development will be used in this program, as applicable.

The approach to the remote handling problem is to establish the criteria of designing for remote installation and removal of the E-1 configuration and designing for remote diagnostic disassembly for the flight configuration.

The E-1 configuration incorporates Conoseals and Marman clamps on the TPA interfaces with the PFS plumbing. The disassembly of this configuration can be accomplished remotely only by employing remote sawing and grinding operations at several joints, but this is a possible means of enabling post-mortem inspection shortly after nuclear testing. The FX configuration remote handling design criteria are being formulated. The interface joints will probably employ Conoseals and Marman clamps as on the E-1 configuration. The internal joints and seals present a problem that cannot be solved by the present Conoseal and Marman clamp approach. The problem is that the existing design does not provide the design feature of control of tolerance stackup that is necessary in the TPA design. A variation of the Marman concept to permit flange face contact, and thus control tolerance stackup, is under consideration. A concept for providing a means to control impeller vane clearances by shimming is also being developed.

TANK SHUTOFF VALVE

A tank shutoff valve (TSOV) is installed at the bottom of the propellant tank for the purpose of opening or closing the propellant-flow passage to the turbopump. The TSOV seal will be critical in that, during a hold period or during first-stage operation, it will protect the engine from hydrogen. A metal-to-metal seal to meet the stringent radiation requirements represents an extension of the state-of-the art.

The Configuration 1 valve assembly (first in the development cycle) development was initiated in May 1962. Further information will be utilized to design and fabricate E-1 configuration hardware. The component design criteria will include the important consideration of remote-handling problems. The engine-component and remote handling equipment and tooling design efforts will be closely coordinated to ensure the compatibility of components and remote handling procedures. These related design studies will be conducted concurrently. The designs of both the engine components and remote-handling equipment will be evaluated at LRP and, later, at NRDS.

Six TSOV's were fabricated during Contract Year 1962 for use in the development program. The fabrication of E-1 configuration hardware was initiated in September 1962. On the basis of past experience, it appears that 5 or 6 items are required for development for each major design change. The hardware schedule is presented in Figure _____. The valve assembly will be tested in conjunction with the rest of the engine system to establish its operational capability. The TSOV tests conducted from November 1962 through January 1963 will utilize hardware funded during Contract Year 1962. Proof, leak, and functional testing will be performed through October 1963 on the E-1 configuration valves. These tests will be used as initial development, acceptance, and calibration test criteria before

and after each endurance and environmental tests, to evaluate the effect of the test conditions to which the valve assembly has been exposed. Further test information will be obtained to include optimum double seal configuration, environmental capabilities and operation life.

COOLDOWN VALVE

The function of the cooldown valve (CDV) is to provide a bleed flow of liquid hydrogen to pass from the propellant tank to the reactor assembly. This bleed flow of liquid hydrogen will be used to cool the engine reactor after the fired engine has been shutdown. The major seal problem in this valve is related to the requirement that it have an operating-life endurance of more than 1000 cycles. This valve will be integrated with the E-1 configuration TSOV.

The design for the Configuration #1 experimental hardware (first in the development cycle) was completed in July 1962.

Fabrication of hardware ordered for the development program was initiated in October 1962.

It is expected that the sealing problem for this valve will be similar to that of the TSOV, and that the experience gained on the TSOV will be directly applicable to the RCDV seal, except that the large number of cycles presents additional difficulties.

The development effort for the cooldown valve will be directed toward establishing operational capability in nuclear and low-temperature environments. Because of the nuclear environment, metal-to-metal sealing will be used for valves, and a ceramic or a silicon-impregnated glass insulation will be used for the actuator motor windings and connectors. Aluminum wire will be substituted for copper to reduce the half-life radioactivity of the motor assembly.

TURBINE POWER CONTROL VALVE

The TPCV is an electro-pneumatically actuated butterfly-type valve located

near the turbine inlet. The purpose of this valve is to control the power to the turbine. The electric-pneumatic actuator is being designed and developed by the Bendix Corporation. The general design features of the valve include low pressure drop, low actuating torque and moderate seal capability. Efforts will be closely coordinated to ensure the compatibility of components and remote-handling procedures. These related design studies will be conducted concurrently. The design of both the engine components and the remote-handling equipment will be evaluated at LRP and, later, at NRDS.

The major problems areas involve the requirements of sealing capability, low actuating torque and operation at 1760°R.

The selection of the butterfly-type valve was made to satisfy the low actuating torque requirements and the lower pressure drop at full flow. This configuration presents a problem, however, since it is more difficult to achieve a good shutoff seal than with a poppet-type configuration. The butterfly configuration requires a sliding motion of the butterfly blade seal against the valve body, whereas the poppet type involves poppet motion perpendicular to the sealing surface, which permits high loading at the sealing surface. The sealing problem is complicated by the requirements that metallic seals must be used, due to the nuclear radiation environment. The maximum permissible leakage rate for the heated bleed valve is 4 cfm at 25 psig and operating temperature conditions. (this may be increased for the hot bleed valve).

The change from heated bleed to hot bleed engine cycle increased problems due to an increase in operating temperatures from 1140°R to 1760°R. This complicates the overall design problem, requires a material change from 347 stainless steel to Inconel X (reactor grade) and presents a need to advance the state-of-the-art regarding needle bearings capable of reliable operation at 1760°R. The overall complexity of developing this component for hot bleed cycle operation is increased

considerably.

The solution of the sealing problem will be accomplished by a laboratory development program designed to evaluate several candidate metal seal designs under simulated environmental conditions. CY 1962 TPCV testing indicates that a piston ring configuration seal will provide acceptable sealing. This configuration will be tested further to obtain additional data on the effects of scoring, cycling, and dimensional changes. Tests also indicate that two thin piston ring type seals will provide better sealing than a wide single seal. This configuration will be further evaluated in CY 1963. Testing at ambient temperature and at 1800°R with a LO_2 - hydrogen gas generation, and hot hydrogen facility will evaluate the valve body scoring caused by the piston ring seal. It is planned to make the seal material softer than the valve body material. The seal configurations will be extensively tested to determine the effects of temperature, scoring, cycling, and dimensional change on valve sealing capabilities. A seal design which provides the desired minimum leak rate and life will then be selected and incorporated into the valve design.

The actuating torque problem will be solved by a test program designed to develop a reliable high temperature (1800°R) needle bearing. The bearing will provide the low valve actuating torque required at operating temperature. The bearing development program will start with a literature search of bearing manufactures to establish the more promising designs and materials. Materials, such as AM355, A-286 and Haynes 93, having high temperature capabilities will be considered as possible candidates. The more promising bearings will be assembled in valves and functionally checked for compatibility at ambient temperatures. Upon completion of this testing, high temperature operational tests will be performed using a LO_2 - LH_2 gas generator. Critical data to be obtained during these tests will be torque, temperature and pressure. Torque data will give information as

to body or shaft deformation or galling at the elevated temperature. Leakage information will also be obtained from these tests. For those bearings which yield low torque data, a series of closed loop dynamic response tests will be performed using valve position to close the loop.

As a back-up program a similar development program will be performed on sleeve bearings. The sleeve bearings are not desirable however, due to higher torque requirements.

SEALS

The propellant feed system line-disconnect static seals require development effort. Due to the destructive effects of the high radiation field on organic materials, it was necessary to investigate static seals of the all-metal type. The objective of this investigation is to find a radiation-resistant seal with a low leakage rate that would be effective and practical, and would be the least expensive.

Several all-metal static seals were ordered from their suppliers. As new items become available, samples may be purchased and tested. At present, however, a decision has been made to use Conoseals as supplied by the Marman Company for all propellant-feed-system line disconnects. A minimum of one backup seal will be developed. The results of tests of Conoseals at WANL and Aerojet indicate that this seal is capable of a high degree of reliability and a low leakage rate. It is presently planned that this seal will be used in the design of the E-1 engine components.

PUMP SUCTION LINE

The design features and preliminary design of the pump suction line have been established. The suction line will be tested as both a component and as an integral part of the propellant inlet system in Contract Year 1963. Component tests will be made with water and later with liquid hydrogen to determine line

pressure drop and line discharge velocity profile. The special directional pressure probes supplied by NASA will be used in these tests. A series of pump performance tests with the TPA - suction line - TSOV connected as a system will be run to determine pump performance as a function of TSOV inlet pressure. These tests will provide data for vehicle tank requirements and will define the hydraulic interaction of the components. A correlation will be made between individual component performance and component performance in the system.

A design layout study is in progress to establish the prototype suction line configuration to include all the necessary functions of the flight hardware. In addition, the results of tests and analyses reported by various agencies with regard to the thermal behavior of propellants during expulsion from a vehicle tank will be applied to improve the design of the pump suction line.

Fabrication techniques will have to be developed to permit efficient and inexpensive production methods of machining and welding the complex structural portion of the two halves of the suction line.

The assembly will be integral with the thrust-structure cones, and will permit angular movement with the use of two actuators. The line assembly will contain a gimbal assembly that must take the total thrust of the engine assembly.

Extensive testing will be required to include proof, leak, and functional tests in conjunction with the Generation II engine simulator and CFDTs test programs. Flange disconnects will be developed to allow remote machine handling, disassembly and assembly. Further structural tests will be conducted to simulate stresses imposed by a flight vehicle.

LINES

The propellant feed lines will include the pump discharge line, turbine exhaust line and turbine inlet line. The preliminary design features such as line size, material, and bellows sections, have been established. Flight load characteristics

will be investigated and support structures will be designed. Standard fabrication techniques and stainless-steel or nickel alloy materials will be used. Flight load stresses will be investigated.

RADIATION EFFECTS TESTING

Propellant feed system components will be fabricated during Contract Year 1963 in support of the radiation effects test program. Components to be fabricated include tank shutoff valves, cooldown valves, turbine power control valves, check valves, TPA bearings, linear and rotary potentiometers, solenoids, and electric actuator motors. These components will be tested in a radiation and cryogenic environment simulating as closely as possible the engine environment. The effects of radiation on component materials, operation, and life will be determined to verify the radiation resistant features of the component designs.

1. Thrust-Chamber Assembly (Task Item 1.4)

The objective of this task is to develop thrust chamber assembly (TCA) components, i.e., pressure vessel, thrust structure, nozzle, and gimbal assemblies for the NERVA engine. Development testing will have been performed for various TCA components in Contract Year 1962 and will continue into Contract Years 1963 and 1964. In addition to TCA development testing, tests will be conducted on engine assemblies to provide additional data applicable to TCA development. The interaction of the actuators and actuator-support structure with the engine thrust structure, gimbal, and interface connections will be analyzed and verified by tests to determine the dynamic response of the engine structure. The interaction effects of the TCA structure with other engine components, such as the turbopump and reactor, will also be evaluated. Structural discontinuities, combined with high pressure, radiation dosage, thermal gradients, and a hydrogen working fluid create complex stresses and material problems in the pressure vessel and nozzle that will require extensive engineering evaluation. In addition, fabrication and test techniques will be developed as required to support the development of the TCA.

Interface coordination will be conducted to ensure the compatibility of the TCA design with reactor tests, handling facilities, and the RIFT vehicle. Master gages will be used to control dimensional requirements.

A pressure vessel, dummy reactor, nozzle, thrust structure, gimbal, and dummy gimbal actuators will be assembled together for the TCA dynamic test program. Another TCA assembly will be made for CFDTs. The CFDTs will demonstrate component ability for operation as a part of an integrated test system while the TCA dynamic test program will demonstrate the capability of the components to work together

structurally and provide necessary design data on TCA response to shock and vibration loads.

Thrust chamber assembly components will be fabricated and tested in the NRX-A Program during Contract Year 1963. Environmental test data resulting from this program will be utilized in TCA design for the E-engines. Several nozzles will be fabricated in support of the Los Alamos Scientific Laboratory Reactor Test Program at NRDS.

Material evaluation studies of nozzle and pressure vessel materials will be performed to provide data for use in the design of the TCA. Pressure vessel material studies will consist primarily of testing forged material to establish design allowables throughout the predicted temperature range and the nozzle materials program will cover braze alloy development and aluminum jacket development. In addition, high strength A-286 bolts and gimbal bearing materials 440 C and 52100 will be tested in their predicted temperature ranges.

Pressure vessel engineering effort will be concentrated on fabrication problems unique to titanium, forward closure configuration optimization, development of the bolted and sealed joints which join the closure to the cylinder and the cylinder to the nozzle, attachment of the pressure vessel to the thrust structure, and evaluating the pressure vessel-reactor interfaces. Development of the pressure vessel will be supported by structural testing and analysis. Fabrication will provide pressure vessels for the NRX-A Program, component development tests, and the engine simulator program. The pressure vessel will be subjected to stress-coat tests, limit-load surveys, and destruction tests that

will provide information on structural integrity as well as maximum load carrying capability. Stress concentrations in the forward closure will be minimized through a program of relief, utilizing a chemical-milling technique.

The design of the thrust structure will be directed towards increasing lateral stiffness and evaluating the mechanical joints between the thrust structure and propellant tank, gimbal, and turbopump. Mounting structures for the gimbal actuators will be developed as an integral part of the thrust structures. In support of the development effort, thrust structures will be fabricated for component development testing and the engine simulator program. Static limit-load surveys will be performed on the thrust structure to determine stress and deflections, and destruction tests will provide information on ultimate capacity. The interface joints to the thrust structure will be simulated and tested with the thrust structure as well as the gimbal.

The gimbal program will concentrate on the development of an assembly which will operate in a LH_2 environment. A testing program will evaluate the performance capabilities at cryogenic temperatures under both static and dynamic loads. Structural analysis will be used to support both the design and testing efforts. Gimbal assemblies will be fabricated for the TCA dynamic test program as well as for component testing and irradiation testing.

For all practical purposes, the NERVA nozzle development program began when Aerojet was funded on the Kiwi B nozzle program in Phase I of the SNPO1 contract. Prior to that time, Aerojet initiated the design and analytical studies leading to the NERVA nozzle design. Two test program were underway to provide more accurate values for the hot gas and coolant heat transfer coefficient, but were

not expected to provide definitive data until later in the program. The design concept of casting an aluminum shell around a stainless steel tube bundle to carry the longitudinal loads in the nozzle was an established design goal, and all the sample fabrication efforts were favorable. Of greater significance, an XLR-87 chamber to be employed in the hot-bleed testing program was fabricated with a cast aluminum shell and was successfully fired with LH_2 in the coolant jacket and LO_2/LH_2 as the propellants.

The goals of the Aerojet Kiwi B nozzle program were to (a) provide a backup nozzle to the Rocketdyne nozzle for the IASL Kiwi B test program, (b) obtain early fabrication experience in the production of NERVA type nozzles, (c) obtain verification that the tube bundle would handle heat fluxes expected in the Kiwi B and NERVA nozzle designs, and (d) provide early verification that the NERVA nozzle design would withstand a reactor environment (from IASL testing of the Kiwi B reactor).

The Kiwi B nozzles (SN-1 and SN-2) have not yet accomplished the objectives set forth in (a) and (d) above, but proved an extremely valuable experience with respect to the objective set forth in (b) above. This program reiterated experiences gained in other hardware programs, i.e., there is no substitute for early fabrication to evaluate the adequacy of a design concept. The same consideration holds true for early testing, because only by testing can the suitability of the design be positively demonstrated.

The purpose of the NERVA nozzle development program as set forth in the Contract Year 1963 program is to continue the logical development of the NERVA nozzle by building and testing prototype hardware. The design of these nozzles will incorporate modifications determined by (a) the most current hot gas and

coolant heat transfer coefficient test data, (b) the most current evaluation of internal heating due to gamma and neutron irradiation and (c) the most current thermal radiation heat load.

The hot bleed cycle selection decision affects the NERVA nozzle and skirt development program in two distinct areas; the addition of the hot bleed port changes the basic nozzle design and the design of the expansion section of the nozzle assembly becomes far more flexible since engine operations are no longer affected by skirt operations. For the purpose of this technical discussion, the salient features of the Hot Bleed NERVA nozzle assembly are summarized as follows:

Basic construction of the nozzle section is similar to the NERVA heated bleed nozzle (Ref. Dwg. 265400).

The hot bleed port will be located in the convergent section of the nozzle as close as practical to the nozzle-pressure vessel flange.

The nozzle section will extend beyond the 4:1 area ratio of the heated bleed nozzle to an area ratio which will allow full flow for sea level testing.

The skirt section will be cooled by radiation and/or the turbine exhaust gases.

The hot bleed port diluent supply may be separately controlled as opposed to a fixed orifice system.

The hot bleed line may be regeneratively cooled to just past the first elbow.

The problem areas unique to the hot bleed system are associated with the bleed port and the skirt designs.

A. Hot Bleed Port: The principal problem areas associated with the hot bleed port are listed below:

(1) Mixing efficiency: Development of an efficiently mixing bleed port is mandatory for successful operation of the engine. Incomplete mixing of the hot gases and diluent gases could result in hot bleed line burnout which would result in a critical engine failure. This problem is aggravated by the low pressure drop requirement of the bleed port system; that is, greater pressure drop allows more flexibility in mixer design. Mixing efficiency must be high since the first elbow in the line is relatively close to the mixing section. Incorporation of a regeneratively cooled elbow reduces the magnitude of the problem, but a high mixing efficiency is still required.

(2) Control System Requirements: Of primary importance is determination of the control system requirements of the hot bleed port system. A fixed orifice diluent system is the most desirable since controller is required. However, if the resulting hot gas temperature characteristics are not compatible with turbopump operation in the off design or transient conditions, then a separately controlled diluent supply will be required to allow exact temperature control.

(3) Bleed Port Entrance Erosion: Although the successful Phase I hot bleed port series conducted on an XLR87-AJ-1 combustion chamber demonstrated erosion free operation of the bleed port

entrance, the geometric differences with the current NERVA hot bleed design concept may require further development. Effects resulting from relocation in the convergent section of the nozzle will require full evaluation.

(4) Boundary Layer Interruption: The presence of the bleed port and its accompanying gas dynamics results in interruption of the hot gas boundary layer in the nozzle. Since successful heat transfer operation of the nozzle depends on this boundary layer, the lack or depletion of it demands special attention. This is true just downstream of the bleed port in the main gas flow. Since a finite length is required to re-establish the boundary layer special attention must be paid to cooling requirements in this area.

B. Skirt Section: The principle problems associated with the skirt development are:

(1) Selection of Area Ratio for Nozzle to Skirt Joint: The divergent requirements of the nozzle and skirt create this problem area; i.e., the skirt requires a large initial expansion ratio for a conservative design while the nozzle expansion ratio should be approximately 10:1.

(2) Contour Selection: This problem area is associated with the tradeoffs between high heat transfer rate characteristics of high performance nozzle contour and the low performance characteristics of a low heat transfer rate nozzle contour. For the purpose of this proposal, it is assumed that the nozzle divergent contour will be conical with $17 \frac{1}{2}^\circ$ half angle.

(3) Skirt Cooling: The technology of a tube-bundle skirt construction is well proven. However, since this skirt will possibly be cooled by a portion of turbine exhaust gases, the amount of cooling capacity of the gases available and the relatively low driving force (pressure drop) allowable may limit the total area capable of being cooled.

(4) Maximum operating temperature requirements and material technology at these high temperatures create the problem of selection of initial expansion ratios for this section of the skirt.

Identification of the principal problem areas relates directly to the establishment of the development program objectives. Listed below are the program objectives of the two principal zones of development (Hot Bleed Port and Skirt) and a description of the associated program:

The Hot Bleed Port program objectives are:

- (1) Develop non-eroding bleed port
- (2) Develop high bleed port mixing efficiency
- (3) Investigate regeneratively cooled elbow
- (4) Determine need and desirability of a separately controlled diluent supply.
- (5) Determine dynamic effects of a "fixed orifice" diluent supply on the control system and turbopump.
- (6) Minimize pressure drop of the bleed port.
- (7) Determine design requirements for heat transfer downstream of the port.

The development program designed to meet these objectives is divided into four somewhat concurrent phases:

Phase I consists of tests to be made using the XLR-87 hot bleed port chamber developed during Phase I of Contract SNP-1. These tests are designed to answer test objectives (2) and (5) above. They will consist of LO_2/LH_2 tests with varying chamber pressure and turbine power control valve positions. The tests will determine the dynamic interactions of the turbine power control valve, chamber pressure, hot gas line temperatures, mixing efficiency, pressure drop, etc. A turbulence ring has been installed since the last test on this bleed port. If necessary, other mixing promoting devices will be evaluated.

Phase II consists primarily of analytical work to upgrade and review simulation techniques, data analyses, determination of design criteria, and investigation of potential simulation devices. The test data obtained and the most recent correlations defining heat transfer characteristics will be used to establish a mathematical model on which the analytical phase of the design improvement effort will be based. This phase relates to all the above test objectives.

Phase III consists of a series of scale model heat transfer tests which will be conducted in Azusa using hot nitrogen and an uncooled chamber. This subscale chamber will incorporate a bleed port. The chief purpose of this device is the determination of the hot side heat transfer coefficients and their effects on design and development. Specific test objectives to be accomplished are (1) and (7) above.

Phase IV is designed to be the test bed for the knowledge gained on the previous three phases. These tests will be LO_2/LH_2 simulation tests

on full scale prototype hardware. The nozzles will most likely vary in detail description in the areas of the bleed port and bleed port line. Emphasis will be on peripheral testing for growth potential and demonstration of inherent reliability. These tests will utilize turbine power control valves and separately controlled diluent supplies as dictated by needs and results from the previous three phases. A systematic plan will be devised to incorporate the various concepts and alternate designs necessary for a logical progression of knowledge.

The Skirt program objectives are:

- (1) Determine design parameters related to contour, heat transfer, performance, and length.
- (2) Determine turbine exhaust cooling capabilities.
- (3) Determine optimum area ratio for joint between nozzle and skirt.
- (4) Demonstrate skirt operation integrity with LO_2/LH_2 testing.

The development program designed to meet these objectives is divided into two phases:

Phase I is the analytical effort which will consist of parametric studies of various contours, expansion ratios, performance levels, nozzle to skirt joint locations, heat transfer characteristics, and length vs performance trade off. This program is designed to provide the parameters required for nozzle assembly configuration.

Phase II is designed as the initial verification tests of the nozzle and skirt assembly. The limited number of tests (3) allows only initial investigation of the validity of the design analysis. These tests will be LO_2/LH_2 simulation tests and will be run in a diffuser.

During Phase I and Contract Year 1962 liquid-side heat-transfer tests were made to better define the heat-transfer conditions in nozzle throat range. These data were correlated, based on Reynolds-number exponent of 0.8, but gave indications that a larger exponent would produce a better data fit. Because of the correlation form, the heat-transfer rates of the tubes near the core may have been over estimated during partial power operation of the nozzle, where the thermal radiation from the core remains but the convective-cooling capability is considerably reduced. The proposed program will obtain additional data needed to evaluate the low Reynolds-number range occurring during this condition of operation and will include evaluation of reverse-curvature effects. These data can then be used to verify the nozzle design, and will also be used in re-correlating LH_2 heat-transfer data obtained during Phase I and Contract Year 1962 to improve the confidence limits of the test data.

Tests were made during Phase I and Contract Year 1962 at the 1/11- and 1/4 scale level to define the gas-side-heat-transfer coefficients in the NERVA nozzle. These tests employed gaseous nitrogen (GN_2) at 1600°R for the test fluid, and covered a wall-to-stagnation-temperature range from 0.4 to 0.9. The test data were correlated with local flow conditions but, due to their limited temperature range, would not be correlated with film-temperature effects. The proposed program will evaluate the effects of wall temperature on heat transfer to the NERVA nozzle by precooling a thin-walled nozzle to liquid-nitrogen (LN_2) temperatures (140°R) before starting the test. The test procedures, instrumentation, and data-reduction methods will remain unchanged from those used in Contract Year 1962. The additional

test data will then be used to remove the remaining uncertainties from the heat-transfer conditions in the NERVA-nozzle extension for use conditions and simulation conditions with the H_2/O_2 propellant combination.

Nozzles, skirts, adaptors, injectors, and advanced nozzles will be fabricated for the component development program described above. In addition, nozzles with a 10:1 area ratio will be fabricated for the NRX-A program and will be acceptance tested prior to delivery to NRDS. In support of the LASL reactor test series three heated bleed nozzles with a 4:1 area ratio will be delivered to NRDS as backup units. A hydrotest will also be conducted utilizing a Hybrid (heated bleed) nozzle and an aluminum pressure vessel furnished by LASL/ACFI. Both components will be instrumented to record strain, deflections, and flange rotations for comparison with predicted values. In addition, a nozzle will be designed and fabricated to be compatible with the KIWI-B6 reactor's cooled Metal Bottom Support Plate (MBSP). Development tests and acceptance tests will be conducted with the B 6 nozzle. Testing to be performed with the MBSP will consist of a hydrostatic test of an assembly consisting of a MBSP, a B 6 nozzle, and a B 6 pressure vessel. This will require a MBSP from WANL and a pressure vessel from LASL. In addition, a coolant flow distribution test of the MBSP will be conducted with an assembly consisting of a MBSP, a B 6 nozzle, and a coolant manifold. The same MBSP will be used in both tests.

For a cast aluminum shell, the similarities between reactor test nozzles and NERVA development nozzles are (a) shell thickness, with only minor deviations, (b) the use of interlocks to mechanically lock the shell to the tubes, (c) coolant channels in the nozzle pressure shell, and (d) the inlet coolant manifold will have one port.

The major differences between reactor test nozzles and NERVA development nozzles are (a) there will be no hot bleed port on reactor test nozzles, and (b) a seal will be located in the nozzle flange for the NERVA development nozzles (downward firing) and in the pressure vessel flange for the reactor test nozzles (upward firing).

The primary assurances that the NERVA reactor test nozzles are safe for reactor tests will come from:

- a. Structural testing of the individual nozzle prior to delivery.
- b. Results of the hybrid-nozzle, ACFI-pressure-vessel-hydrotest program.
- c. Definition of the hot-gas and coolant heat-transfer coefficients from the scale-model testing program and the LH_2 heat-transfer-coefficient test programs (with the tube bundle resulting from the data of these programs to be designed conservatively).
- d. Interpretation of KIWI-B reactor tests at NRDS using Rocketdyne KIWI-B nozzles.

RADIATION EFFECTS TEST

I. INTRODUCTION

The radiation effects program presented in NCS-208 was funded for only the first four months of Contract Year 1963 and included two tests at General Dynamics, Fort Worth, Texas. The components involved in both tests were the TSOV, TPCV, bearing tester and static flange seal assembly. A radiation effects program for the entire Contract Year 1963 was prepared and is presented in this cost study. This program includes the same two tests previously planned and the hardware required for these tests. The remainder of the program as reported in NCS 208 is by necessity changed and thus the hardware and engineering requirements that were included in the previous program to support tests scheduled during the last eight months of Contract Year 1963 will be different. The total mechanical tests scheduled for this contract year were changed from 8 to 6. The electrical and instrumentation tests remain the same for this contract year.

The proposed radiation effects test program encompasses experiments on engine components that are considered to be critical items whose improper functioning could seriously degrade operation of the NERVA engine or could possibly cause complete failure of the engine system. These experiments are designed to obtain preliminary information early in the component development program regarding the effects of a combined radiation and cryogenic environment on these NERVA engine non-nuclear components. This effect, if any, of a combined environment on the materials and components of the NERVA engine system must be determined prior to operation of the NERVA engine in order to insure reliable operation of the engine and to prevent unnecessary hazards to personnel and equipment.

Since the development time scale for the NERVA engine make complete investigation of all non-nuclear components impossible, a group of critical engine components have been selected for test. Limited useful information exists on the

damaging effect of radiation on various materials, as well as their behavior in a cryogenic environment. Behavior of various materials in a combined cryogenic and radiation environment is practically unknown, making radiation testing therefore an important part in the development of the non-nuclear components for the NERVA engine.

II. NEED FOR EXPERIMENTS

One of the major problems involved in the design of the engine components is the effect of volume heating within a material produced by exposure to radiation. The resulting increase in temperature produces thermal stresses and reduces material strength. In addition, relative deformations are produced by temperature gradients resulting from the non-uniform cooling through surfaces exposed to liquid hydrogen. Because of the complexities of component designs, analytical methods for determining the effects of radiation combined with liquid hydrogen operation become very difficult and required confirmation by experimental methods.

For effective experiments it is necessary to test the dynamic characteristics of the engine components with liquid hydrogen in contact with normal wetted surfaces. This information derived from the radiation effects tests will aid in redesigning, if necessary, those components that exhibit unreliable operation in a radiation field and will permit the provisioning of more highly developed components to the first block of E engines.

III. TEST SUPPORT EQUIPMENT

The components to be tested will be mounted on a pallet, of which several configurations will be required, consisting essentially of an aluminum structural portion designed to support the components in various positions relative to the radiation field of the adjacent reactor. Aluminum will be used for the structural portion of the pallet because of the relatively short half-life and loud heat generation due to radiation. Computations of radiation induced heat on a typical

pallet have been made and are of such a low order of magnitude that cooling of the pallet is not required. Some of the pallets will be designed to include cryostates capable of holding liquid hydrogen, others will be designed to support electrical and fluid control devices. Most of the components will be mounted in containers purged with either helium or gaseous nitrogen for safety purposes. These containers will have provision for ducting waste hydrogen to a facility burn stack.

Each test pallet interface will contain the necessary supply lines for liquid hydrogen, gaseous hydrogen helium and for gaseous nitrogen where required, and the return or vent lines for these. This same interface supplies electrical power and signal wiring for control and measurement. Each control valve for the fluid lines will be mounted on the pallet and located to take advantage of the shadow effect provided by the test components.

IV. TEST DESCRIPTIONS - MECHANICAL

A schedule of the proposed tests as well as the components to be tested is shown in Figure 1. The scheduling of these tests was based on the availability of NERVA engine hardware and the design and fabrication lead times for the test support equipment. This schedule also reflects a considered judgement of when radiation effects verification tests should be conducted in order to support the development program on each of the engine components.

1. Mechanical Irradiation Test No. 1 - January 1962.

a. Static Flange Seal Assemblies

(1) Object - This test is designed to show the effect of radiation combined with liquid hydrogen temperatures and pressures on the seals and flanges.

(2) Test Assembly - The test assembly contains three (3) "Conoseals" manufactured by the Marman Division of Aeroquip Inc., for static

flanges used with six (6) inch tubing. The tester contains the following joints: an aluminum seal between stainless steel-to-aluminum flanges; an aluminum seal between aluminum-to-aluminum flanges; and, a stainless steel seal between stainless steel seal between stainless steel-to-stainless steel flanges.

(3) Test Procedure

(a) Acceptance Test - Prior to installation on the test pallet, the test assembly must perform satisfactorily when subjected to the following acceptance tests: proof (hydrostatic) leak (gaseous helium), high temperature)periodic leak check) and hydrogen leak tests.

(b) Check Out Test - The Test assembly will be mounted on the test pallet and checkout tests will be performed at AGC-LRP and after installation at the reactor facility. All critical parameters will be monitored and a hazards evaluation will be made to ascertain that the experiment can be performed safely without endangering personnel or equipment.

(c) Radiation Effects Test - Prior to the start of the radiation exposure test, the system will be purged with gaseous nitrogen to evacuate all air from the test assembly. The system is then filled and pressurized with liquid hydrogen. The temperature and pressure of the liquid hydrogen and the flange metal temperature will be measured during the activation period of the reactor. At the conclusion of the test run, the system will again be purged with gaseous nitrogen.

(d) Post - Radiation Evaluation - The test assembly will be subjected to a reacceptance test and after the proper relaxation period the test assembly will be disassembled. A visual examination and physical analysis of the detailed parts of the test assembly will be made.

b. Tank Shutoff Valve

(1) Object - This test is designed to show if a combined radiation and cryogenic environment has any detrimental effect on the valve operation and component parts, in particular, changes in the sealing ability of the main shutoff seal. In addition, this test will provide information on the accuracy of the position indicator in a radiation field as well as determine if the potentiometer materials can withstand the effects of a radiation environment.

(2) Test Assembly - The TSOV will be immersed in liquid hydrogen and mounted in a container on the test pallet. This cryostat consists of two aluminum concentric right cylinders with an asbestos-type insulation between the walls, which will be purged with helium throughout the tests. The cryostat is penetrated by a liquid hydrogen fill line and ducting of hydrogen boil-off to the facility burn stack is provided.

The Configuration No. TSOV has single seals throughout including the main poppet seal, which consists of a single raised annular surface on the poppet mating on a beveled seat. A pneumatic (GH_2) piston-type actuator, which is an integral part of the valve, is provided. Valve position is recorded through the use of a radiation resistant potentiometer, which senses poppet motion by means of a linkage arrangement. Actuating gas is controlled by

a three-way solenoid valve, which also controls the actuation gas for the TPCV.

(3) Test Procedure

- (a) Acceptance Test - The TSOV will be thoroughly tested prior to installation on the test pallet. A leak check will be conducted on the main shutoff seal and the leakage rate will be measured and recorded. The valve will be cycled and the valve trace recorded using the TSOV position indicating potentiometer. Valve times and actuation pressure will be recorded.
- (b) Check Out Tests - The TSOV will be mounted in the Cryostat on the test pallet and the system will be purged with gaseous nitrogen. Following an appropriate cooldown time, the valve will be actuated one while immersed in liquid hydrogen using 250 psig gaseous hydrogen as the actuation fluid. The valve displacement trace will be recorded and proper operation of the valve and the potentiometer verified. All actuations of the valve will be recorded and the number of actuations kept at a minimum. Pressure, temperature and liquid level pickups will be monitored and recorded during the test.
- (c) Radiation Effects Test - Prior to functioning, the test fixture and actuator will be purged with gaseous nitrogen to remove all air. This purge will be followed by a hydrogen gas purge and the cryostat will then be filled with liquid hydrogen. The TSOV will be cycled open and closed five times while exposed to the radiation field. Actuation will be accomplished by using a three-way pilot valve and 250 psig gaseous hydrogen.

When the reactor is deactivated, the test system will be purged with gaseous nitrogen to remove all hydrogen from the test fixture. The parameters to be measured and recorded during the test are pressure and temperature of actuation gas at the inlet to test pallet, temperature of TSOV actuator skin on the opening side of the actuator, tank pressure, liquid level of liquid hydrogen in cryostat and the position indicating potentiometer displacement.

(d) Post Radiation Evaluation - After the proper relaxation period, the TSOV will be subjected to an ambient temperature 50 psig gaseous nitrogen leak check. Leakage will be measured and compared with the leakage recorded during the pre-radiation acceptance test. The valve will be bled in with liquid nitrogen and leak tested at 50 psig with the poppet in the closed position. This leakage rate will also be compared with the results of the similar test conducted during acceptance testing. The valve will be actuated five times and the valve displacement traces will be compared with the original curves. The valve will be disassembled and all parts examined for evidence of deterioration or damage.

c. Turbine Power Control Valve

(1) Object - This test has been designed to show the effect of radiation upon the materials and operation of the Configuration No. 1 TPCV. It is intended that this test show the effect, if any, of radiation on the required actuating torque for the TPCV, the deterioration of seals, the reduction of material strength and the effect of radiation on the position indicator. This test will be conducted with ambient temperature actuator fluid. Later tests will be conducted at rated operation conditions for this component.

(2) Test Assembly - The TPCV will be mounted on the test pallet and connected into the gaseous hydrogen line. This is a three (3) inch valve and the butterfly, shaft and body are Hastelloy "B" material. A special pneumatic actuator with a spring return will be used due to the unavailability of a Bendix actuator radiation - resistant rotary indicating potentiometer will be used. Gaseous hydrogen for the actuator will be supplied through the same three-way solenoid valve used for the TSOV.

(3) Test Procedure

(a) Acceptance Test - The TPCV will be inspected and calibrated in the laboratory before it is mounted on the test pallet. Physical measurement and recording of all critical part dimensions, including spring rates, will be made. A check of the indicating potentiometer for electrical characteristics, linearity and conformance with blade setting will also be made. All sealing joints will be subjected to laboratory leakage tests. The torque necessary to rotate the blade and the required actuation pressure for cracking and full open position of the actuator piston will be recorded.

(b) Checkout Tests - The checkout of the TPCV assembly mounted on the test pallet will be conducted both at AGC-LRP and Fort Worth prior to testing in a radiation environment. All the test conditions will simulate those expected in the ASTR environment, with the exception of the radiation. These checkout tests will determine the pressure differential across the valve in the closed position and will allow sizing of the downstream orifice with the valve open to maintain

250 psi when flowing 0.5 pounds of gaseous hydrogen per second.

During the checkout tests, the pressure differential across the blade versus blade position under flow conditions will be recorded for ten (10) degree increments of blade positions. Actuation torque versus blade position under flow conditions will also be recorded for each (10) ten degree increment by measuring the pressure differential across the actuator. The opening and closing time of the valve under flow conditions, as well as the required actuation pressure for cracking and also full travel of the actuator piston, will be recorded.

(c) Radiation Effects Test - As in the case of the other experiments, the test system will be purged with gaseous nitrogen to remove all air from the test assembly prior to pressurizing with gaseous hydrogen. During the radiation test, the following parameters will be recorded continuously: downstream and upstream line pressures, pressure differential across the valve blade, inlet pressure to the actuator, position indicator potentiometer trace, TPCV inlet gas temperature and TPCV body temperature. The test information derived from the data obtained during the five (5) actuations will be tabulated in the same manner as in the pre-irradiation checkout tests. At the conclusion of the test run, the system will again be purged with gaseous nitrogen.

(d) Post Radiation Evaluation - After a visual inspection of the TPCV assembly, the actuator will be removed and the

torque required to actuate the valve will be measured without pressure or flow in the TPCV. The position indicator will be checked for linearity, hysteresis and resolution, dielectric strength, , insulation resistance and continuity and power consumption. The TPCV assembly will be reassembled and subjected to the test program specified under Acceptance Test.

d. Bearing Tester

(1) Object - The bearing test proposed for this experiment is expected to provide preliminary information on operation of liquid hydrogen cooled and lubricated bearings for the turbopump assembly power transmission during radiation exposure. Design of bearings for this application is a difficult task even without consideration of the nuclear radiation environment. Since gamma heating of the bearing accounts for about 40% of the heat generated during turbopump operation, it is extremely desirable to operating a bearing subjected to an appropriate nuclear flux.

(2) Test Assembly - The bearing tester for the first test is a Mark III, Mod O, three (3) bearing tester. The candidate bearings to be tested are Armalon caged roller and ball bearings. An electric motor with the following characteristics is used to drive the tester: 50 hp, 24,000 rpm, 3 phase, 208 volts, 400 cps and 442 amps starting current. The bearing tester will be mounted on the test pallet and a liquid hydrogen inlet and an outlet to the facility vent system will be provided.

(3) Test Procedure

(a) Acceptance Tests - The bearing tester will be tested in the LRP test area prior to its installation on the test pallet.

Candidate bearings will be installed in the tester, and operating parameters, system start characteristics and maximum length of run time will be established.

(b) Checkout Tests - The bearing tester will be mounted on the test pallet and checkout tests will be conducted at AGC-LRP prior to shipping the experiment to Fort Worth, Texas.

The test procedure requires that the liquid hydrogen line and test assembly be first purged with gaseous nitrogen to evacuate the air from the system. Liquid hydrogen is then supplied to the bearing tester at a rate of 0.1 pounds per second and a pressure of 300 psig. The electric motor, which drives the tester, is turned on ten (10) seconds after the liquid hydrogen flow starts. During the test, the following parameters will be recorded: inlet pressure, outlet pressure, bearing housing pressure, inlet temperature, inside bearing housing temperature (3 locations), outlet temperature and housing temperature (2 location) and motor current.

At the conclusion of the test the motor is turned off and then the liquid hydrogen flow is shut off. The lines and test assembly are again purged with gaseous nitrogen.

(c) Radiation Effects Test - The test procedure for the radiation test is the same as that for the checkout test. Once the system has been purged and pressurized, the reactor is activated and then liquid hydrogen is supplied to the bearing tester. The liquid hydrogen to the bearing tester is shut off after the reactor is deactivated.

The parameters that will be recorded during the test are the same as those described under Checkout tests.

(d) Post Radiation Evaluation - After the proper relaxation period, the bearing tester will be disassembled and a visual inspection of the component parts will be made. A weight check and metallurgical or chemical examination of the test bearings will be conducted and compared with control specimens.

2. Mechanical Irradiation Test No. 2 - April 1962

This test is essentially a repeat of test no. 1, except for components that malfunctioned. Inadequate lead time prevents scheduling a test with different objectives, so an alternate concept is to repeat the test to provide additional data.

The components and test pallet used for this test will be the same as those used on the first mechanical test. Those component parts that exhibited reliable operation during the first test either will remain the same, or will be replaced with similar parts. Those component parts that malfunctioned or were permanently damaged during the first test will be replaced with suitable substitutes.

All instrumentation will be replaced with components that have been calibrated and checked out at AGC-IRP. Due to the compressed schedule and long lead procurement required for the instrumentation components, instrumentation that exhibits unreliability during the first test can not be replaced with a substitute configuration. In procuring the instrumentation for this test, the best available radiation - resistant components will be purchased to reduce the possibility of unreliable operation to a minimum. However, due to lead time requirements no advantage can be scheduled from the first radiation effects

test.

New seals will be installed in the static flange seal assembly and a leak test will be conducted prior to the radiation test. These seals will be the same as those tested in the first mechanical test, unless their performance was considered inadequate.

The tank shutoff valve will remain basically the same configuration is anticipated that only minor rework, if any, would be necessary. If major rework was required as a result of the first test, there would not be sufficient time to accomplish this under the proposed test schedules and the TSOV would be eliminated from the test.

It is expected that the test on the turbine power control valve will be the same as the first mechanical test. An investigation is currently being made as to the possibility of using a Bendix actuator for this test. Availability of the actuator and installation problems because of the change in configuration are the main areas of concern.

The bearing tester used in the first mechanical test will be used in this test also. A replacement drive motor will be installed, if necessary, prior to the checkout test. The bearings to be tested will be determined after the post-mortem evaluation of the first irradiated bearings is completed. Several candidate configurations will be available.

The test procedure, parameters to be monitored and/or recorded and the operating requirements will be the same as those established for the first mechanical test. Due to the limited "turn around" time between the first two tests, all disassembly, assembly and pre-radiation checkout will be conducted at General Dynamics, Fort Worth, Texas.

3. Mechanical Irradiation Test No. 3 - September 1963.

This proposed test will include a configuration No. 2 TSOV, a

Configuration No. 1 RCDV, candidate potentiometers and solenoids for the TSOV and candidate potentiometers and motors for the RCDV. Program planning ground rules established that all tests conducted at Fort Worth after June 1963 would be designed for use with GTR instead of ASTR. Available space envelope configuration for testing is dictated by the GTR facility making it necessary to reduce the number of engine components to be tested on a single pallet.

The configuration No. 2 TSOV will contain double seals with the space between the seals vented. A leak test will be conducted on the valve main poppet seals during the radiation test. The main poppet seals consist of a fixed annular raised surface and a bellows-loaded raised surface mating with the fixed beveled seat. Instrumentation requirements and the test procedure will be similar to those used in the tests conducted on the Configuration No. 1 TSOV on Test No. 1 except for the leak test requirement.

A radiation test on the RCDV is considered appropriate at this time in support of the normal development program on the component. The non-radiation program includes the development of a poppet seal good for 1000 cycles of operation and acceptable leakage standards. The radiation test will include cycling of the valve and a leakage test during operation.

The linear and rotary potentiometers, solenoids and motors will all be candidates for future use with the TSOV and RCDV.

4. Mechanical Irradiation Test No. 4 - September 1962.

For this test, a pallet will be designed and fabricated that contains a gimbal assembly immersed in liquid hydrogen, loaded and actuated. This test is proposed to investigate the effect of radiation on the bearing material and lubricant under cryogenic conditions. Full flow around the Gimbal will not be achieved, thereby making a test of this type more severe

than would be expected on the NERVA engine.

Actuation of the Gimbal will be simulated, since prototype actuations will not be available at the time of testing. The entire test assembly and associated test support equipment will be instrumented and the necessary parameters recorded throughout the test.

5. Mechanical Irradiation Tests Nos. 5 & 6 - August & September 1963

These tests are proposed as an integral part of the development of bearings for the turbopump assembly power transmission. The Mark III, Mod I four (4) bearing configuration tester will be used for both of these tests. Candidate bearings will be developed in the non-radiation testing program for testing in a combined radiation and cryogenic environment.

The bearing tester will be mounted on a test pallet and the instrumentation requirements and test procedure will be similar to the first two radiation tests. Unlike the first bearing tester, the Mark III, Mod I tester is designed so that axial and radial rated loads can be applied to the bearings.

The initial effort in this program will involve development of components that require non-metallic parts (bearing cages and/or bearing solid lubricants). Prior to the first E-1 engine test, complete turbopumps may be exposed to radiation effects, paralleling bearing tester radiation effects testing.

V. Test Descriptions - Electrical

Candidate NERVA engine instrumentation components, selected on the basis of laboratory evaluations, test stand use and irradiation test data, will be integrated into test systems for irradiation testing. The test systems will include the required containers and transducer actuation devices.

The environmental conditions and actuation of test items during the radiation test will simulate, insofar as practical, the conditions anticipated

in actual use. Sufficient units of a given type will be tested in and out of the nuclear environment to permit statistical estimates of test item performance.

Five electrical (instrumentation) irradiation tests are planned for CY 1963 in order to provide test data for use in selecting transducers for the "E" series engines. Figure 1 shows the components to be tested and the schedule of testing.

N E R V A
HOT BLEED CYCLE NCS-211A
TECHNICAL DISCUSSION
LRP SPECIAL TEST EQUIPMENT & OTHER GOV'T PROPERTY
(CONTRACT YEAR 1963)

I. SPECIAL TEST EQUIPMENT, TASK 5.0

Introduction

The LRP research and development program during NERVA CY 1963 will require STE design, procurement, and installation. Modification of existing STE and installation of new STE (mechanical and instrumentation/controls) will be needed for the non-nuclear laboratory and test facilities created under Phase I and CY 1962 contracts. In addition, it is anticipated that other STE will be required as a result of hardware configuration changes that will evolve during the course of development. This general STE requirement is frequently considered operating STE; it is programmed on the basis of facility utilization and program cost experience gained during operation of similar laboratory and test facilities.

STE required at the Liquid Rocket Plant is separated by sub-task, which are based upon geographical plant location. Thus, Sub-task 5.1 refers to Test Zone C and specifically to STE required for test stands C-6, 7, and 8. Sub-task 5.2, in turn, includes STE required in Test Zone A for the Engineering Cryogenics Laboratory, while Sub-task 5.3 includes STE required in Test Zone H for Test Stands H-4, 5 and 6. Finally, Sub-task 5.9 includes STE required for laboratories not in the test area (e.g.,) electrical and vibration laboratories).

In addition to CY 1963 requirements, sub-tasks also include carryover CY 1962 elements of STE commitment for procurement, fabrication and installation.

Table III presents detailed STE requirements (by item and system for each sub-task) in support of the CY 1963 Program. It also includes required CY 1962 carryover efforts.

A. Sub-Task 5.1 - Test Zone "C" - Test Stands C-6, C-7 and C-8

The purpose of this sub-task is to provide continued design, procurement, fabrication, and modification of STE during CY 1963 in Test Zone "C". All systems are "state-of-the-art" in performance capabilities.

The existing operational NERVA testing complex (test stands C-6, C-7 and C-8) is the only one at LRP that can now provide a high-thrust liquid-hydrogen testing capability at NERVA flow rates.

1. Test Stand C-6

This facility was the first test stand to serve the NERVA R&D effort and has adequately met the non-nuclear TPA, thrust chamber, and nozzle testing requirements imposed since the program's inception.

During the latter part of CY 1962, the stand underwent modification to raise the LH₂ run-vessel to a higher level in the superstructure. This will permit the installation of a supersonic diffuser. to provide altitude simulation for the nozzle development test program: altitude pressure conditions attainable at the exit plane of the NERVA nozzle are equivalent to 60,000 ft.

During CY 1963 continued utilization of this stand will require additional STE. Specifically the diffuser will require a special water-cooled adapter to provide full expansion of the rocket exhaust-gases to the 40:1 nozzle expansion ratio of the altitude configuration. Service piping to provide water coolant to the adapter will be a necessary STE system. In addition, operating STE (mechanical and instrumentation/controls) will be needed to serve test-setup modifications which must be made as the hardware configurations change.

2. Test Stand C-7

This facility created to serve Phase I extended - duration TPA testing, was completed in January 1962. During CY 1962 follow-on effort, the stand was equipped with the necessary STE to provide a bi-propellant hot-gas drive system for TPA and TPCV testing.

The CY 1963 test program will continue to utilize this test position. Only moderate operating STE requirements are anticipated to accommodate test hardware configuration changes.

3. Test Stand C-8

This facility was constructed during CY 1962 to serve the non-nuclear, development test programs of the Generation II, Mod I and Mod IB Simulators.

Programmed for continued utilization during CY 1963, the stand will require additional STE installation. Of particular significance is the ejector systems which will provide turbine exhaust and main load-line simulator exit-pressure conditions comparable to those that will be experienced under the high altitude upper stage, start transient conditions of the NERVA engine. In addition, a special 500-gallon, start-transient vessel will be installed for accurate control of pump-suction pressures and inflow conditions.

A more detailed description of the STE requirements of test stand C-8 is presented with the other 5.1 requirements in Tables III - 5.1.1 and Table 5.1.2.

In comparing these requirements to those delineated in the negotiated contractual work statement (supplement 1 to Appendix B as revised November 6, 1963) for the Heated Bleed Program (NCS-208), only minor additions, deletions and other changes have been necessary to accommodate the Hot Bleed Program testing requirements. These include; service piping for the afore-described water cooled adapter required for diffuser testing, a change in the physical dimensions of the ejector systems suggested by data obtained through scale model testing recently completed, and finally the reduction in capacity of the C-8 run vessel from 3,000 gallons to 500 gallons due to test stand physical limitations. In addition, the X-Y plotter previously required for Zone C has been removed from Sub-task 5.1 and added to Sub-task 5.3 for Zone H. This change necessary to serve the needs of the test stand H-5 simulator test program. The net effect of these changes is an increase in estimated cost for this Sub-task.

B. Sub-Task 5.2, Test Zone "A" - Engineering Cryogenics Laboratory

The purpose of this sub-task is to provide continued design, procurement, fabrication, installation, and modification of Cryogenics Laboratory STE ^{DURING} CY 1963. A continued program of STE development for this laboratory facility is necessary to continue serving the numerous component development tasks. All systems are "state-of-the-art" in performance capabilities.

The Cryogenics Laboratory, under construction during CY 1962, will be utilized extensively during CY 1963. A continuing program of new equipment and systems installation is planned following the activation of this facility in January 1963. Specifically, individual test-bay STE is required to initiate and maintain the planned component development test programs. These include special test setups for: turbine power control valve, tank shutoff valve, turbo-pump suction line bellows, AGE purge and chill down unit, electrical control components and TPA hydrogen cooled main bearing. STE requirements anticipated for transducers, leak measurement apparatus, and metallics testing equipment are also programmed. The remaining STE required will be utilized for normal operating modifications to accommodate the varying hardware configurations. A detailed tabulation of STE required for this Sub-task is presented in Table III - 5.2. CY 1962 carryover effort is also delineated in this table.

Comparing these requirements to those previously submitted and negotiated for CY 1963, only minor additions, deletions, and other changes have been made. These include; reduction in the number of bearing testers required for the Cryogenics Laboratory from three to two, and increase in the number of bearing testers required for the radiation effects program, ^{INCLUDING} ~~to include~~ those needed in CY 1964 but requiring initiation of procurement during CY 1963, elimination of the gas generator assy. to be used in support of TPCV testing due to revised plans for conduct of tests in H-4A, and finally the addition of test bay activation and checkout as a discreet element of the CY 63 STE effort not initiated during CY 62 and therefore not included as a carryover item.

The changes described have resulted in an increase in the estimated cost for this sub-task.

C. Sub-Task 5.3. Test Zone "H" -- Test Stands H-4, 5, and 6

The purpose of this sub-task is to provide continued design, procurement, fabrication, installation, and activation of STE required in Test Zone H during CY 1963. The STE effort initiated and funded during CY 1962 will be accomplished. Thus, the STE described below augments that funded in Contract Year 1962 and is required to complete activation and permit operational utilization of the test zone.

NERVA non-nuclear test facilities in Zone "H" represent the primary LRP testing capability. During CY 1962 more than 60% of the basic Zone H construction was completed. However, before occupancy of Test Stand H-6 in mid-April 1963, on-stand piping, instrumentation, and control systems must be completed and final test bay installation and activation conducted.

Occupancy of Test Stand H-4 is scheduled in June 1963. Pressure fed nozzle tests with supersonic diffuser are planned. The diffuser configuration will be similar to that of test stand C-6, cylindrical with thru-flow tubular construction and a length-to-diameter ratio (L/D) of 6. Detailed theoretical analysis and study of empirical data available from other similar diffuser tests served as the basis for selecting this cylindrical configuration. The C-6 and H-4 diffusers will be fabricated to permit interchangeability with a minimum of modifications. The altitude pressure conditions attainable at the exit plane of the NERVA nozzle are equivalent to 60,000 ft.

The majority of STE required during CY 1963 is associated with the H-4 pressure-fed nozzle test system installation and modifications to H-5 for simulator testing. The latter installation includes relocation of the ejector systems located on Test Stand C-8, and the addition of a new RIFT-type run vessel (tank bottom only) for overhead mounting within the H-5 superstructure. The H-5 test stand will thus be equipped with RIFT interface configurations and have the capability of simulating altitude pressures for turbine exhaust and load line effluents.

In addition, a high pressure, continuous flow, hot hydrogen heat exchanger will be required. This system will provide hot GH_2 for use as a turbine-drive media for test-stand H-6 turbopump development testing.

The remaining required STE will be utilized for: (1) turbine power control valve testing on H-4A; (2) equipping the existing test shop with special hardware work platforms; (3) fabrication of a water-cooled nozzle adapter for diffuser testing applications; (4) relocation of the C-zone analog computer to the H-2 control room for use in conduct of simulator tests; and (5) normal operating test stand modifications to accommodate hardware configuration changes.

Table III - 5.3 presents sub-task STE requirements in detail.

Comparison of these requirements to those previously submitted and negotiated for CY 1963 reveals the following changes: a reduction in the number of gas generators required from three to two based upon revised testing requirements; the delineation of discreet STE requirements for VH 12 and VH 13 in place of the previous single item entry of "pressure fed nozzle test system"; the addition of the test stand H-5 simulator test system, including relocation of C-8 ejectors, installation of new 1,500 gal. RIFT type, start transient run vessel, relocation of analog computer from C to H Zones, installation of X-Y plotter for relocated analog computer, and the other mechanical and instrumentation/control systems attendant with this new test stand H-5 configuration; the addition of TPCV testing in test stand H-4A; the addition of a water coolant supply piping system for nozzle adapter; and finally the very significant addition of a hot hydrogen heat exchanger to the Zone H complex.

The net effect of these changes and new additions is a significant increase in the estimated cost of this sub-task.

D. Sub-Task 5.7 - Test Zone "G". Test Stand G-7

STE requirements for this sub-task are confined to CY 1962 carryover effort exclusively and are the same as those previously negotiated.

Design, procurement, fabrication, and installation activities have been initiated on the following carryover efforts:

1. Fabrication and installation of high-speed bearing test fixture.
2. Instrumentation system modification to accommodate high-speed bearing test fixture.

E. Sub-Task 5.8 - Bldg. 3308, Temperature Laboratory

The STE required during CY 1963 for this sub-task is confined to CY 1962 carryover effort exclusively, and are the same as those previously negotiated.

F. Sub-Task 5.9, Bldg. 2002 - Controls, Chemistry & Vibration Laboratories

The purpose of this sub-task is to provide design, procurement, fabrication, installation, and activation of various laboratory STE.

Continued utilization of LRP laboratory facilities in Building 2002 and in the SRP Test Area is planned for CY 1963. These facilities will continue to augment the capabilities provided by the Cryogenic Laboratory.

The nature of STE required within these laboratories is basically "operating STE" with certain modifications and additions to existing systems. The Controls Laboratory will require extension of existing LN₂ vacuum piping systems for supply of cryogenics to a specimen-conditioning test bench. Special environmental conditioning chambers for low-temperature test specimen study applications are also programmed for the Chemistry Laboratory. The planned vibration development test program will necessitate moderate modifications being made to existing SRP vibration laboratory equipment to accommodate the unique NERVA component configurations. In addition, instrumentation and controls STE for a turbine speed sensor development test setup, and a NERVA electrical component acceptance test set-up will be needed.

Table III - 5.9 describes in more detail the items of STE required by this sub-task including CY 1962 carryover efforts. These requirements are the same as those previously negotiated.

II. OTHER GOVERNMENT PROPERTY, TASK 6.0

Introduction

In addition to the STE described under Task 5.0, other items of government equipment are also required. This equipment is normally described as being "severable" and was designated during CY 1962 as GFE.

A. Sub-Task 6.1 - Test Zone H

CY 1963 requirements under this sub-task are confined exclusively to carry-over efforts from CY 1962. Engineering design, fabrication, and installation activities have been initiated on the following carryover item: design, fabrication, installation of a 82,000 SCFH, 5,000 psig, 30 HP, LN₂ pump and vaporizer unit. These requirements are the same as previously negotiated.

B. Sub-Task 6.2. Test Zone "H" - Engineering Cryogenics Laboratory

The purpose of this sub-task is to provide design, procurement, fabrication, and installation of government furnished equipment to complement and support STE installed in the Cryogenics Laboratory.

The Cryogenics Laboratory, essentially completed during CY 1962, will require additional equipment during CY 1963.

A variable-frequency power supply is needed for LH₂ bearing development testing. Bearings will be performance-tested in liquid hydrogen under simulated speed and load conditions. The STE bearing testers being provided under Sub-Task 5.2 will require 400 cycle, 3-phase power and variable speed control to obtain a complete spectrum of test conditions for development studies: E.G., cooling, lubrication, and overall performance characteristics of the bearings used in the NERVA liquid hydrogen turbo-pump assy.

In addition, mass spectrometers will be needed to detect leaks in hardware and workhorse test set-ups. The mass spectrometer leak detector, using helium gas as a detection media, has proven itself an efficient inspection instrument.

A spot-welder is required for attaching weldable strain gauges, thermocouples, and leads to surfaces which must be subjected to cryogenic temperatures. An additional use of the welder will be in the structural testing of lines, bellows, pumps and turbine housings, and frame members.

A "memory-type" oscilloscope will provide display of non-recurring or transient electrical phenomena. This equipment will allow better recording of test results, ~~that are presently unrecorded.~~

A low-frequency function generator will be used in testing the servo-controlled system components (e.g., TPCV and the gimbal actuator). This equipment will generate the signal necessary to drive the components under test conditions which simulate operational commands.

Residual gas analyzer equipment will be used during component testing for obtaining a quantitative measurement of hydrogen leakage. This unit will be capable of measuring leakage in the range of 1×10^{-6} cc/sec.

The special power supplies (each of 50 KW rating) will be required for operation and control of the special LH_2 heat transfer apparatus provided during CY 1962, under STE Sub-Task 5.2.

Removable patch boards, in addition to those provided during Contract Year 1962, will be needed to complete the overall instrumentation/control systems installation requirements now planned.

Table III - 6.2 tabulates the detailed equipment requirements of sub-task. These requirements are the same as previously negotiated except for the 1000 liter portable LH_2 vessel for supplying propellant to the materials conditioning containers. During negotiation a transfer piping system, extending from LH_2 run vessels within the Cryogenics Lab. complex to these containers, was included in lieu of the 1000 liter portable LH_2 vessel. Further examination of this system reveals the desirability of reinstating the original portable vessel and eliminating the comparable piping system. The net effect of this change is a slight increase in the estimated cost of this sub-task.

NERVA SPECIAL TEST EQUIPMENT (STE)

I. (AGC-LRP) TEST ZONE "C" - TEST STAND C-6

A. MECHANICAL

1. Fabricate and install nozzle/^{adapter}water coolant supply piping system.
2. Continuing test setup modifications to accommodate test hardware configuration changes.

B. INSTRUMENTATION AND CONTROLS

1. Continuing test setup modifications to accommodate test hardware configuration changes.

II. (AGC-LRP) TEST ZONE "C" - TEST STANDS C-7, C-8

A. MECHANICAL

1. Fabricate and install one LO_2/LH_2 Gas Generator Assembly.
2. Fabricate and install 48 x 48 two stage, main load line, ejector.
3. Fabricate and install 36 x 36 two stage, turbine exhaust line, ejector.
4. Fabricate and install GN_2 piping, including valves, regulators and flanges.
5. Fabricate and install ejector horizontal support structure and work platforms.
6. Fabricate and install special ducting to adapt between simulator interface and ejector inlet.
7. Fabricate and install special 500 gallon, LH_2 simulator, start transient vessel.
8. Fabricate and install vessel fill, vent, pressurization and deluge systems.
9. Modify existing test stand superstructure and simulator handling system.
10. Activation of ejectors and simulator start transient run vessel.
11. Continuing test setup modifications to accommodate test hardware configuration changes.

B. INSTRUMENTATION AND CONTROLS

1. Procure and install electrical controls for ejector and simulator start transient run vessel.

2. Fabricate and install liquid level sensing probe for simulator run vessel.
3. Procure and install transducers for simulator start transient run vessel.
4. Activation of ejectors and simulator start transient run vessel.
5. Continuing test setup modifications to accommodate test hardware configuration changes.

CONTRACT YEAR 1962 CARRYOVER EFFORT

5.1.1 Test Stand C-6 Mechanical STE

- (1) Complete modifications to existing STE, and fabrication and installation of propellant, deluge, and purge piping systems.

5.1.5 Test Stands C-7, C-8 Mechanical STE

- (1) Complete fabrication and installation of test stand superstructure and associated piping and mechanical systems.

5.1.7 Test Stand C-7 Instrumentation and Control STE

- (1) Complete electrical control system installation and checkout.

III. (AGC-IRP) TEST ZONE "A" -- ENGINEERING CRYOGENICS LABORATORY

A. MECHANICAL

1. Fabricate and install two high speed bearing testers and one spare motor for Cryo. Lab. **and ten high speed bearing testers for radiation effects program**
2. Fabricate and install environmental chamber for high and low temperature conditioning.
3. Fabricate and install special hardware test carts and fixtures.
4. Fabricate and install tank shutoff valve test system including; tank, lines and valves.
5. Fabricate and install turbine power control valve cold flow test system.
6. Fabricate and install LH₂ piping system from portable trailer to test specimen conditioning chambers.
7. Fabricate and install side by side hardware checkout and test setup.
8. Test bay activation and checkout.
9. Continuing test setup modifications to accommodate test hardware configuration changes.

B. INSTRUMENTATION AND CONTROLS

1. Transducers, including torque, pressure, position and temperature measuring.
2. Procure and install special leak measurement apparatus.
3. Procure and install wiring and controls for electrical component testing.
4. Test bay activation and checkout.
5. Continuing test setup modifications to accommodate test hardware configuration changes.

CONTRACT YEAR 1962 CARRYOVER EFFORT

5.2.1 Cryogenics Laboratory Mechanical STE

- (1) Complete fabrication and installation of hydrogen burnoff stack.

5.2.2 Cryogenics Laboratory Mechanical STE

- (1) Complete fabrication and installation of special LH₂ containers for conditioning specimens to cryogenic temperatures.
- (2) Complete fabrication and installation of Special cryogenic heat transfer test apparatus.

5.2.3 Cryogenics Laboratory Instrumentation and Control STE

- (1) Complete fabrication, installation, activation and check-out of data acquisition system.
- (2) Complete fabrication and installation of LH₂ run vessel liquid level sensing system.

IV. (ACC-LRP) TEST ZONE "H" - TEST STANDS H-4, 5, AND 6

A. MECHANICAL

1. Fabricate and install special work platforms in the Test Zone H shop.
2. Fabricate two LO_2/LH_2 Gas Generator Assemblies.
3. Modify existing VH-13 inner vessel supporting structure and test stand mounting fixtures.
4. Fabricate and install LH_2 discharge and GN_2 pressurization systems for Vessel VH-12.
5. Fabricate and install LO_2 discharge and GN_2 pressurization systems for Vessel VH-13.
6. Fabricate and install hydraulic supply system for flow control valves, including pump, piping and valves.
7. Remove and reinstall ejectors from Test Stand C-8 to Test Stand H-5.
8. Fabricate and install special work platforms for CFDIS and ejector test system including ejector supporting structure.
9. Fabricate and install 1500 gallon, LH_2 start transient, run vessel.
10. Fabricate and install fill, vent and pressurization systems for 1500 gallon LH_2 vessel.
11. Fabricate and install ejector GN_2 piping system including valves, regulators, and flanges.
12. Fabricate and install special ducting to adapt between simulator interface and ejector inlet.
13. Fabricate and install a hot hydrogen heat exchanger, including heating source. (10#/sec. 1760°R)
14. Fabricate and install heat exchanger supply and distribution piping.
15. Fabricate and install special turbine power control valve test fixture including hot gas supply and carry off ducting.
16. Fabricate and install nozzle adapter, water coolant supply piping system.
17. Test Zone "H" Facility Activation.
18. Continuing test setup modifications to accommodate test hardware configuration changes.

B. INSTRUMENTATION AND CONTROLS

1. Fabricate and install additional drop boxes and electrical controls for Vessel VH-12 and TPCV test system.
2. Fabricate and install the ejector and simulator vessel electrical control systems.
3. Remove and relocate analog computer from Test Zone "C" to Test Zone "H".
4. Procure and install analog computer checkout equipment.
5. Procure and install an X-Y plotter for pre-checking function generators on the analog computer.
6. Fabricate and install liquid level sensing probe for simulator start transient vessel.
7. Procure and install electrical controls for hot hydrogen heat exchanger (10#/sec. 1760°R).
8. Test Zone "H" facility activation.
9. Continuing test setup modifications to accommodate test hardware configuration changes.

CONTRACT YEAR 1962 CARRYOVER EFFORT

5.3.4 Test Zone "H". Mechanical STE

- (1) Complete fabrication and installation of the following:
 - (a) GH₂ piping and components
 - (b) Diffuser positioning equipment and support structure
 - (c) Hardware handling system
 - (d) Hydraulic supply system
 - (e) Necessary LH₂ piping system components

5.3.5 Test Zone "H". Mechanical STE

- (1) Diffuser and Engine Chamber Vessel

5.3.7 Test Zone "H". Instrumentation and Controls STE

- (1) Design, fabrication and installation, activation, and checkout of Test Zone H Instrumentation and Control System.

V. (AGC-LRP) TEST ZONE "G" - TEST STAND G-7

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5.7.1 Test Zone G Mechanical STE

- (1) Complete fabrication and installation of high speed bearing test fixture.

5.7.2 Test Zone G Instrumentation and Controls

- (1) Complete instrumentation system modifications to accommodate high speed bearing test fixture.

TABLE III - 5.8-1
15 November 1962
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VI. (AGC-LRP) - BLDG. 3008, TEMPERATURE LABORATORY

CONTRACT YEAR 1962 CARRYOVER EFFORT

5.8.2 Bldg. 3308 - Temperature Lab. Instrumentation & Controls
STE

- (1) Complete fabrication, installation and activation of
special temperature sensor calibration cryostat.

VII. (ACC-IRP) MISCELLANEOUS NON-TEST-AREA LABORATORIES

A. MECHANICAL

1. Fabricate and install LN₂ piping extension for low temperature conditioning (Electrical Lab.).
2. Fabricate and install environmental conditioning chamber (Electrical Lab.).
3. Fabricate and install special vibration equipment and fixtures (SRP Vibration Lab.).
4. Continuing test setup modifications to accommodate test hardware configuration changes (All Labs.).

B. INSTRUMENTATION AND CONTROLS

1. Fabricate and install speed sensor test setup (Electrical Lab.).
2. Fabricate and install electrical components acceptance instrumentation (Electrical Lab.).
3. Continuing test setup modifications to accommodate test hardware configuration changes (All Labs.).

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5.9.1 Controls and Chemistry Laboratory Mechanical STE

- (1) Complete fabrication and installation of gimbal test setup fixture.

5.9.2 Controls and Chemistry Laboratory Instrumentation and Controls STE

- (1) Complete fabrication and installation of required instrumentation for gimbal test setup.

TABLE III - 6.1-1
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NERVA OTHER GOVERNMENT PROPERTY
(FORMERLY GOVERNMENT FURNISHED EQUIPMENT)

I. (ACC-LRP) TEST ZONE "H"

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6.1.1 Test Zone H Mechanical GFE

- (1) Complete design, fabrication, installation and activation of a 82,000 SCFH, 5000 psig, 30 HP, LN₂ pump and vaporizer unit.

NERVA OTHER GOVERNMENT PROPERTY

II. (AGC-LRP) TEST ZONE "A" -- ENGINEERING CRYOGENICS LABORATORY

A. MECHANICAL

1. Fabricate and install LN₂ distribution piping system extension to environmental chambers.
2. Procure and install 1000 liter portable LH₂ vessel for supplying propellant to the material conditioning containers.
3. Fabricate and install a humidity conditioning chamber.

B. INSTRUMENTATION AND CONTROLS

1. Procure and install variable frequency power supply for the electrical drive, bearing testers.
2. Procure and install two mass spectrometer leak detectors.
3. Procure and install oscillogram scanner.
4. Procure and install precision voltmeter.
5. Procure and install strain gage indicator, frequency converter, five power supplies, electrical spot welder, oscilloscope, low frequency function generator, and residual gas analyzer.
6. Procure and install two power supplies for operation of heat transfer apparatus.
7. Provide removable patch boards.

CONTRACT YEAR 1962 CARRYOVER EFFORT

6.2.2 - Test Zone A - Cryogenic Laboratory, Instrumentation and Controls.

- (1) Complete procurement and installation of all required signal conditioning and recording equipment.