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TEST CELL C

SINGLE TURBOPUMP MODIFICATION

BASIS FOR DESIGN

C F BRAUN & CO

EG&G, INC

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MASTER

TEST CELL C
SINGLE TURBOPUMP MODIFICATION
BASIS FOR DESIGN

PREPARED FOR
SPACE NUCLEAR SYSTEMS OFFICE

BY

C F BRAUN AND COMPANY and EG&G, INCORPORATED

230 12-11
SEPTEMBER
1971

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REVISION SHEET

BASIS FOR DESIGN

Date	Revision No.	Change and Authorization	Approved For Release

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Section 1 SCOPE

This document defines the basis for design of modifications to Test Cell "C", NRDS, for the purpose of NERVA Single Turbopump Development. It is intended to be consistent with the basis in Facilities Requirements Document, F004-CP091149-G1, and in conjunction with referred standards, provides the basis for designing the piping, instruments, controls, etc, required to accommodate a NERVA Turbopump Assembly (TPA) in Test Cell "C". A cross-section of the NERVA TPA is shown as Figure 1.

Section 2. APPLICABLE DOCUMENTS

2.1 Government Documents.- The following documents, of the exact issue shown, form part of this specification to the extent specified herein. In the event of conflict between referenced documents and detailed requirements of Section 3 and 4, request for resolution shall be submitted to the government.

SPECIFICATION

Military

MIL-E-6051D	7 Sept 1967	Electromagnetic Capability Requirements, Systems
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STANDARDS

Military

MIL-STD-100A	1 Oct 1967	Engineering Drawing Practices
MIL-STD-130C	29 Sept 1967	Identification Marking of U.S. Military Property
MIL-STD-143A	14 May 1963	Specifications and Standards, Order of Precedence
MIL-STD-171B	16 Mar 1965	Finishing of Metal and Wood Surfaces
MIL-STD-1646A	18 Aug 1967	Product Cleanliness Levels and Contamination Control Program
MS-33586A	16 Dec 1958	Metals, Definition of Dissimilar

National Aeronautics And Space Administration

NHB-1700.1 Vol I & III	July 1969	NASA Safety Manual
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Space Nuclear Propulsion Office

FEO-1	Oct 1970	NERVA Facility Structural Design Standards
FEO-2	Aug 1970	NERVA Facility Seismic Design Standards
FEO-3A	Sept 1971	NERVA Facility Engineering & Design Standards
SNPO-C-4 Revision 1	Sept 1969	Quality Assurance Requirements For Facility and Ground Support Equipment
NRDS-STD-101	April 1967	Electrical/Electronic Workmanship Standards Manual

SECTION 2. APPLICABLE DOCUMENTS

STANDARDS Continued

Atomic Energy Commission

AEC Manual	(latest	Health and Safety
Part 1500	issues)	

2.2 Other Publications.— The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between referenced documents and detailed requirements of Section 3 and 4, request for resolution shall be submitted to the government.

American Welding Society

AWS A2.0-68	Standard Welding Symbols
AWS A3.0-61	AWS Definitions, Welding and Cutting

American Institute of Steel Construction

Specification for the Design, Fabrication and Erection
of Structural Steel for Buildings February 12, 1969

American Society of Mechanical Engineers

ASME Boiler and Pressure Vessel Code

Section III 1968	Nuclear Vessels
& Summer Addenda 1968 & 1969	

Section IX 1968	Welder Qualifications
& Summer Addenda 1968	

American National Standards Institute

USAS C1-1968 National Electric Code (NFPA-70-1968)
ANSI B31.1 Power Piping
ANSI B31.7 Nuclear Power Piping

Other

"Shock and Vibration Handbook" by Harris and Crede, Volume III, (McGraw-Hill 1961)

"Stresses in Skin Panels Subjected to Random Acoustic Loading" by Brian L. Clarkson, Institute of Sound and Vibration Research, University of South Hampton, dated June 1967

"Wind Forces and Structures," ASCE Paper No. 3269, Transactions of The American Society of Civil Engineers, Vol. 126, 1961

"The CSI Format for Construction Specifications," The Construction Specifications Institute, 1964

2.3 Aerojet Nuclear Systems Company Documents.- The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents and detailed requirements of Sections 3 and 4, request for resolution shall be submitted to the government.

PUBLICATIONS

NTO-SOP-0047	14 Dec 1965	Compatible Lubricants, Sealants, Gaskets, Cleaning Fluids and Materials at ETS-1
EC90149A		Performance/Design and Qualification Requirements for Turbopump Assembly
F004-CP091149-G1		Test Cell "C" NERVA Turbopump Development, Facility Requirements

DRAWINGS

1139290	Turbopump Dimensional Envelope
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Section 3 Requirements

3.1 Performance.-

3.1.1 Functional Characteristics.-

3.1.1.1 Primary Performance Characteristics.-

3.1.1.1.1 Test Support Systems Performance.- The modifications to Test Cell C shall be designed to achieve the results described below.

(a) Permit the turbopump to be operated at any point within the Mechanical Design Limit Envelope shown on Figure 2, Predicted Pump Performance Map of ANSC Document F004-CP091149-G1. Operational information to be used for the facility design is provided in Tables I through VI and Figures 2, 3, and 4. Tables I through VI give the predicted operating conditions at the designated engine operating points. This information has been reprinted from the Turbopump Specification EC 90149A. Figures 2, 3, and 4 show the turbine operating conditions which correspond with the three points shown on Figure 2 of ANSC Document F004-CP091149-G1 as the corners of the mechanical design limit envelope. These were generated for various possible turbine inlet temperatures. The facility designer shall select those conditions which most severely impact on the facility as a basis for facility design.

(b) The facility should be capable of simulating as closely as possible the startup and shutdown transients defined in the Turbopump Specification ED 90149A. The transients are shown in Figures 8 through 55 of that document.

(c) The pump suction fluid conditions will be controlled using the fluid conditioner located in the suction line. The fluid conditioner should be similar to the one used in the LH₂ Pump Component Development Program in the Electric Pump Room at Test Cell C.

(d) There is no requirement to investigate the performance of a turbopump during the transient from engine normal mode operation to single turbopump mode operations.

3.1.1.1.1 Test Support Systems Performance Continued

(e) The following maximum operating pressures have been used in the design of the various turbopump housings:

- (a) Pump Inlet 100 psig @ 40°R
- (b) Pump Discharge 1850 psig @ 60°R
- (c) Turbine Inlet 1450 psig @ 285°R
- (d) Turbine Exhaust 1450 psig @ 285°R

The facility design pressures should in all cases be equal to or greater than these values.

(f) The required flow schematic for turbopump testing in Test Cell "C" is shown in Figure 5. Liquid hydrogen will be provided to the pump from Dewar 1 or 2. The pump inlet line must contain a fluid conditioner as well as provisions to conduct chilldown tests. Valves OBV-1 and C-1 allow the turbopump to be isolated while the facility is being chilled down through valves OBV-2 and C-2. During the chilldown of the pump, low flow rates (zero to five pounds per second) can be measured by diverting suction flow through valve ACV-1 and measuring the flow through a turbine type flowmeter, F-1.

The pump discharge line has a turbine type flowmeter, F-2, to measure pump discharge flow rate. A portion of the pump discharge flow is diverted to a catch dewar through valve L-90. Another turbine type flowmeter, F-3, is utilized to measure the flow supplied to the turbine after bootstrap operation has been established. Flowmeter F-3 may also be used in conjunction with flowmeter F-2 to establish the flow being discharged through valve L-90. At operating points where the flow through valve L-90 is small and needs to be measured with more accuracy than can be obtained by using the difference between F-2 and F-3, it may be diverted through ACV-6 instead of L-90 and measured directly with F-5.

The existing Turbine Energy Source will be utilized to provide the required energy input to the turbine drive fluid. The temperature conditioning of the turbine drive gas will be accomplished by mixing LH₂, bypassing the TES with conditioned H₂ exiting from the TES. Initial turbine drive gas will be provided from the existing tank farm through valve H-53. Check valves C-3 and HC-2043 prohibit turbine drive gas from flowing into the pump discharge system during startup. Vent valves OBV-3 and H-101 are used to chill down the facility prior to turbopump operation.

3.1.1.1.1 Test Support Systems Performance Continued

Turbine inlet pressure is controlled by valve ACV-4. The turbine flow rate during initial operation is measured using flow venturi F-4. Valve OBV-4 is required to shut off turbine flow in the event of a turbopump or system malfunction. The turbine back pressure is controlled by valve ACV-5.

(g) The turbopump does not have provision to be effectively purged by use of a sweep purge. It has been designed to utilize the planned purge sequence of the engine, which is to be several repeated cycles of alternately pressurizing and evacuating the system. This method will have to be used prior to operation of the turbopump during development testing as well as on the engine.

3.1.1.1.2 Instruments and Controls Performance.-

3.1.1.1.2.1 Measurement/Transducer Characteristics.- The measurement/transducer requirements associated with the New Facility additions and the Turbopump Assembly (TPA) are shown in Table VIII through XIX inclusive. Table XX is a tabulation of the required existing facility parameters. They must be considered during the facility design stage. Table XXI is a summary of the measurement parameters listed in the foregoing figures. The measurement/transducer requirements are detailed by the following paragraphs:

(a) Pressure Transducer - The pressure transducer shall be of the self-contained temperature compensated, gage type transducer. The transducer combined hysteresis and linearity shall be less than 0.35 percent of Full Scale output. The resolution shall be infinite with a repeatability within 0.1 percent of Full Scale output. The sensitivity of the transducer shall be greater than 2.5 mv/v. The excitation power shall be a nominal 10VDC.

The measurement bandwidth shall be less than 8 Hz except as noted in Table VIII, Pressure Measurement Requirements - New Facility and Table IX, Pressure Measurement Requirements - TPA.

Twelve of the pressure measurements require an overall channel accuracy within ± 0.2 percent of Full Scale. The high accuracy channels and their associated transducers have not yet been identified.

The transducers shall not be mounted directly on the measurement point but shall be remoted from the measurement point via sense line tubing. The length of the sense line tubing shall be such as not to impede the required bandwidth of the measurement.

3.1.1.1.2.1 Measurement/Transducer Characteristics Continued

Pressure transducer installation shall be such that any one transducer may be placed in an operational mode, in place calibrated or removed without disturbing any other operating transducer.

Table VIII, Pressure Measurement Requirements - New Facility and Table IX, Pressure Measurement Requirements - TPA are a tabulation of the pressure measurement parameters.

(b) Resistance Thermometer Transducer (RTT) - The RTT's shall be of the platinum resistance type with an ice-point calibration accurate to $\pm 0.04^{\circ}\text{C}$. The RTT shall repeat calibration at the ice-point within $\pm 0.1^{\circ}\text{C}$. The transducer case shall be internally wired to accommodate a four wire circuit.

Twelve of the temperature measurements require an overall channel accuracy within $\pm 0.2^{\circ}\text{R}$. These high accuracy channels and their associated transducers have not as yet been identified.

Table X, Temperature Measurement Requirements - New Facility and Table XI, Temperature Measurement Requirements -- TPA, are a tabulations of the temperature measurement parameters. It should be noted that in Table XI some of the temperature transducers will be supplied by the Test Article (TPA) Supplier.

(c) Accelerometer Transducer - The accelerometer transducers shall be compatible with a cryogenic environment. Their intelligence frequency response shall be within 5 percent into a 100 M-Ohm load and their mounted frequency response shall be in excess of 30 KHz. The transducer charge sensitivity shall be 2 pk pc/pk g or greater with a transverse sensitivity less than 5 percent. The amplitude linearity shall be ± 1 percent or better over the range and frequency of interest. Table XII, Accelerometer Measurement Requirements - New Facility is a tabulation of the accelerometer measurement parameters associated with the New Facility additions. All of the accelerometer ranges are ± 50 Gpk at 1000 Hz bandwidth.

Table XIII, Accelerometer Measurement Requirements - TPA, is a tabulation of accelerometer measurement parameters associated with the Turbopump Assembly. All of the accelerometer ranges are ± 50 Gpk at 5 KHz bandwidth.

(d) Displacement, Stem Position Contacting Transducers - The transducers for the displacement and stem position measurements, which are in physical contact with the parameter to be measured, shall be of the linear motion potentiometer type. Their resistance shall be 1000 Ohms where the stroke length will permit and a power rating of 1 W/in. The linearity shall be ± 0.5 percent or better. The stroke velocity shall be as required to ensure the attainment of the intelligence bandwidth of the respective channel. The transducers used for the displacement measurements may be dual element units. The transducers used for the stem position measurements shall be dual element units with six wires extending from the case. The transducers shall have infinite resolution.

Table XIV, Displacement Measurement Requirements - New Facility and Table XV, Stem Position Measurement Requirements - New Facility are a tabulation of the displacement measurement requirements associated with the New Facility additions.

(e) Displacement, Non-Contacting Transducers - The transducers that are to be used to make a non-contacting measurement of distance shall be Kaman-Nuclear UNI-VIT system, Model K-2011. The transducers and their associated electronics shall be supplied by the Test Article Supplier. Table XVI, Displacement Measurement Requirements - TPA is a tabulation of the non-contacting displacement measurement requirements associated with the TPA.

(f) Strain Gage - The strain gages shall be compatible with a cryogenic environment. The size, shape, configuration, resistance, and other characteristics of the gages are dependent upon the particular application that the unit will be subjected to within the New Facility.

Table XVII, Strain Measurement Requirements - New Facility is a tabulation of the strain measurement parameters associated with the New Facility.

(g) Flow Transducers (Meters) - The flow meters shall be compatible with a cryogenic environment. The turbine type flow meters shall be capable of flow measurements of 1 percent or better and the venturi type shall be capable of measurements of 2 percent or better.

Table XVIII, Flow Measurement Requirements, is a tabulation of the flow measurement parameters associated with the New Facility.

(h) Speed Transducers - The transducers that are to be used to make a RPM measurement shall be supplied by the Test Article Supplier. The output of the speed transducers is a wave train whose frequency is proportional to pump shaft RPM. Table XIX, Speed Measurement Requirements - TPA, is a tabulation of the speed measurement parameters associated with the TPA.

3.1.1.1.2.2 Controls Characteristics - The required controls shall consist of both binary and analog controls. The modes of operation which the Control System shall provide are Pump Speed, pump Discharge Pressure, Pump Q/N, Turbine Drive Temperature, and Turbine Pressure Ratio. The Control requirements associated with the New Facility are shown in Table XXII, Preliminary Valve Operating Requirements and in Table XXIII, Preliminary Valve Controller Requirements.

The control requirements are detailed by the following paragraphs:

(a) Actuator - The actuator shall be of the electro-hydraulic type operating with up to 3000 psig hydraulic pressure and responding to a 1 to 5 milli-amp DC signal.

(b) Remote Controller - The remote controller shall be electronic capable of responding to an input signal up to 100 DC and shall present a balanced load to the source. The output signal shall not exceed ± 10 VDC with an output impedance of 1000 ohms or less.

(c) Local Controller - The local controller shall respond to an input signal up to 100 VDC. The output shall be 1 - 5 milli-amp DC for full scale control mode.

(d) Meters - Operation of the control loop requires the feedback and auto demand signal to be displayed on meters as well as the valve closed limit, mode error signals and stem position. The meter accuracy shall be ± 1 percent of full scale. A total of five meters shall be installed on any given panel.

(e) Shutdown Chain - The shutdown chain shall be capable of terminating the test if any one of a number of predetermined limits is exceeded. The shutdown chain shall consist of multiple high speed comparators for rapidly varying parameters and shall contain slower response comparators for the slow response signals. The shutdown chain shall have the capability to override selected parameters and control valve circuits displaying the status of each parameter. The chain shall also contain interlock circuits which will require specific conditions to be established prior to reset. The response time of the chain shall be less than 2 milliseconds from time of detected malfunction to actual command.

3.1.1.1.2.2 Controls Characteristics Continued

(f) Run Profile Generation - An automatic control set point generation capability, that satisfy the F-004-CP091149-G1 profile plots, shall be provided. These profiles will be used to control selected loops during the program mode of operation. The non-linearity introduced into the controller by the set point generator must not exceed ± 1 percent.

The required performance parameters shall permit operation anywhere within the mechanical design limit envelopment shown on the Predicted Pump Performance Map included in the F-004 document.

3.1.1.1.2.3 Data Recording Characteristics - The data recording requirements, as shown in Table 11 of the F-004 document, are preliminary in nature but characteristic of the type that will be required. The recording requirements are detailed by the following paragraphs:

(a) Strip Chart Recorders, Multi-Channel - The multi-channel strip chart recorder shall contain at least eight non-overlapping channels. The paper speeds shall be varied and selectable. The frequency response shall be at least 40 Hz. The input impedance shall be greater than 100K ohms either side of ground.

(b) Strip Chart Recorder, Single Channel - The single channel strip chart recorder shall be equipped with multi-range input, multi-speed chart transport, full range zero set, electric pen lift, event marker and synchronous motor chart drive. The chart paper shall have a writing width of 8 inches or greater. The response time shall be one-half second or less for full scale deflection. The input impedance shall be 100K ohms either side to ground.

(c) Oscillograph - The oscillographic recorder shall be multi-channel, multi-speed, and shall be equipped with a trace identifier, event marker and a development lamp. The frequency response shall be 10 KHz or greater. The input impedance shall be 100K ohms single ended.

(d) X-Y Plotter - The X-Y Plotter shall be equipped with multi-range input and multi-range time sweep. The plotter shall have a minimum input impedance of 200 K ohm/volt and a slewing speed of 20 inches/second.

3.1.1.1.2.3 Data Recording Characteristics Continued

(e) Magnetic Tape Recorder - The magnetic tape recorder shall be a 14 track recorder utilizing 1-inch magnetic tape, 1-mil thick. The direct record electronics and the FM electronics shall conform to IRIG standards.

(f) Meters - The display meters shall have a meter accuracy of ± 1 percent of full scale.

(g) Oscilloscopes - The oscilloscope shall be a 1 MHz dual-beam type capable of differential or single-ended inputs for dual beam or single beam X-Y display as well as dual beam or single beam time-based displays.

(h) Dynamic Analysis System - The dynamic analysis system shall have a useful frequency range of 1 Hz to 50 KHz. Two outputs per channel are required. One output shall provide amplitude versus frequency information; the other output shall measure the phase relationship between the input signal and a reference signal. The analyzer shall be capable of providing this information on-line.

3.1.2 Operability.-

3.1.2.1 Reliability.- In assessing facility reliability, a primary discipline shall be to choose the most reliable procurable components. Facility systems shall be engineered so that any plausible malfunction will not preclude safe securing of the facility system whether the malfunction or failure occurs during startup, operation or shutdown of a test. The design goal of the system, subsystems, component and parts shall be to eliminate all potential failures including:

(a) Piping or structural failures which would result in uncontrolled release of LH_2 , GH_2 or high pressure N_2 to the pump test room or adjacent areas.

(b) Control system failures that might result in destruction or damage of the turbopump due to overspeed or other causes.

(c) Faulty safety devices or erroneous signals that could mislead operating personnel as to the true conditions existing in the test facility.

3.1.2.2 Maintainability.-

3.1.2.2.1 Maintenance and Repair Provisions.- Routine access to the test cell will be permitted after the LH₂ dewars have been secured, the test system purged and tested free of hydrogen, and the nitrogen inerting gas replaced with air. The modification design shall permit maximum utilization of the existing building crane for removal of the turbopump or components of the piping system. Assembly and disassembly of the turbopump will be performed in existing facilities located at NRDS.

3.1.2.2.2 Maintenance Access.- Modifications to Test Cell C shall be designed to permit maximum access of personnel to the turbopump test position and its associated piping to facilitate maintenance operations.

3.1.2.3 Useful Life.- When operating within the mechanical design limit envelope shown in Figure 2, the Test Cell Systems shall be designed for a minimum of 1000 pump tests, including cooldowns, startups, shutdowns, and warmups. The duration of each pump test at steady or variable operating conditions shall be taken as thirty minutes. This requirement shall be demonstrated by analysis for uniquely designed components, and by appropriate test or experience data for off-the-shelf hardware.

3.1.2.4 Environmental.- All facilities shall be capable of withstanding environments listed in Table VII throughout their useful life.

3.1.2.4.1 Wind.- All aboveground structures shall be designed to resist wind forces as prescribed in ASCE Paper No. 3269, "Wind Forces on Structures," using a 50 year basic wind velocity of 80 mph.

3.1.2.4.2 Seismic Loads.- The design of equipment and equipment supports shall be in accordance with FEO-2. In applying FEO-2 to the design and analysis of this facility, all liquid hydrogen, and high-pressure gaseous nitrogen, hydrogen and helium systems shall be considered to be "critical" systems. Refer to Subsection 1.03 of FEO-2. Since time-history data are not available for the Test Cell "C" area, seismic effects shall be determined using spectral analysis methods.

3.1.2.5 Transportability.- The transportability of each component to a facility for assembly and installation shall be a design constraint.

3.1.2.6 Human Performance.- All functions required for conducting a turbopump test shall be performed remotely from the Test Cell "C" control center.

3.1.2.7 Safety. - To the maximum practical extent, all facility equipment and systems shall be designed so that no single failure or credible combination of errors, malfunctions or accidents can cause personal injury, and/or facility destruction, facility damage, test article or test data loss, in the order of priority. Fail-safe features shall be incorporated. Fail positions shall be such as to maintain the safest possible configuration for the total system. (i.e. Category III or IV hazard conditions as defined in 3.1.2.7.2 shall be precluded from designs to the maximum practical extent).

3.1.2.7.1 Order of Preference. - Actions for satisfying the above criteria shall be in the following order of preference.

(a) Design for Minimum Hazard - Maximum practical effort shall be made during all phases of design to ensure the optimum degree of inherent safety through the selection of appropriate design features and qualified components.

(b) Safety Devices - Known hazards which cannot be eliminate by design selection shall be reduced where possible to an acceptable minimum through use of appropriate safety devices as part of the system, subsystem, or equipment.

(c) Warning Devices - For those instances where it becomes impossible to preclude occurrence of a known hazardous condition, appropriate devices shall be employed for detection of the condition and generation of an adequate warning signal.

(d) Special Emergency Procedures - For those instances where design consideration or use of safety and warning devices fail to reduce the magnitude of a known or potential hazard to an acceptable level, special emergency procedures shall be developed. These procedures shall include identification of the hazardous period time span, actions required if such hazards occur, and, where applicable, special operating procedures to reduce possibility of occurrence.

3.1.2.7.2 Hazards Categories. - Hazardous conditions shall be categorized in accordance with the following criteria:

(a) Category I - Negligible Condition(s) such that personnel error, environment, design characteristics, procedural deficiencies, or subsystem or component malfunction will not result in damage or personnel injury.

(b) Category II - Marginal Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction which can be counteracted or controlled without major damage or any injury to personnel.

3.1.2.7.2 Hazards Categories Continued

(c) Category III - Critical Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem, or component malfunction will cause major equipment damage or personnel injury, or will result in a hazard requiring immediate corrective action for personnel or system survival.

(d) Category IV - Catastrophic Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will severely degrade system performance and cause subsequent system loss, or death or severe injuries to personnel.

3.1.2.7.3 Safety Standards. - The design of facility equipment and systems shall comply with AEC Manual Part 0500 and NHB-1700.1 Vol I and Vol III.

3.2 Test Support Systems Definition. -

3.2.1 Interface Requirements. -

3.2.1.1 Schematic Arrangement. -

3.2.1.1.1 Test Support Systems Schematic Arrangement. -

The schematic arrangement of the test support systems is shown as Figure 5. Existing piping, valves, and equipment are shown with light lines. New piping, valves and equipment are shown with heavier lines.

Preliminary isometric drawings of the proposed piping layout are shown as Figures 6 and 7. It will be the responsibility of the Design Contractor to verify the layout by detailed design and stress analysis.

3.2.1.1.2 Instrument and Controls Schematic Arrangement. -

(a) The instrumentation boss locations and/or transducer installation points for the New Facility are shown graphically in Figure No.'s 9 and 10.

(b) Figure No. 11 is a typical one-line diagram showing interface mechanics between the New Facility and TPA, and the existing Instrumentation and Controls System.

3.2.1.2 Detailed Interface Definition. -

3.2.1.2.1 Test Support System Detailed Interface Definition.-

The turbopump/facility interfaces will occur at the turbopump trunnion mount and at the turbopump flanges at the pump inlet, pump discharge, turbine inlet, and turbine exhaust. The seals and fasteners for the interface flanges will be provided by the facility.

The location and sizes of the turbopump/facility interfaces are shown in Figure 7. This information is taken from ANSC Drawing 1139290 and represents the orientation required of the turbopump contained in the #2 Turbopump Assembly and Valves Module on the "E" Engine configuration.

(a) Fluid Conditions Due to the complicated nature of the operation of a turbopump, the required fluid conditions at the interfaces cannot be readily specified as singular values which may be used as design requirements. The operating conditions including fluid interface conditions are specified in Section 3.1 for all of the important operating points. The requirements for any given portion of the facility design activity must be carefully selected from the conditions given in Section 3.1 to assure that the requirements used truly govern that portion of the design.

(b) Critical Components The facility components which attach directly to the turbopump must exert very specific loads on the turbopump. For this reason, the design of the turbopump mounting frame and the lines attached to the turbopump will be provided by the Test Article Supplier. The fabrication of these components and any detailed design package required for fabrication will be provided by the facility.

(c) Critical Piping Interfaces Flanged connections will be used between the critical piping sections and the balance of the facility piping. The design of these flanges will be provided by the Test Article Supplier. The allowable forces imposed on these flanges will be specified by the Test Article Supplier.

(d) New/Existing Interfaces The interfaces between the new and existing facility piping are shown schematically on Figure 5. The approximate physical location of the interfaces are shown on Figures 6 and 7. Verification of the exact physical location of these interfaces is the responsibility of the design contractor.

3.2.1.2.2 Instrumentation and Controls Detailed Interface Definition. - The equipment required to sense the physical stimuli, control the New Facility and TPA, provide for performance evaluations, shall conform to the following functional requirements:

(a) Excitation Power - The transducer excitation power in the case of constant voltage shall not exceed 28 VDC. In the case of constant current, the current shall not exceed 2 milli-amps DC.

(b) Output Signal - The full scale output signal generated by the transducer may be of any wave shape and up to 10 KHz and between 10 milli-volts and 10 volts or between 1 milli-amp and 50 milli-amps.

(c) Data System Interface - Signals of 10 KHz or less and not generated by a capacitive or an inductive source shall be carried by either two or four conductor shielded cables and will enter the Data System via a cross-connect rack. Output signals greater than 10 KHz and/or generated by capacitive or an inductive source shall be carried by co-axial type cable and will enter the Data System directly and terminate at the input to the signal conditioning equipment.

(d) Controllers - The controller chassis shall have sufficient flexibility in the basic electrical and mechanical design to permit adaptation to any of the automatic control subsystems by means of plug-in subassemblies with relatively simple wiring modifications.

3.2.2 Component Identification. -

(a) Test Support Systems Components The test support systems components will consist of the following:

- (1) Turbopump Mounting Frame (design by ANSC)
- (2) Critical Piping Sections (design by ANSC)
- (3) Fluid Conditioner
- (4) New Facility Piping and Valves (shown on Figure 6)
- (5) Gimbals, Expansion Joints, Pipe Supports as required to give the necessary piping flexibility and to control forces on the critical piping sections

3.2.2 Component Identification Continued

(a) Test Support Systems Components Continued

- (6) Structural concrete and steel as required to support the turbopump mounting frame, and to support or restrain piping systems.
- (7) Ladders or stairs and platforms as required to provide ready access to equipment.
- (8) System Safety Devices (not yet defined)
- (9) Transducer Panels
- (10) New Data Acquisition Equipment
- (11) Additional Controls System

3.2.2.1 Government Furnished Components. - The test article itself, plus all existing vessels, piping, valves, flare stacks, structures, instruments and wiring, maintenance facilities and tools, and all other items not specifically listed in Subsection 3.2.2 above are government furnished components.

3.2.2.1.1 Water System. - The hot water system that provides heat to the Turbine Energy Source is existing. No change in this system is believed necessary.

3.2.2.1.2 Electrical Power Systems. - Existing electrical power systems will be adequate for all anticipated needs.

3.2.2.1.3 Nitrogen Gas. - Exist nitrogen storage and piping systems are adequate for inerting, purging and actuator operation.

3.2.2.1.4 Installation and Removal Equipment. - There are no special requirements for installation and removal of the test article. The existing building crane is adequate for in-site handling. Handling yokes and special tools will be supplied by the Test Article Supplier.

3.2.2.1.5 Instrumentation and Controls. - The present capability of the existing NRDS I&C Systems is sufficient to comply with existing facility requirements originated by test operations. These systems are captured by a program only during that program's test series.

(a) Data Acquisition - The existing TCC Data Acquisition System will be available for use as required. Table XXIV lists this complement of I&C channels.

(b) Data Recording - The existing TCC/RCP Data Recording System will be available for use as required. Table XXV lists this complement of recording equipment.

3.3 Design and Construction. -

3.3.1 General Design Features. - The configuration of the Test Article is shown in Figure 8. The Test Support System Schematic Diagram is shown on Figure 5. Figures 6 and 7 are isometric drawings of the proposed piping layout. The design of the turbopump test stand and the critical piping sections will be provided by the Test Article Supplier. The instrumentation and control requirements are described in Subsections 3.1.1.1.2, 3.2.1.1.2, and 3.2.2. The design contractor will be responsible for developing and analyzing the final configuration of the Test Support System piping and accessory equipment and supports.

3.3.1.1 Structural and Piping Criteria. - Design of the Modifications to Test Cell "C", including structural and dynamic analysis, shall be in accordance with FEO-1--Nerva Facility Structural Design Standards. In event of conflicts between documents referenced herein, the requirements of FEO-1 shall be considered superseding. In applying FEO-1 to the design and analysis of this facility, all liquid hydrogen, and high-pressure gaseous nitrogen, hydrogen and helium systems shall be considered to be "critical" systems. Refer to Subsection 1.3.3 of FEO-1.

3.3.1.1 Structural and Piping Criteria Continued

The following sections and subsections of FEO-1 are considered of particular interest in designing the Modifications to Test Cell "C".

Section 1 General Provisions
 Section 2 Loads
 Section 3.1 Provisions applicable to all Components
 Subsection 3.2.1 Steel Structures
 Subsection 3.2.2 Concrete
 Subsection 3.2.6 Special Problems
 Subsection 3.2.7.1 Foundations
 Section 3.3 Piping

3.3.1.1.1 Cyclic Life Analysis.- The cyclic life analysis for design of structural members shall utilize methods and data conforming to Section 1.7 AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, February 12, 1969. The cyclic life analysis of critical piping systems shall utilize the procedures defined in Sections F-106 and F-107 of ANSI B3.1.7 Nuclear Power Piping.

3.3.1.1.2 Vibrations.- Fatigue stress values shall be calculated for vibrations induced by pressure fluctuations and seismic or "event" shock. It shall be assumed that an earthquake or an "event" does not occur while the system is in operation. Vibrations induced by a seism or an "Event" shall be calculated based on the criteria of 3.1.2.4.2.

3.3.1.2 Drawings and Specifications.- Drawings shall be prepared in accordance with MIL-STD-100. Weld symbols and nondestructive testing symbols used on the drawings shall be in accordance with requirements of SNPO-C-4. Fabrication specifications shall be prepared in accordance with the format generated by the Construction Specifications Institute (CSI).

3.3.1.3 Component Design.-

3.3.1.3.1 Turbopump Mounting Frame.- The design of the turbopump mounting frame will be provided by the Test Article Supplier.

3.3.1.3.2 Critical Piping Sections.- The design of the critical line sections that are attached directly to the turbopump will be provided by the Test Article Supplier.

3.3.1.3.3 Fluid Conditioner.- The design of the fluid conditioner will be similar to that presently installed in the Electric Pump Room at Test Cell "C", adjusted as necessary to the fluid conditions specified herein. The mechanical design of the fluid conditioner shall be in accordance with ANSI-B31.7 Nuclear Power Piping.

3.3.1.3.4 New Facility Piping and Valves.- The new facility piping and valves shall be designed in accordance with Section 3.3 of FEO-1. Line sizing shall be checked to insure that the test requirements specified in Paragraph 3.1.1.1.1 can be achieved. To the extent possible, piping shall be arranged for easy access by operating and maintenance personnel. Design pressures and temperatures shall not be less stringent than those given in Paragraph 3.1.1.1.1(e). In general, lines carrying liquid hydrogen will be vacuum-jacketed. Other lines will be insulated or bare. Careful consideration must be given to thermal expansion, piping flexibility, and forces imposed on the Test Article.

3.3.1.3.5 Gimbals, Expansion Joints, Pipe Supports.- Pressure-containing piping accessories shall be designed to the same codes and standards as the piping systems in which they are placed. Non-pressure-containing accessories shall be designed in accordance with guidelines provided in FEO-1.

3.3.1.3.6 Structural Concrete and Steel, Ladders and Platforms.- Miscellaneous concrete and steel structures shall be designed in accordance with FEO-1.

3.3.1.3.7 Instrumentation and Controls.- The design of the new data channels and control channels shall be consistent with the design of the existing I&C System.

Figure 12 shows a standard narrowband data channel.

Figure 13 shows a standard wideband data channel for FM multiplex.

Figure 14 shows a standard wideband data channel for channel/track recording.

Figure 15 shows a typical analog control configuration.

Figure 16 shows a typical remote binary valve control.

3.3.1.3.7 Instrumentation and Controls Continued

The Data Reduction System is compatible with the output of the Data Recording System and requires no special design or considerations.

Each controller shall supply the Data Acquisition with the feedback signal and the controller command signal to the valve. Signals delivered to the Data Acquisition system shall have source impedances no greater than 1,000 ohms and be 0 to plus or minus 10 volts in magnitude. The data signals coming from the controllers shall be buffered in such a manner that a fault in the Data Acquisition system (or in the metering, etc.) will not significantly affect the control loop.

The feedback signal to the Data System shall be obtained from an isolation amplifier, properly scaled to provide the required output.

3.3.2 Selection of Specifications and Standards.- The selection and use of specifications and standards shall be governed by MIL-STD-143.

3.3.3 Materials, Parts, and Processes.-

3.3.3.1 Materials.- Selection of materials shall conform to the criteria given in FEO-1. Electrical materials shall conform to USAS C1-1968 National Electric Code. Lubricants, sealants, gaskets and cleaning fluids shall be in accordance with NTO-SOP-0047.

3.3.3.2 Processes.- Existing material fabrication processes such as forming, welding, heat treating, surface coating, etc shall be evaluated for incorporation into the design and procedures prepared for utilization in fabrication. All welding shall conform to the requirements of the ASME Boiler and Pressure Vessel Code, Section III. Welding definitions shall conform to AWS A3.0. Welding symbols shall conform to AWS A2.0. All welders and welding procedures shall be qualified in accordance with ASME Boiler and Pressure Vessel Code, Section IX. Welders who are qualified to other standard codes may be used if they satisfy the above. Feasibility of joints and sections requiring welding of an unusual nature shall be demonstrated by suitable mock-ups prior to start of fabrication. Each component design shall delineate weld mock-up requirements on the design drawings by the use of an identifying symbol which is defined in the drawing legend. Mock-ups shall be required for any weld in either of the following categories.

(a) Full penetration welds which cannot be adequately inspected.

3.3.3.2 Processes Continued

(b) Welds for which accessibility constitutes a major fabrication problem.

(c) Welds which require unusual operator position to accomplish the weld.

(d) Welds where distortion/shrinkage may be a problem e.g., close fitting parts requiring precise alignment or clearance after welding, assemblies having a tight over-all tolerance with a number of welds influencing that tolerance.

3.3.3.3 Cleanliness.- System cleanliness shall conform to the following requirements:

(a) All mating surfaces and all surfaces which are in contact with process fluids shall be assigned cleanliness levels in accordance with MIL-STD-1246.

(b) Assigned levels shall be specified as applicable in the fabrication specifications.

3.3.3.4 Nondestructive Testing.- Nondestructive testing (NDT) requirements and acceptance standards shall be as defined by the applicable codes. Penetrant inspection shall be performed in addition to radiography and also on welds that are not inspectable by radiography. NDT requirements shall be incorporated in the design documents in accordance with SNPO-C-4, Part II, Paragraph 1.2.1.3. Written procedures for NDT methods shall be required. As NDT requirements exceeding the above become evident during the design phase, details shall be included in the fabrication specifications. These requirements may include: NDT methods other than those listed, critical NDT inspections warranting more restrictive procedures than permitted by referenced codes or acceptance levels differing from code requirements. Where special NDT methods may be required that are not defined in the applicable codes, the contractor shall establish and submit for review the technique, acceptance standards and operator certification method.

3.3.4 Standard and Commercial Parts.- Commercial parts may be used only if an appropriate standard part cannot be selected as specified in 3.3.2. Commercial parts shall be controlled by specifications or specification control drawings. Those parts requiring qualification shall be controlled by source control drawings or component specifications containing qualification requirements.

3.3.5 Moisture and Fungus Resistance.- Facility equipment and systems shall be designed to resist degradation due to moisture and fungus growth in the environments identified in Table VII.

3.3.6 Corrosion of Metal Parts.- Unless protected against electrolytic corrosion, dissimilar metals shall not be used in intimate contact with each other. Dissimilar metals shall be as defined in MS33586. Finish and surface treatments shall be incorporated as necessary to protect from deterioration during exposure to the environments specified in 3.1.2.4. The selection and application of protective treatments and surface finish shall be in accordance with MIL-STD-171.

3.3.7 Interchangeability and Replaceability.- All parts having the same manufacturers part number shall be directly and completely interchangeable with respect to installation and performance.

3.3.8 Workmanship.- All workmanship shall be of a quality consistent with the requirements of this document. Electrical workmanship shall conform to NRDS-STD-101.

3.3.9 Electromagnetic Interference.- Electromagnetic interference shall conform to the requirements of MIL-E-6051.

3.3.10 Identification and Marking.- Identification and marking shall conform to MIL-STD-130.

Section 4. QUALITY ASSURANCE PROVISIONS

This section defines the general requirements for the verification of performance and design requirements of Section 3.

The Contractor's Quality Assurance Program shall conform with SNPO-C-4, NERVA Program Quality Assurance Requirements for Facility and Ground Support Equipment.

4.1 Category I Test. - The following tests shall be conducted at the component level.

4.1.1 Inspection. - Verification by inspection shall be performed by a visual and dimensional inspection of each finished component.

4.1.2 Analyses. - Verification by analysis, shall be performed by a detailed review of the engineering data which includes drawings, specifications and analytical work.

4.1.3 Demonstrations. - Verification by demonstration, shall be performed by a functional checkout of the operating components.

4.2 Category II Test. - The following tests shall be conducted at the system level.

4.2.1 Inspection. - Verification by inspection shall be performed by a visual and dimensional inspection of the assembled and installed system or systems.

4.2.2 Analyses. - Verification by analysis shall be performed by a detailed review of the engineering data which includes drawings, specifications and analytical work.

4.2.3 Demonstrations. - The following tests shall be included at the system level.

- (a) Hydrostatic tests.
- (b) Hydroflow tests.
- (c) Leak tests.
- (d) Design demonstration tests.

4.2.4 Safety Analyses.- A hazards analysis shall be conducted to provide an early comprehensive qualitative assessment of safety. Qualitative fault tree analyses may be performed as appropriate when needed to provide a realistic assessment of system safety. Hazardous conditions shall be categorized as specified in paragraph 3.1.2.7.2.

4.2.5 Reliability Tests and Analyses.- There shall be no testing solely for reliability demonstration. Verification of reliability shall be accomplished by:

- (a) Performance of a failure analysis to determine the probable modes of failures and their effects.
- (b) Analysis of available test data to determine reliability history.
- (c) Review of fabrication, assembly and acceptance procedures to minimize probability of failure.
- (d) Review of the subsystem test program and evaluation of the use of peripheral test levels if necessary to improve reliability assessment.

4.3 Application.- Design and document reviews/concurrence shall be in accordance with Part I, Section 4 and Part II, paragraph 1.2 of SNPO-C-4.

TABLE I
TURBOPUMP PERFORMANCE - STEADY STATE
NORMAL MODE OPERATION - RATED CONDITIONS

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	47.0	47.0	22.6	28.6	36.7	40.9
	Nom	46.2	46.2	21.8	27.8	36.4	40.6
	Min	45.4	45.4	21.0	27.0	36.1	40.3
Pump Outlet	Max	46.7	46.7	1486	1487	57.4	62.4
	Nom	45.9	45.9	1431	1431	55.2	60.2
	Min	45.1	45.1	1398	1398	53.9	58.9
Turbine Inlet	Max	44.8	44.4	1128	1138	288	299
	Nom	42.3	41.9	1088	1098	276	287
	Min	40.8	40.4	1065	1075	265	275
Turbine Outlet	Max	45.1	44.7	746	752	263	273
	Nom	42.5	42.2	733	739	252	262
	Min	41.0	40.7	720	726	241	251

TABLE II
TURBOPUMP PERFORMANCE - STEADY STATE
SINGLE TURBOPUMP MODE OPERATION

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	75.5	75.5	24.4	30.3	36.7	40.9
	Nom	74.0	73.9	23.5	29.5	36.4	40.6
	Min	72.4	72.3	22.8	29.7	36.1	40.3
Pump Outlet	Max	75.0	75.0	1386	1394	56.9	62.3
	Nom	73.4	73.4	1333	1340	54.7	60.1
	Min	71.8	71.8	1301	1309	53.4	58.8
Turbine Inlet	Max	49.9	49.8	1103	1119	305	318
	Nom	44.4	44.3	1084	1080	290	303
	Min	41.2	41.1	1045	1057	277	289
Turbine Outlet	Max	50.4	50.3	620	625	270	280
	Nom	44.9	44.8	605	610	257	267
	Min	41.7	41.6	590	595	244	254

TABLE III

TURBOPUMP PERFORMANCE - STEADY STATE

NORMAL MODE THROTTLING OPERATION - 60% THRUST

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	28.5	28.5	22.7	28.7	35.7	40.9
	Nom	27.7	27.7	21.9	27.9	36.4	40.6
	Min	26.9	26.9	21.1	27.1	36.1	40.3
Pump Outlet	Max	28.3	28.3	1035	998	52.7	56.4
	Nom	27.5	27.5	992	955	51.8	55.5
	Min	26.7	26.7	967	929	51.3	55.0
Turbine Inlet	Max	23.2	22.7	657	656	323	333
	Nom	21.7	21.2	627	626	313	323
	Min	20.8	20.3	609	609	303	313
Turbine Outlet	Max	23.5	22.9	469	471	302	310
	Nom	21.9	21.4	457	460	292	300
	Min	21.0	20.5	446	446	282	290

TABLE IV.

TURBOPUMP PERFORMANCE - STEADY STATE

SINGLE TURBOPUMP MODE THROTTLING OPERATION - 60% THRUST

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	57.0	57.1	24.6	30.5	36.7	40.9
	Nom	55.4	55.5	23.8	29.7	36.4	40.6
	Min	53.8	53.9	23.0	28.9	36.1	40.3
Pump Outlet	Max	56.5	56.6	1041	1030	50.6	55.3
	Nom	54.9	55.0	998	987	49.7	54.4
	Min	53.3	53.4	973	962	49.2	53.9
Turbine Inlet	Max	31.5	31.3	759	766	320	332
	Nom	28.4	28.2	729	736	311	321
	Min	26.6	26.4	711	718	300	311
Turbine Outlet	Max	32.0	31.7	473	477	290	300
	Nom	28.9	28.6	452	465	280	290
	Min	27.1	26.3	450	454	270	280

TABLE V

TURBOPUMP PERFORMANCE - STEADY STATE

NORMAL MODE EMERGENCY OPERATION

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	24.0	-	24.6	-	36.7	-
	Nom	23.2	-	23.3	-	36.4	-
	Min	22.4	-	23.0	-	36.1	-
Pump Outlet	Max	23.8	-	684	-	46.2	-
	Nom	23.0	-	641	-	45.3	-
	Min	22.2	-	616	-	44.8	-
Turbine Inlet	Max		-		-		-
	Nom	16.13	-	450	-	258	-
	Min		-		-		-
Turbine Outlet	Max		-		-		-
	Nom	16.25	-	346	-	240	-
	Min		-		-		-

TABLE VI

TURBOPUMP PERFORMANCE - STEADY STATE
SINGLE TURBOPUMP MODE EMERGENCY OPERATION

State Point		Flow Rate lbs/sec		Pressure, psia		Temperature °R	
		Start of Life	End of Life	Start of Life	End of Life	Start of Life	End of Life
Pump Inlet	Max	48.0	-	24.6	-	36.7	-
	Nom	45.4	-	23.8	-	36.4	-
	Min	44.8	-	23.0	-	36.1	-
Pump Outlet	Max	47.6	-	684	-	46.2	-
	Nom	46.0	-	641	-	45.3	-
	Min	44.4	-	616	-	44.8	-
Turbine Inlet	Max	24.8	-	550	-	268	-
	Nom	21.3	-	520	-	258	-
	Min	19.92	-	502	-	248	-
Turbine Outlet	Max	25.2	-	357	-	243	-
	Nom	22.9	-	346	-	233	-
	Min	20.2	-	335	-	223	-

ENVIRONMENTS

Environment	<u>Non-operating</u>	<u>Operating</u>
(a) Relative humidity, percent	0-100	0-100
(b) Temperature, °F	+ 5 to + 110	+ 5 to + 180
(c) Pressure, average, psia	12.8	12.8
(d) Atmosphere	Ambient Air	Ambient Air
(e) Sand and Dust	As encountered in desert regions	
(f) Water		
(1) Rainfall, in.*	3.24	3.24
(2) Deluge	None	½ gpm/ft ²
(g) Wind	See 3.1.2.3.1	
(h) Seismic Loads	See 3.1.2.3.2	
(i) Radiation, Max. (full power NERVA engine run)		
(1) Gamma flux, Rads (C)/hr	TBD	TBD
Gamma Dose, Rads (C)	TBD	TBD
(2) Fast (E > 1 Mev) neutron flux, neutrons/cm ² /sec	TBD	TBD
Fast (E < 1 Mev) neutron fluence, neutrons/cm ²	TBD	TBD
(j) Acoustic		TBD

* Average annual rainfall.

TABLE VIII

PRESSURE MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
OBV-1 bypass line, flowmeter F-1, turbopump chill	0-100 psig	
Turbopump bypass line, facility chill	0-100 psig	
Upstream fluid conditioner, suction line $\theta = 0^\circ$	0-50 psig	
Upstream fluid conditioner, suction line $\theta = 90^\circ$	0-50 psig	
Upstream fluid conditioner, suction line $\theta = 180^\circ$	0-50 psig	
Upstream fluid conditioner, suction line $\theta = 270^\circ$	0-50 psig	
Downstream fluid conditioner, suction line $\theta = 0^\circ$	0-50 psig	
Downstream fluid conditioner, suction line $\theta = 90^\circ$	0-50 psig	
Downstream fluid conditioner, suction line $\theta = 180^\circ$	0-50 psig	
Downstream fluid conditioner, suction line $\theta = 270^\circ$	0-50 psig	
Suction line flange, at pump suction $\theta = 0^\circ$	0-50 psig	
Suction line flange, at pump suction $\theta = 90^\circ$	0-50 psig	
Suction line flange, at pump suction $\theta = 45^\circ$	+ 50 psig	2000 Hz
Suction line flange, at pump suction $\theta = 225^\circ$	+ 50 psig	2000 Hz
Downstream pump discharge valve	0-2000 psig	
Downstream pump discharge valve	+ 2000 psig	5000 Hz
Pump discharge line engine/facility joint	0-2000 psig	
Pump discharge flowmeter, F-2	0-2000 psig	
Pump discharge flowmeter, F-3, turbine LH ₂ flow	0-2000 psig	
Downstream ACV-2, upstream L-31 & L-32	0-2000 psig	
Pump discharge bypass line, upstream ACV-3	0-2000 psig	
Pump discharge bypass to mixing chamber	0-1500 psig	
Pump discharge bypass to flare, downstream OBV-3	0-100 psig	
Turbine inlet line from TES upstream mixing chamber	0-1500 psig	
Turbine inlet venturi, upstream	0-1500 psig	
Differential turbine inlet venturi	0-100 psid	Differential Pressure
Turbine inlet venturi, downstream	0-1500 psig	
Turbine inlet line facility/engine joint	0-1500 psig	
Turbine inlet valve, upstream $\theta = 0^\circ$	0-1500 psig	

TABLE VIII Continued

PRESSURE MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Turbine inlet valve, upstream $\theta = 90^\circ$	0-1500 psig	
Turbine inlet valve, upstream $\theta = 180^\circ$	0-1500 psig	
Turbine inlet valve, upstream $\theta = 270^\circ$	0-1500 psig	
Turbine discharge valve, downstream $\theta = 0^\circ$	0-1000 psig	
Turbine discharge valve, downstream $\theta = 90^\circ$	0-1000 psig	
Turbine discharge valve, downstream $\theta = 180^\circ$	0-1000 psig	
Turbine discharge valve, downstream $\theta = 270^\circ$	0-1000 psig	
Turbine discharge line engine/facility joint	0-1000 psig	
Turbine discharge line downstream ACV-5	0-1000 psig	
Pressure bypass flow F-5	0-2000 psig	
Pump discharge flowmeter, F-2	0-200 psig	Narrow range (10%
Pump discharge flowmeter, F-3, turbine LH ₂	0-200 psig	Narrow range (10%
Bypass flow F-5	0-200 psig	Narrow range (10%

TABLE IX

PRESSURE MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Inducer Discharge Static Tip	0-200 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 0^\circ$, R=4.25	0-500 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 120^\circ$, R=4.25	0-500 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 240^\circ$, R=4.25	0-500 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 0^\circ$, R=4.8	0-750 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 120^\circ$, R=4.8	0-750 psig	
Impeller Suction Shroud, 1st Stage, $\theta = 240^\circ$, R=4.8	0-750 psig	
Impeller Tip, Suction, 1st Stage, $\theta = 0^\circ$	0-1000 psig	
Impeller Tip, Suction, 1st Stage, $\theta = 120^\circ$	0-1000 psig	
Impeller Tip, Suction, 1st Stage, $\theta = 240^\circ$	0-1000 psig	
Impeller Tip, Back, 1st Stage $\theta = 0^\circ$	0-1000 psig	
Impeller Tip, Back, 1st Stage $\theta = 180^\circ$	0-1000 psig	
Impeller Back Vane Inlet, 1st Stage $\theta = 0^\circ$	0-1500 psig	
Impeller Back Vane Inlet, 1st Stage $\theta = 180^\circ$	0-1500 psig	
Back Vane Feed, 1st Stage, $\theta = 0^\circ$	0-1500 psig	
Back Vane Feed, 1st Stage $\theta = 180^\circ$	0-1500 psig	
Back, Impeller Hub, 1st Stage	0-1500 psig	
Impeller Bearing Feed, 1st Stage	0-1500 psig	
Crossover Vane, No. 1	0-1000 psig	
Crossover Vane, No. 2	0-1000 psig	
Crossover Vane, No. 3	0-1000 psig	
Crossover Vane, No. 4	0-1000 psig	
Crossover Vane, No. 5	0-1000 psig	
Crossover Vane, No. 6	0-1000 psig	
Crossover Vane, No. 7	0-1000 psig	
Crossover Vane, No. 8	0-1000 psig	
Crossover Vane, No. 9	0-1000 psig	
Crossover Vane, No. 10	0-1000 psig	

TABLE IX Continued
PRESSURE MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Crossover Vane, No. 11	0-1000 psig	
Impeller Inlet Tip, 2nd Stage	0-1000 psig	
Impeller Suction Surface, 2nd Stage $\theta = 0^{\circ}$, R=3.8	0-1000 psig	
Impeller Suction Surface, 2nd Stage $\theta = 180^{\circ}$, R=3.8	0-1000 psig	
Impeller Suction Surface, 2nd Stage $\theta = 0^{\circ}$, R=4.65	0-1500 psig	
Impeller Suction Surface, 2nd Stage $\theta = 180^{\circ}$, R=4.65	0-1500 psig	
Impeller Tip, 2nd Stage, $\theta = 0^{\circ}$	0-1500 psig	
Impeller Tip, 2nd Stage, $\theta = 180^{\circ}$	0-1500 psig	
Diffuser Vane Inlet, No. 1	0-1500 psig	
Diffuser Vane Inlet, No. 2	0-1500 psig	
Diffuser Vane Inlet, No. 3	0-1500 psig	
Diffuser Vane Inlet, No. 4	0-1500 psig	
Diffuser Vane Inlet, No. 5	0-1500 psig	
Diffuser Vane Inlet, No. 6	0-1500 psig	
Diffuser Vane Inlet, No. 7	0-1500 psig	
Diffuser Vane Inlet, No. 8	0-1500 psig	
Diffuser Vane Inlet, No. 9	0-1500 psig	
Pump Bearing Feed Discharge	0-1000 psig	
Diffuser Vane Discharge, No. 1	0-2000 psig	
Diffuser Vane Discharge, No. 2	0-2000 psig	
Diffuser Vane Discharge, No. 3	0-2000 psig	
Diffuser Vane Discharge, No. 4	0-2000 psig	
Diffuser Vane Discharge, No. 5	0-2000 psig	
Diffuser Vane Discharge, No. 6	0-2000 psig	
Diffuser Vane Discharge, No. 7	0-2000 psig	
Diffuser Vane Discharge, No. 8	0-2000 psig	
Diffuser Vane Discharge, No. 9	0-2000 psig	
Pump Discharge Flange, $\theta = 0^{\circ}$	0-2000 psig	
Pump Discharge Flange, $\theta = 90^{\circ}$	0-2000 psig	

TABLE IX Continued

PRESSURE MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Pump Discharge Flange $\theta = 90^{\circ}$	0-200 psig	Narrow Range
Differential Pressure Suction/Pump Discharge Flange $\theta = 90^{\circ}$, Pump Overall Pressure Rise	0-2000 psig	Differential
Pump Discharge Flange, $\theta = 180^{\circ}$	0-2000 psig	
Pump Discharge Flange, $\theta = 180^{\circ}$	0-200 psig	Narrow Range
Pump Discharge Flange, $\theta = 270^{\circ}$	0-2000 psig	
Thrust Balancer, Tip, $\theta = 0^{\circ}$	0-1500 psig	
Thrust Balancer, Tip, $\theta = 180^{\circ}$	0-1500 psig	
Thrust Balancer, R = 4.65, $\theta = 0^{\circ}$	0-1500 psig	
Thrust Balancer, R = 4.65, $\theta = 120^{\circ}$	0-1500 psig	
Thrust Balancer, R = 4.65, $\theta = 240^{\circ}$	0-1500 psig	
Thrust Balancer, R = 3.5, $\theta = 0^{\circ}$	0-1000 psig	
Thrust Balancer, R = 3.5, $\theta = 180^{\circ}$	0-1000 psig	
Feed Turbine Bearing, $\theta = 0^{\circ}$	0-1000 psig	
Feed Turbine Bearing, $\theta = 180^{\circ}$	0-1000 psig	
Balancer Feed Discharge, $\theta = 0^{\circ}$	0-1000 psig	
Balancer Feed Discharge, $\theta = 180^{\circ}$	0-1000 psig	
Turbine Inlet Flange, $\theta = 0^{\circ}$	0-1500 psig	
Turbine Inlet Flange, $\theta = 0^{\circ}$	0-200 psig	Narrow Range
Turbine Inlet Flange, $\theta = 90^{\circ}$	0-1500 psig	
Turbine Inlet Flange, $\theta = 180^{\circ}$	0-1500 psig	
Turbine Inlet Flange, $\theta = 180^{\circ}$	0-200 psig	Narrow Range
Turbine Inlet Flange, $\theta = 270^{\circ}$	0-1500 psig	
Turbine 1st Stage Nozzle, Inlet, $\theta = 0^{\circ}$	0-1500 psig	
Turbine 1st Stage Nozzle, Inlet, $\theta = 90^{\circ}$	0-1500 psig	
Turbine 1st Stage Nozzle, Inlet, $\theta = 180^{\circ}$	0-1500 psig	
Turbine 1st Stage Nozzle, Inlet, $\theta = 270^{\circ}$	0-1500 psig	
Turbine 1st Stage Rotor, Inlet Tip, $\theta = 0^{\circ}$	0-1500 psig	
Turbine 1st Stage Rotor, Inlet Tip, $\theta = 180^{\circ}$	0-1500 psig	

TABLE IX Continued

PRESSURE MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Turbine 1st Stage Rotor, Discharge Tip, $\theta = 0^\circ$	0-1500 psig	
Turbine 1st Stage Rotor, Discharge Tip, $\theta = 180^\circ$	0-1500 psig	
Turbine 2nd Stage Rotor, Inlet Tip, $\theta = 0^\circ$	0-1500 psig	
Turbine 2nd Stage Rotor, Inlet Tip, $\theta = 180^\circ$	0-1500 psig	
Turbine 2nd Stage Rotor, Discharge Tip, $\theta = 0^\circ$	0-1000 psig	
Turbine 2nd Stage Rotor, Discharge Tip, $\theta = 180^\circ$	0-1000 psig	
Turbine Guide Vane, Inlet, No. 1	0-1000 psig	
Turbine Guide Vane, Inlet, No. 2	0-1000 psig	
Turbine Guide Vane, Inlet, No. 3	0-1000 psig	
Turbine Guide Vane Inlet, No. 4	0-1000 psig	
Turbine Guide Vane, Inlet, No. 5	0-1000 psig	
Turbine Aft Hub Cavity	0-1000 psig	
Turbine Discharge Flange, $\theta = 0^\circ$	0-1000 psig	
Turbine Discharge Flange, $\theta = 0^\circ$	0-200 psig	Narrow Range
Turbine Discharge Flange, $\theta = 90^\circ$	0-1000 psig	
Turbine Discharge Flange, $\theta = 180^\circ$	0-1000 psig	
Turbine Discharge Flange, $\theta = 180^\circ$	0-200 psig	Narrow Range
Turbine Discharge Flange, $\theta = 270^\circ$	0-1000 psig	
Interstage Feed Venturi	0-1000 psig	
Interstage Feed Venturi	0-50 psid	Differential
Turbine Bearing Feed Discharge, $\theta = 0^\circ$	0-1000 psig	
Turbine Bearing Feed Discharge, $\theta = 180^\circ$	0-1000 psig	
Filter Discharge No. 1	0-2000 psig	
Filter Discharge No. 1	0-50 psid	Differential
Filter Discharge No. 2	0-2000 psig	
Filter Discharge No. 2	0-50 psid	Differential

TABLE X

TEMPERATURE MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Pump discharge line, top surface	35-650 ^o R	
Pump discharge line, longitudinal surface	35-650 ^o R	
Turbine inlet line, top surface	200-650 ^o R	
Turbine inlet line, longitudinal surface	200-650 ^o R	
Turbine discharge line, top surface	200-650 ^o R	
Turbine discharge line, longitudinal surface	200-650 ^o R	
OBV-1 bypass line, flowmeter F-1, turbopump chill	35-60 ^o R	
Turbopump bypass line, facility chill	35-600 ^o R	
Upstream fluid conditioner, suction line $\theta = 45^{\circ}$	35-45 ^o R	
Upstream fluid conditioner, suction line $\theta = 135^{\circ}$	35-45 ^o R	
Upstream fluid conditioner, suction line $\theta = 225^{\circ}$	35-45 ^o R	
Upstream fluid conditioner, suction line $\theta = 315^{\circ}$	35-45 ^o R	
Downstream fluid conditioner, suction line $\theta = 45^{\circ}$	35-45 ^o R	
Downstream fluid conditioner, suction line $\theta = 135^{\circ}$	35-45 ^o R	
Downstream fluid conditioner, suction line $\theta = 225^{\circ}$	35-45 ^o R	
Downstream fluid conditioner, suction line $\theta = 315^{\circ}$	35-45 ^o R	
Suction line flange, at pump suction $\theta = 180^{\circ}$	35-45 ^o R	
Suction line flange, at pump suction $\theta = 270^{\circ}$	35-45 ^o R	
Downstream pump discharge valve	35-75 ^o R	
Pump discharge line engine/facility joint	35-75 ^o R	
Pump discharge flowmeter, F-2	35-75 ^o R	
Pump discharge flowmeter, F-3, turbine LH ₂ flow	35-75 ^o R	
Downstream ACV-2, upstream L-31 & L-32	35-200 ^o R	
Pump discharge bypass line, upstream ACV-3	35-75 ^o R	
Pump discharge bypass to mixing chamber	35-200 ^o R	
Pump discharge bypass to flare, downstream OBV-3	35-200 ^o R	
Bypass flow F-5	37-75 ^o R	
Turbine inlet line from TES upstream mixing chamber	100-700 ^o R	
Turbine inlet venturi, upstream	150-600 ^o R	

TABLE X Continued

TEMPERATURE MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Turbine inlet venturi, downstream joint	150-600°R	
Turbine inlet line facility/Engine joint	150-600°R	
Turbine inlet valve, upstream $\theta = 45^\circ$	150-600°R	
Turbine inlet valve, upstream $\theta = 135^\circ$	150-600°R	
Turbine discharge valve, downstream $\theta = 45^\circ$	150-600°R	
Turbine discharge valve, downstream $\theta = 225^\circ$	150-600°R	
Turbine discharge line engine/facility joint	150-600°R	
Turbine discharge line downstream, ACV-5	150-600°R	

TABLE XI

TEMPERATURE MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Pump/Turbine Interstage Housing Metal, $\theta = 0^\circ$, Hub	35-600 $^\circ$ R	TAS Supplied
Pump/Turbine Interstage Housing Metal, $\theta = 180^\circ$, Hub	35-600 $^\circ$ R	TAS Supplied
Turbine Housing Metal, $\theta = 45^\circ$	35-600 $^\circ$ R	TAS Supplied
Turbine Housing Metal, $\theta = 135^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Discharge Flange, $\theta = 45^\circ$	35-80 $^\circ$ R	
Pump Discharge Flange, $\theta = 225^\circ$	35-80 $^\circ$ R	
Turbine Inlet Flange, $\theta = 45^\circ$	150-600 $^\circ$ R	
Turbine Inlet Flange, $\theta = 225^\circ$	150-600 $^\circ$ R	
Turbine Discharge Flange, $\theta = 45^\circ$	150-600 $^\circ$ R	
Turbine Discharge Flange, $\theta = 225^\circ$	150-600 $^\circ$ R	
Pump Bearing Fluid, $\theta = 0^\circ$	35-100 $^\circ$ R	TAS Supplied
Pump Bearing Fluid, $\theta = 90^\circ$	35-100 $^\circ$ R	TAS Supplied
Interstage Feed Venturi	35-100 $^\circ$ R	
Turbine Bearing Fluid, $\theta = 0^\circ$	35-100 $^\circ$ R	TAS Supplied
Turbine Bearing Fluid, $\theta = 90^\circ$	35-100 $^\circ$ R	TAS Supplied
Pump Housing, Forward Metal, $\theta = 35^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Housing, Forward Metal, $\theta = 115^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Interstage Outer Housing Metal, $\theta = 40^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Interstage Outer Housing Metal, $\theta = 220^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Interstage Hub Metal, $\theta = 60^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump Interstage Hub Metal, $\theta = 180^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump 2nd Stage Housing Metal, $\theta = 50^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump 2nd Stage Housing Metal, $\theta = 230^\circ$	35-600 $^\circ$ R	TAS Supplied
Pump/Turbine Interstage Housing Metal, $\theta = 0^\circ$, Outer	35-600 $^\circ$ R	TAS Supplied
Pump/Turbine Interstage Housing Metal, $\theta = 180^\circ$, Outer	35-600 $^\circ$ R	TAS Supplied
Pump Discharge Flange, $0=45^\circ$ /Pump Bearing Fluid, $\theta=0^\circ$	0-20 $^\circ$	Differential
Pump discharge flange, $0=45^\circ$ /Turbine bearing fluid, $\theta=0^\circ$	0-20 $^\circ$	Differential
Pump discharge flange, $0=225^\circ$ /pump bearing fluid, $\theta=90^\circ$	0-20 $^\circ$	Differential
Pump discharge flange, $0=225^\circ$ /turbine bearing fluid, $\theta=90^\circ$	0-20 $^\circ$	Differential

TABLE XII
ACCELEROMETER MEASUREMENT REQUIREMENTS

DESCRIPTION

Pump Discharge Valve Inlet Flange X-Axis

Pump Discharge Valve Inlet Flange Y-Axis

Pump Discharge Valve Inlet Flange Z Axis

Turbine Inlet Valve Inlet Flange X Axis

Turbine Inlet Valve Inlet Flange Y Axis

Turbine Inlet Valve Inlet Flange Z Axis

Turbine Inlet Line Flange X Axis

Turbine Inlet Line Flange Y Axis

Turbine Inlet Line Flange Z Axis

Turbine Discharge Valve Flange, X-Axis

Turbine Discharge Valve Flange, Y Axis

Turbine Discharge Valve Flange, Z Axis

Pump Discharge Line, X-Axis

Pump Discharge Line, Y-Axis

Pump Discharge Line, Z-Axis

Turbine Inlet Line, X-Axis

Turbine Inlet Line, Y-Axis

Turbine Inlet Line, Z-Axis

Turbine Discharge Line, X Axis

Turbine Discharge Line, Y Axis

Turbine Discharge Line, Z Axis

TABLE XIII

ACCELEROMETER MEASUREMENT REQUIREMENTS - TPA

DESCRIPTION

TPA Trinon #1 Axial

TPA Trinon #1 Radial Y

TPA Trinon #1 Radial Z

TPA Trinon #2 Axial

TPA Trinon #2 Radial Y

TPA Trinon #2 Radial Z

TPA Interstage Axial

TPA Interstage Radial Y

TPA Interstage Radial Z

TABLE XIV

DISPLACEMENT MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>BANDWIDTH</u>
Pump Discharge Line, X Axis	$\pm .2$ inch	100 Hz
Pump Discharge Line, Z Axis	$\pm .2$ inch	100 Hz
Turbine Inlet Line, X Axis	$\pm .2$ inch	100 Hz
Turbine Inlet Line, Z Axis	$\pm .2$ inch	100 Hz
Turbine Discharge Line, X Axis	$\pm .2$ inch	100 Hz
Turbine Discharge Line, Z Axis	$\pm .2$ inch	100 Hz
Turbopump Inlet Flange, X Axis	$\pm .2$ inch	100 Hz
Turbopump Inlet Flange, Y Axis	$\pm .2$ inch	100 Hz
Turbopump Inlet Flange, Z Axis	$\pm .2$ inch	100 Hz
Turbopump Turbine Flange, X-Axis	$\pm .2$ inch	100 Hz
Turbopump Turbine Flange, Y Axis	$\pm .2$ inch	100 Hz
Turbopump Turbine Flange, Z Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Pump Discharge, X Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Pump Discharge, Y Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Turbine Inlet, X Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Turbine Inlet, Y Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Turbine Exhaust, X Axis	$\pm .2$ inch	100 Hz
Critical Line Flange Turbine Exhaust, Y Axis	$\pm .2$ inch	100 Hz

TABLE XV

STEM POSITION MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>BANDWIDTH</u>
ACV-1	0-100%	8 Hz
ACV-2	0-100%	8 Hz
ACV-3	0-100%	8 Hz
ACV-4	0-100%	8 Hz
ACV-5	0-100%	8 Hz
ACV-1	0-100%	100 Hz
ACV-2	0-100%	100 Hz
ACV-3	0-100%	100 Hz
ACV-4	0-100%	100 Hz
ACV-5	0-100%	100 Hz
OBV-1, O/C	0-100%	100 Hz
OBV-2, O/C	0-100%	100 Hz
OBV-3, O/C	0-100%	100 Hz
OBV-4, O/C	0-100%	100 Hz
L-31, O/C	0-100%	100 Hz
L-32, O/C	0-100%	100 Hz

TABLE XVI

DISPLACEMENT MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>
Spinner, $\theta = 0^\circ$, Radial	$\pm .01$ in.
Spinner, $\theta = 90^\circ$, Radial	$\pm .01$ in.
Pump Interstage Shaft, Radial $\theta = 0^\circ$	$\pm .01$ in.
Pump Interstage Shaft, Radial $\theta = 90^\circ$	$\pm .01$ in.
Pump Interstage Shaft, Radial $\theta = 180^\circ$	$\pm .01$ in.
Pump Interstage Shaft, Radial $\theta = 270^\circ$	$\pm .01$ in.
Turbine Interstage Shaft, Radial $\theta = 0^\circ$	$\pm .01$ in.
Turbine Interstage Shaft, Radial $\theta = 90^\circ$	$\pm .01$ in.
Turbine Interstage Shaft, Radial $\theta = 180^\circ$	$\pm .01$ in.
Turbine Interstage Shaft, Radial $\theta = 270^\circ$	$\pm .01$ in.
Turbine Rotor Radial $\theta = 0^\circ$	$\pm .01$ in.
Turbine Rotor Radial $\theta = 90^\circ$	$\pm .01$ in.
Turbine Rotor Radial $\theta = 180^\circ$	$\pm .01$ in.
Turbine Rotor Radial $\theta = 270^\circ$	$\pm .01$ in.
Thrust Balancer Axial $\theta = 0^\circ$	$\pm .025$ in.
Thrust Balancer Axial $\theta = 90^\circ$	$\pm .025$ in.
Thrust Balancer Axial $\theta = 180^\circ$	$\pm .025$ in.
Thrust Balancer Axial $\theta = 270^\circ$	$\pm .025$ in.

NOTES:

1. The displacement transducers, non-contacting, to be supplied by the Test Article Supplier.
2. All measurements will be paralleled to both the wideband system and the narrowband system.
3. The wideband frequency response shall be DC-10K Hz.
4. The narrowband frequency response shall be DC-8Hz.

TABLE XVII

STRAIN MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Pump Discharge Line, Top Centerline, Z Axis	$\pm .002$ in/in	
Pump Discharge Line, Top Centerline, Y Axis	$\pm .002$ in/in	
Pump Discharge Line, Longitudinal Centerline, Y Axis	$\pm .002$ in/in	
Pump Discharge Line, Longitudinal Centerline, X Axis	$\pm .002$ in/in	
Turbine Inlet Line, Top Centerline, Z Axis	$\pm .002$ in/in	
Turbine Inlet Line, Top Centerline, Y Axis	$\pm .002$ in/in	
Turbine Inlet Line, Longitudinal Centerline, Y Axis	$\pm .002$ in/in	
Turbine Inlet Line, Longitudinal Centerline, X Axis	$\pm .002$ in/in	
Turbine Discharge Line, Top Centerline, Z Axis	$\pm .002$ in/in	
Turbine Discharge Line, Top Centerline, Y Axis	$\pm .002$ in/in	
Turbine Discharge Line, Longitudinal Centerline, Y Axis	$\pm .002$ in/in	
Turbine Discharge Line, Longitudinal Centerline, X Axis	$\pm .002$ in/in	

TABLE XVIII

FLOW MEASUREMENT REQUIREMENTS - NEW FACILITY

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
OBV-1 Bypass Line, Flowmeter F-1	0-5 lb/sec	
Pump Discharge Line, Flowmeter F-2	0-90 lb/sec	
Pump Discharge Line, Flowmeter F-3 to TES	0-60 lb/sec	
Turbine Inlet Venturi	0-60 lb/sec	
Bypass Flow F-5	0-10 lb/sec	

TABLE XIX

SPEED MEASUREMENT REQUIREMENTS - TPA

<u>DESCRIPTION</u>	<u>RANGE</u>	<u>NOTES</u>
Turbopump Shaft	0-35KRPM	8Hz Narrowband 1KHz Wideband TAS Supplied
Turbopump Shaft	0-35KRPM	8Hz Narrowband, Back-up TAS Supplied

TABLE XX
REQUIRED EXISTING FACILITY PARAMETERS

<u>DESCRIPTION</u>	<u>NARROW BAND CHANNEL</u>	<u>RANGE NARROW BAND</u>
Pressure Dewar 1	LP 061	0-100 psig
Pressure Dewar 2	LP 062	0-100 psig
Temperature Dewar 1, Bottom	LT 071	35-60 ^o R
Temperature Dewar 2, Bottom	LT 072	35-60 ^o R
Temperature Line From Dewar 1	LT 001	35-60 ^o R
Temperature Line From Dewar 2	LT 002	35-60 ^o R
Pressure Common Upstream L-3 LH ₂ Main Propellant	LP 003	0-100 psig

TABLE XXI
MEASUREMENT/TRANSDUCER PARAMETERS

<u>PARAMETER</u>	<u>EXISTING FACILITY</u>	<u>NEW FACILITY</u>	<u>TURBO- PUMP</u>	<u>TOTALS</u>
<u>NARROWBAND</u>				
Pressure	3 ^①	38 ^②	107 ^③	148
Differential P		1	4	5
Temperature	4 ^①	37	25	66
Differential T			4	4
Stem Position		5		5
Displacement, N-C			18 ^④	18
Strain		12		12
Flow		5		5
Speed			2	<u>2</u>
		Narrow Band Sub-Total		265
<u>WIDEBAND</u>				
Pressure		3		3
Stem Position		11		11
Acceleration		21	9	20
Displacement, N-C			18 ^④	18
Displacement, Contact		18		18
Speed			1	<u>1</u>
		Wideband Sub-Total		71
		GRAND TOTAL		336

NOTES: ① Do not require transducers.
 ② Three of the measurements do not require transducers.
 ③ Six of the measurements do not require transducers.
 ④ 18 measurement points only, to be recorded in both the Narrowband and Wideband Systems.

TABLE XXII

PRELIMINARY VALVE OPERATING REQUIREMENTS

DESIGNATION REF. FIG. 12	SIZE REF. FIG. 14	RESPONSE	FAILURE MODE	REMARKS
ACV-1	3 inch	slow	closed	
ACV-2	6 inch	slow	open	
ACV-3	6 inch	slow	open	
ACV-4	6 inch	slow	closed	
ACV-5	6 inch	slow	closed	
ACV-6	4 inch	slow	closed	
OBV-1	10 inch	slow	open	Must be ball valve to result in minimum flow disturbance
OBV-2	2- $\frac{1}{2}$ inch	slow	closed	
OBV-3	6 inch	slow	closed	
OBV-4	6 inch	fast	closed	Used for emergency shutdown

TABLE XXIII

PRELIMINARY VALVE CONTROLLER REQUIREMENTS

VALVES	CONTROL FUNCTION	RAMP INPUT FOR STARTUP AND SHUTDOWN	REMARKS
ACV-1	Position		
ACV-2	Position	Yes	
	Pump Q/N		
ACV-3	Position	Yes	
	Turbine Drive Temperature		
ACV-4	Position	Yes	
	Pump Speed		
	Pump Discharge Pressure		
ACV-5	Position	Yes	
	Turbine Back Pressure		
ACV-6	Position		

TABLE XXIV
EXISTING DATA ACQUISITION CHANNELS

<u>SUB-SYSTEM</u>	<u>INPUT</u>		<u>BANDWIDTH</u>	<u>CHANNELS</u>
	<u>IMPEDANCE</u>	<u>VOLTAGE</u>		
Narrowband				
Amplifiers, Diff	500K ohms	100 MV	100 Hz	528
Multiplex				
Low Level	5 M ohms	100 MV	8Hz	846
High Level	500K ohms	10V	8Hz	611
Signal Conditioners				1384
Wideband				
Amplifiers, Diff	5M ohms	1V	Dc-10KHz	198
Amplifiers, Diff	100M ohms	10V	Dc-100KHz	8
VCO MPLX	50K ohms	10V	22-70KHz+ <u>7.5%</u>	21 groups of
VCO	20K ohms	10V	82.5KHz+ <u>40%</u>	12
Status Summary		+10V	DC	250
Carrier				None
Dynamic Analysis				None
Charge Amplifiers				None
Displacement (N. C.)				None

TABLE XXV
EXISTING DATA RECORDING CHANNELS

<u>DESCRIPTION</u>	<u>UNITS</u>	<u>INPUT</u>		<u>BANDWIDTH</u>	<u>CHANNELS</u>
		<u>IMPEDANCE</u>	<u>VOLTAGE</u>		
Recorder, Strip Chart, Multi-ch.	24	100K ohms	+20V	40Hz	192
Recorder, Magnetic Tape					
FM Record	2	Standard	IRIG		24
Direct Record	7	Standard	IRIG		84
Recorder, X-Y 8½ x 11	5	2M Ohms	50V/in	20 in/sec	
Recorder, Oscillographic	4				21
Galvos 3KHz	25				25
5KHz	25				25
10KHz	3				3
Recorder, event	2				120
DDP-116	1	100M ohms	+10V	DC	448

TURBOPUMP LAYOUT

FIGURE 1

PREDICTED TURBINE CONDITIONS
AT PUMP DP 1800 PSI AND CPM 12

PERMITTED THERMAL EXPANSION
AT 1000°F. TO 1200°F.
AND FROM 1200°F. TO 1500°F.

PREDICTED TURBINE CONVEYANCE
AT $N = 30000 \text{ RPM}$ AND PUMP D/N = 30

SINGLE TPA FLOW
SCHEMATIC
8/13/71

RCP

FIGURE 6

TEST CELL C
SINGLE TPA INSTALLATION
PROPOSED
LH2 PIPING
AT
TURBOPUMP

DUCT ID AT INTERFACES:

PUMP INLET	9.500
PUMP DISCHARGE	4.650
TURBINE INLET	7.188
TURBINE EXHAUST	7.250

TURBOPUMP INTERFACE INFORMATION

FIGURE 9

INSTRUMENTATION NEW FACILITY

T = TEMPERATURE, FLUID
 P = PRESSURE
 A = ACCELERATION
 D = DISPLACEMENT
 TS = TEMPERATURE, SURFACE
 S = STRAIN
 $P(W)$ = PRESSURE, WIDEBAND

INSTRUMENTATION, CRITICAL NEW FACILITY COMPONENTS

FIGURE 10

INTERFACE MECHANICS

FIGURE 11

STANDARD NARROW BAND DATA CHANNEL

STANDARD WIDEBAND DATA CHANNEL
FM MULTIPLEX

STANDARD WIDEBAND DATA CHANNEL
CHANNEL / TRACK

TYPICAL ANALOG CONTROL CONFIGURATION

FIGURE 15

TYPICAL BINARY VALVE
CONTROL CIRCUITS

FIGURE 16