JUSTIFICATION FOR WIDE BAND INSTRUMENTATION IN TEST CELL "A"

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DISCLAIMER

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JUSTIFICATION FOR WIDE BAND INSTRUMENTATION IN TEST CELL "A"

This document will present factors justifying the procurement of 195 channels of wide band instrumentation for use at Test Cell "A" during NRX-A-1 testing.

During this testing it will be necessary to evaluate reactor behavior by determining the following:

A. Sources of vibration in the reactor and propellant feed system.

B. If vibrations exist, how they are transmitted.

C. The effects of vibration on the various components.

D. The effects of thermal gradients and mechanical displacements.

E. The correlation between experimental results and the analytical models used for computation.

F. The modifications shown to be necessary.

These six goals can be accomplished by high-frequency measurements (to approximately 1000 cycles) of certain pressures, differential pressures, strains, and vibrations. Analysis of these tests will lead to performance evaluation and development of new designs.

Previous tests on similar type reactors indicate the existence of oscillatory forces capable of causing reactor failure. The NRX reactor is designed to eliminate such oscillation but verification of this design can only be accomplished through actual tests with an adequate instrumentation system, namely, wide band instrumentation. This system would determine the existence of oscillatory forces and the manner in which the force is transmitted to reactor components. These forces are non-sinusoidal and non-repetitive, requiring instruments with rapid response times, and a wide band data recording system to sense and record them without deterioration of wave shape and frequency.

The KIWI-B4-A reactor is thought to have failed because the core was excited by distributed pressure effects at approximately 30 cps. Flow variations also occur in the exhaust nozzle which are expected to cause structural vibrations in the range of 150-450 cps. Frequencies up to 1800 cps have been measured in the sound spectrum from the B4-A exhaust (LASL Report No. N-2146).

If sources of vibration are found, it becomes necessary to find the manner in which it is transmitted to other components. Once these are determined, corrective action can be taken either to eliminate the source or the transmission path. Transmission of vibration through either fluids or mechanical components can cause harmonics of the fundamental frequency to be generated, due to factors related to component configuration and stress. Instrumentation used to sense and record the frequencies which may be present must have characteristics which enable them to present a true picture of the vibrational forces.

Once the extent of the vibrations has been determined, it is desirable to diagnose its effects on reactor components. Because of the higher frequencies involved, the utilization of wide band equipment is necessary to record data from which an analysis can be made.

Analyses show that thermal gradients set up by flow blockage or throttling can cause certain components to fail due to the stresses created. This type of failure could be precipitated by movement of reactor components. Thermal gradients can result from improper flow distribution or from coolant leaks into non-flow areas. These may be caused by movement of components which block or restrict the passage of coolant through the passages in the reactor. These gradients can set up large stresses in some components which ultimately lead to failure. Instrumentation was chosen and positioned to allow an analysis of the recorded data to show cause of failure.

The NRX tests offer an opportunity to check actual performance against the calculations used for flow, heat transfer, and stress analysis. The data that can be gained from these tests will provide the designers with much of the data needed to predict the behavior of cryogenic fluids in this configuration and provide information needed to correct any defects that were found. For example, areas in which two phase flow can be present are considered one of the possible sources of vibration. Reliable evidence is needed to show whether this may be a contributing factor in failure analysis. For this reason, instrumentation has been selected and positioned to determine if pressure oscillations occur due to two phase flow. This instrumentation includes sensors to determine the amount of vibrational forces contributed by two phase flow. Experiments by Los Alamos,[1] NBS Cryogenic Engineering Laboratory, Lewis Labs, and others, show that pressure oscillations do exist in LH_2 systems. For the example cited, fluctuations occurred up to 8 psi and of variable frequency in a vacuum jacket line 1 3/8 in. ID. Pressure oscillation frequency was reproducible, and could be calculated reasonably accurately using system parameters such as density, pressure, lengths, and specific heats.

Wide band channels are required to make measurements of pressure and flow fluctuations in the NRX hydrogen system due to the difference in design as compared to experiment stated above. It is particularly important that simultaneous reactor, test car, and propellant system measurements be made so that perturbations can be traced regardless of source.

NRX design differs from that of KIWI by including an untested multiple seal arrangement. The performance of these seals is critical to an overall satisfactory test; and consequently, much wide band instrumentation must be used in this area to acquire sufficient data concerning the design of these seals.

Assumptions have been made about possible existing conditions within the reactor that may cause failures. Instruments and their locations have been selected

(1) Bronson, J. C., et al., Problems in Cooldown of Cryogenic Systems, Paper F-2, Advances in Cryogenic Engineering, Vol. 7, page 198. Plenum Press, N. Y., 1962.

to cover the various areas in which these forces may originate, both in the fluid flow and in mechanical components through which these forces may be transmitted.

The attached TMI-303, entitled "Measurement Requirements for NRX-A-1 Cold Flow", is a listing of the instrumentation which WANL design groups assume will be sufficient to meet the stated objectives by providing an analysis of the cold flow test. This analysis is based on the assumptions that:

A. Flow, pressure distributions, and strain are symmetrical in the reactor and pressure vessel where measurements could not be made.

B. Shifting of reactor components could occur and eventually cause blocking or restriction of coolant flow, but that it is not necessary to measure all areas where shifting might occur.

More evidence is needed to support these assumptions.

Since the data acquisition system would not accept the total of these measurements, it was necessary for WANL to reduce the number of measurements by limiting some test objectives. The objectives so limited are:

A. Temperature maldistribution in reactor materials and gas streams, both radial and azimuthal.

B. Measurements of flow distribution in all parts of the reactor, the nozzle and the pressure vessel.

C. Complete diagnostic information if a failure should occur.

D. Duplicate measurements to provide statistical reliability.

Many measurements, including strain, pressure and temperature, will be made of slowly varying parameters and can be recorded by the PAM/FM data system which has a frequency response limitation of 5 cycles per second, maximum. The narrow band data acquisition system at Test Cell "A" is not suited for recording high frequency data.

The narrow band data system is composed of selector switches (called multiplexers), electronic equipment, and tape recorders.

The multiplexers presently at Test Cell "A" have two sampling rates: 10 samples/sec and 40 samples/sec. The lower speed multiplexers have 42 channel inputs, while the rest have 47. All eight of the 10 samp/sec multiplexers and two of the 40 samp/sec multiplexers are limited to low level signals ($E < 100$ millivolts). Those remaining are high level ($0 < E < 5$ volts) operable at 40 samp/sec.

The amplifiers used with low-level signals have a bandwidth error of ± 3% at 40 cycles. This causes data so recorded to have a total error approaching ± 5% at 40 cps.

Analysis shows that to reproduce transducer output wave shapes within 0.1%, one cycle must be sampled 10 times during its period. An analysis is presented in Appendix I to show how reproduced wave shapes differ with various sampling ratios.

It has been proposed that WANL strap together several points on each multiplexer to increase frequency response to 40 cycles/sec. On the 10 samples/sec multiplexer, this means 40 points have to be strapped together leaving only two narrow band channels. There are 8 of these, giving a total of 8 wide band (40 cycle) channels and 16 narrow band channels. There are ten 40 sample/sec multiplexers requiring 10 points each for one 40-cycle channel. Each multiplexer supplies four 40-cycle channels and seven narrow band channels. This provides a total of 40 wide band and 70 narrow band channels. The overall totals for both types are:

48 wide band (40-cycle channels)
86 narrow band channels

Including the presently available 18 wide band FM channels at the test cell, this gives a total of 66 wide band channels. For comparison, the AGC requirements alone for NRX-A-1 total 74 narrow band and 34 wide band channels. The totals for all requirements needed for NRX-A-1 are 577 narrow band and 195 wide band channels.

It must be clearly understood that WANL requires 195 channels of wide band instrumentation in order to satisfy all objectives necessary to the development of a successful NERVA reactor. This figure of 195 channels is the minimum number of channels which can be used for recording of parameters to give WANL, AGC, and LASL enough information to draw valid conclusions during the cold flow test.

Other needs will exist in the NERVA Development Program as testing of the actuator, instrumentation and control systems becomes necessary. It is known, for example, that the NERVA reactor control system, the Test Cell "A" hydrogen propellant system, and the NERVA nuclear detection systems will require experiments at the NRDS.

In summary, WANL requests that the necessary additional equipment be provided to supply 195 channels of wide band recording capability because of the development programs required for the reactor, its instrumentation, and its control systems.

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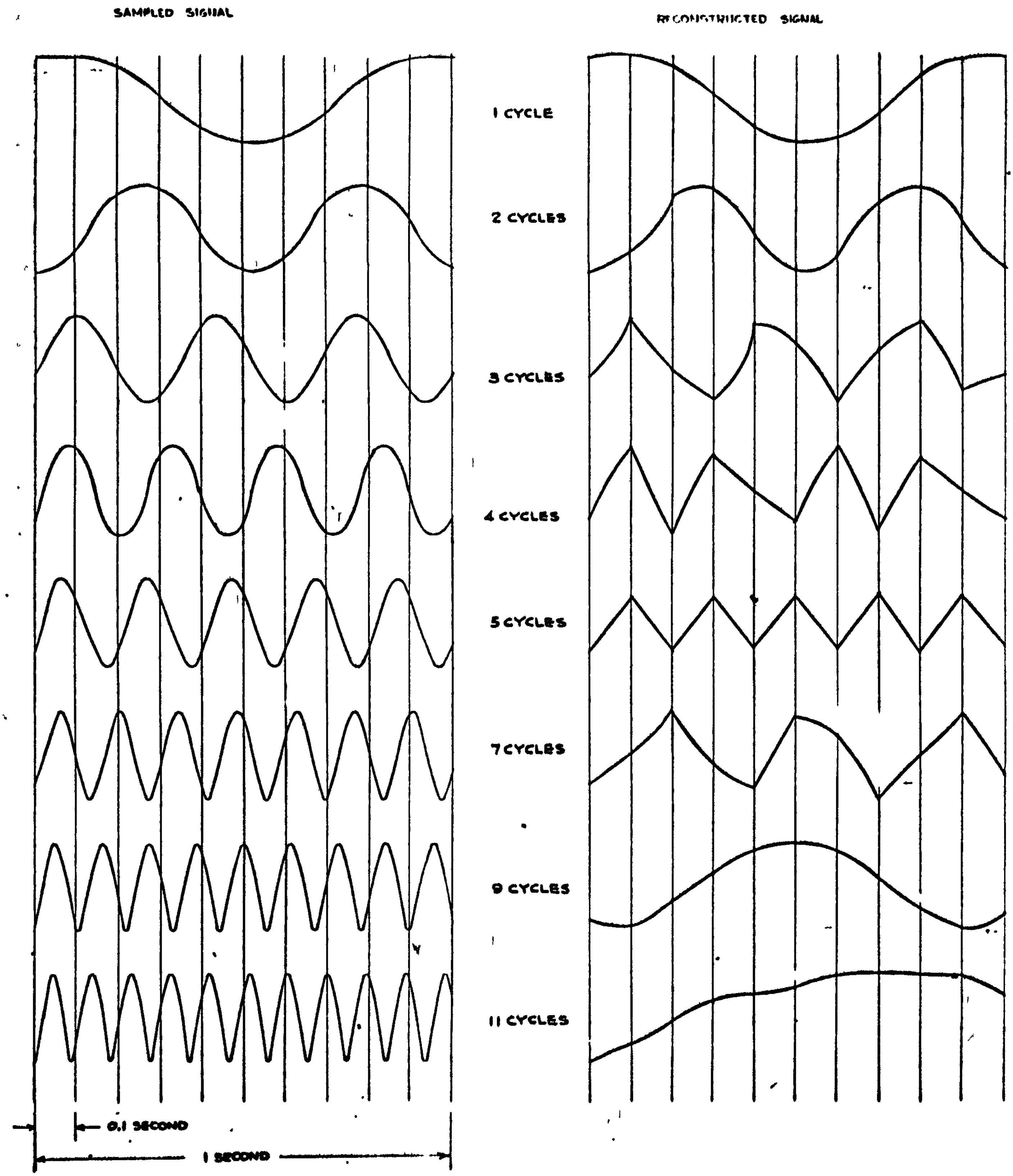
APPENDIX I

Appendix I shows the deterioration in wave shape of the reconstructed wave from that of the original as frequency of signal is increased with the sampling rate constant.

A sine wave is shown only for purposes of illustration of the effect of sampling rate on various low frequencies. The wave forms expected in NRX-A-1 tests will not be sinusoidal and will be non-repetitive. This makes an exact reconstruction of these wave shapes impossible.


SAMPLED SIGNAL
RECONSTRUCTED SIGNAL
1 CYCLE
2 CYCLES
3 CYCLES
4 CYCLES
5 CYCLES
7 CYCLES
9 CYCLES
11 CYCLES
0.1 SECOND
1 SECOND

TP-303

From: Test Planning & Analysis

Date: April 4, 1963

MEASUREMENT REQUIREMENTS FOR NRX-A-1 COLD FLOW

(Revision 2)

Prepared by: L. J. Wickas

Test Planning & Analysis

TABLE I - SPECIFIC OBJECTIVES

Objective	Test in Series: Facility Flow Tests	Test in Series: Ambient Gas Tests	Test in Series: Cold Gas Tests	Methods of Evaluation: Post-Operational Disassembly Inspections	Methods of Evaluation: Instrumentation Visual, TV, etc.	Objective Priority: Facility Flow Tests	Objective Priority: Ambient Gas Tests	Objective Priority: Cold Gas Tests
1. Determine effect of environmental conditions on structural integrity of reactor assembly components.		X	X	X			P	P
2. Determine amplitudes and frequencies of reactor assembly and test car component vibrations, displacements, and strains for comparison with design predictions, correlation with prior testing, and for test evaluation.		X	X		X		P	P
3. Determine material temperature distributions during thermal transients for comparison with design predictions and for test evaluations.			X		X			P
4. Determine fluid temp. pressure and flow transient behavior for comparison with design predictions and for test evaluation	X	X	X		X	P	P	P
5. Determine leakage across seals.			X		X			P
6. Determine source and magnitude of any coolant flow maldistribution in the reactor assembly			X		X			P
7. Determine torque requirements for control drums.		X	X		X		P	P
8. Determine causes of any reactor vibrations.		X	X		X		P	P
9. Determine overall performance of feed system when coupled with NRX-A-1 assembly.		X	X		X		P	P
10. Determine integrity of diagnostic instrumentation under actual test conditions.		X	X	X	X		P	P
11. Verify overall feed system dynamic response with simulated impedance.	X				X	P		
12. Verify leak tightness of reactor assembly.		X	X	X	X		P	P

Table II

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT (NUMBERS REFER TO TABLE I)
OUTER REFLECTOR	Reflector Inlet Plenum (Nozzle End)	Temperature	12	0-5 cps	40-600°R	Determine propellant temperature and azimuthal distribution. Objectives 4, 6, 8, 10
		Pressure	2	0-200 cps	*	Determine propellant pressure, amplitudes and frequencies of pulsations. Objectives 4, 8, 10
		Displacement	12	0-5 cps	± 0.25"	Measure eccentricity of the inner and outer core annuli. Objectives 2, 10
	Reflector Outlet Plenum (Dome End)	Temperature	12	0-5 cps	40-600°R	Determine propellant temperatures and azimuthal distribution. Objectives 4, 6, 8, 10
		Pressure	2	0-200 cps	*	Determine propellant pressure, amplitudes and frequencies of pulsations. Objectives 4, 8, 10
		Delta Pressure	1	0-200 cps	*	Determine pressure drop across outer reflector, amplitudes and frequencies of pulsations. Objectives 4, 8, 10
		Displacement	12	0-5 cps	± 0.25"	Measure eccentricity of the inner and outer core annuli. Objectives 2, 10
	Control Drums	Temperature	6	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
		Acceleration	3	0-1000 cps	*	Measure amplitude and frequency of vibration. Objectives 2, 8, & 10
	Bearings	Temperature	2	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
	Sectors	Temperature	18	0-5 cps	40-600°R	Determine material temperature. Objectives 3, 10
		Strain	12	0-5 cps	*	Measure material strains and directions of strain. Objectives 2, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
OUTER REFLECTOR (Continued)	Tie Bolts	Temperature	2	0-5 cps	40-600°R	Determine material temperature and spatial distribution. Objectives 3, 10
		Strain	4	0-5 cps	*	Measure material strain. Objective 2, 10
			2	0-200 cps	*	
	Support Ring (Dome End)	Temperature	2	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
		Strain	4	0-5 cps	2000×10^{-6} in/in	Measure material strains, directions of strains, amplitudes and frequencies of vibrations. Objectives 2, 10
			14	0-200 cps	2000×10^{-6} in/in	
	Support Ring (Nozzle End)	Temperature	2	0-5 cps	40-600°R	Determine material temperature. Objectives 3, 10
		Acceleration	2	0-1000 cps	1-10g	Measure amplitude and frequency of vibration. Objectives 2, 8, 10
INNER REFLECTOR	Core Support Ring	Temperature	3	0-5 cps	40-600°R	Determine material temperature. Objectives 3, 10
		Strain	6	0-5 cps	1500×10^{-6} in/in	Measure material strain, directions of strains. Objectives 2, 10
	Aluminum Support Barrel	Temperature	2	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
		Strain	9	0-5 cps	400×10^{-6} in/in	Measure material strains, directions of strain. Objectives 2, 10
	Graphite Cylinder	Temperature	12	0-5 cps	400-600°R	Determine material temperature. Objectives 3, 10
		Strain	9	0-5 cps	830×10^{-6} in/in	Measure material strains, directions of strains. Objectives 2, 10
		Delta Pressure	1	0-200 cps	*	Measure pressure drop across inner reflector, amplitudes and frequency of pulsations. Objectives 4, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
INNER REFLECTOR (Continued)	Filler Strips	Temperature	12	0-5 cps	400-600°R	Determine material temperature. Objectives 4, 8, 10
		Strain	24	0-5 cps	830×10^{-6}	Measure material strain and distribution. Objectives 2, 10
		Acceleration	12	0-1000 cps	0-10g	Measure amplitudes and frequencies of vibration. Objectives 2, 8, 10
	Seal Rings	Temperature	24	0-5 cps	40-600°R	Determine fluid temperatures, seal leakage indications. Objectives 4, 5, 6, 10
		Pressure	16	0-5 cps	*	Measure fluid pressure, spatial pressure distribution amplitudes and frequencies of pulsations, Objectives 4, 8, 10
			16	0-200 cps	*	
		Delta Pressure	48	0-5 cps	*	Determine pressure drop from seal chamber to core. Objectives 4, 8, 10
		Strain	8	0-5 cps	*	Measure material strains and distribution. Objectives 2, 10
	Leaf Springs	Temperature	3	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
		Strain	8	0-5 cps	*	Measure material strains, spatial distribution of strains, frequencies and amplitudes of vibration. Objectives 2, 10
			8	0-200 cps	*	
	Inner Reflector and Seal Graphite	Temperature	44	0-5 cps	40-600°R	Determine material temperatures & spatial distributions. Objectives 3, 10
	Nozzle Interface Seal	Temperature	12	0-5 cps	40-600°F	Determine fluid temperatures azimuthal temperature distribution, seal leakage. Objectives 5, 6, 8, 10
	Axial Spring Assembly	Temperature	2	0-5 cps	40-600°R	Determine material temperatures and spatial distributions. Objectives 3, 10

Table II (Cont.)
INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
SHIELD	Dome End of Shield	Temperature	12	0-5 cps	40-600°R	Determine propellant temperature and azimuthal distribution. Objectives 4, 6, 8, 10
	Dome End Support Plate	Temperature	3	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
	Nozzle End Support Plate	Temperature	3	0-5 cps	40-600°R	Determine material temperatures. Objectives 3, 10
	Between Shield and Dome	Pressure	1	0-200 cps	*	Measure propellant pressures, amplitudes and frequencies of pulsations. Objectives 4, 8, 10
	Between Shield and & Core Top Support Plate	Temperature	3	0-5 cps	40-600°R	Determine propellant temperature, azimuthal distribution. Objectives 4, 6, 10
CORE ASSEMBLY	Inlet Plenum (Dome End)	Temperature	12	0-5 cps	40-600°R	Determine propellant temperatures and azimuthal distribution. Objectives 4, 6, 8, 10
		Pressure	2 4	0-200 cps 0-5 cps	* *	Measure propellant pressure, amplitudes, and frequencies of pulsations. Objectives 4, 8, 10
		Delta Pressure	1	0-200 cps	*	Measure pressure drop across shield and support plate, amplitudes and frequencies of pulsations. Objectives 4, 8, 10
	Support Plate	Temperature	9	0-5 cps	40-600°R	Determine material temperatures and spatial distribution. Objectives 3, 10
		Strain	6	0-5 cps	1200×10^{-6} in/in	Measure material strains, spatial distribution of strain, frequencies, and amplitudes of vibration. Objectives 2, 10
		Strain	2	0-200 cps	1200×10^{-6} in/in	Measure material strains, spatial distribution of strains, frequencies, and amplitudes of vibration. Objectives 2, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
CORE ASSEMBLY (Continued)	Support Plate (Continued)	Acceleration	6	0-1000 cps	1-10 g	Measure amplitudes and frequencies of vibration. Objectives 2, 8, 10
		Displacement	7	0-5 cps	± 0.25"	Measure differential movement between plate and surrounding components. Objectives 2, 10
	Fuel Modules	Temperature	9	0-5 cps	100-600°R	Determine material temperatures and spatial distributions. Objectives 3, 10
		Strain	42	0-5 cps	830×10^{-6} in/in	Measure material strains, spatial distributions of strains, amplitudes and frequencies of vibration. Objectives 2, 10
			12	0-200 cps	830×10^{-6} in/in	
	Tie Rods	Temperature	1	0-5 cps	40-600°R	Determine material temperature. Objectives 3, 10
		Strain	4	0-5 cps	2000×10^{-6} in/in	Measure material strains, spatial distribution of strains, amplitudes, and frequencies of vibration. Objectives 2, 10
			2	0-200 cps	2000×10^{-6} in/in	
	Bottom Support Blocks	Acceleration	6	0-1000 cps	1-10 g	Measure amplitudes and frequencies of vibration. Objectives 2, 8, 10
	Core Exit Plenum	Temperature	12	0-5 cps	300-600°R	Determine propellant temperatures and azimuthal distribution. Objectives 4, 6, 8, 10
		Pressure	1	0-200 cps	*	Measure propellant pressure amplitudes and frequencies of pulsations. Objectives 4, 8, 10
		Delta Pressure	1	0-200 cps	*	Determine core pressure drop (including orifices), and amplitudes and frequencies of pulsations. Objectives 4, 8, 10
			6	0-5 cps	*	

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
TEST CAR						
	Main Propellant Line	Temperature	3	0-5 cps	*	Objectives 3, 10,
	Main Propellant Line	Acceleration	3	0-1000 cps	*	Objectives 2, 8, 10
	Reactor Support Stool Legs	Strain	2	0-5 cps	*	Objectives 2, 8, 10
	Privy Roof	Acceleration	3	0-1000 cps	*	Objectives 2, 8, 10
	Privy Wall	Acceleration	3	0-1000 cps	*	Objectives 2, 8, 10
		Microphone	1	0-5000 cps	*	Measure frequency spectrum of air-borne energy
		Microphone	1	0-5000 cps	*	
		Microphone	1	0-5000 cps	*	
NOZZLE						
	Nozzle Manifold Inlet	Pressure	1 1	0-5 cps 0-3000 cps	* *	Determine propellant pressure, amplitudes, and frequencies of pulsations. Objectives 4, 6, 8, 10
		Temperature	2	0-5 cps	*	Determine propellant temperature amplitudes and frequencies of pulsations.- Objectives 4, 6, 10
	Nozzle Tube Outlet	Pressure	1 1	0-5 cps 0-300 cps	* *	Determine propellant pressure, amplitudes and frequencies of pulsations. Objectives 4, 6, 8, 10
		Temperature	2	0-5 cps	*	Determine propellant temperature. Objectives 4, 6, 10
	Nozzle Chamber	Pressure	1	0-5 cps	*	Determine propellant pressure. Objectives 4, 6, 8, 10
		Temperature	4	0-5 cps	*	Determine propellant temperature and azimuthal distribution. Objectives 4, 6, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
NOZZLE						
	Nozzle Flange	Strain	4 4	0-500 cps 0-5 cps	* *	Determine material strains, directions of strains, spatial distribution, amplitudes and frequencies of vibrations. Objectives 2, 8, 10
	Flange Coolant Lines	Flow	3	0-300 cps	*	Determine fluid flow rate, amplitudes and frequencies of pulsations. Objectives 4, 6, 8, 10
	Nozzle	Acceleration	9	0-1000 cps	*	Determine amplitudes and frequencies of vibrations. Objectives 2, 10
	Nozzle Wall	Temperature	6	0-5 cps	*	Determine material temperature, and spatial distributions. Objectives 3, 6, 10
	Nozzle Tube	Delta Pressure	1 1	0-5 cps 0-300 cps	* *	Measure Pressure drop across nozzle tubes.
		Temperature	2	0-5 cps	*	Measure Temp. drop across nozzle tubes
	Nozzle Flange	Temperature	6	0-5 cps	*	Determine material temperature and spatial distributions. Objectives 3, 10
	Nozzle Flange Bolts	Temperature	3	0-5 cps	*	Determine material temperature and spatial distribution. Objectives 3, 10
	Torus Around Nozzle	Temperature	3	0-5 cps	40-600°R	Determine propellant temperature and azimuthal distribution. Objectives 4, 6, 10
		Delta Pressure	2	0-200 cps	*	Measure pressure distribution in torus, amplitudes, and frequencies of pulsations. Objectives 4, 6, 8, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
PRESSURE VESSEL						
	Control Drum Actuators	Pressure	1 1	0-5 cps 0-5 cps	250-750 psia 250-750 psia	Determine hydraulic fluid pressure.
		Temperature	1 1	0-5 cps 0-5 cps	520-585°R	Determine hydraulic fluid temperature.
			9	0-5 cps	520-585°R	Measure torque transducer temp.
		Torque	9	0-200 cps	± 250 in-lbs	Determine control drum torque requirements. Objectives 7, 10
		Position	9	0-200 cps	0-180°	Measure control drum positions. Objectives 7, 10
		Acceleration	2	0-100 cps	0-10g	Measure amplitude and frequency of vibration. Objectives 2, 8, 10
		Command Signal	5	0-200 cps	0-1 volt	Measure input signal.
	Reflector Outlet	Pressure	1 1	0-5 cps 0-300 cps	* *	Measure fluid pressure.
		Temperature	2	0-5 cps	*	Measure fluid temperature.
	Pressure Vessel Annulus @ Reflector Outer Plenum	Temperature	1	0-5 cps	*	Determine fluid temperature. Objective 4, 10
		Pressure	1	0-200 cps	*	Measure fluid pressure amplitudes. and frequencies of pulsations. Objectives 4, 8, 10
	Pressure Vessel and Dome	Temperature	6	0-5 cps	*	Determine material temperatures and spatial distributions.
	Pressure Vessel AFT	Strain	8 8	0-500 cps 0-5 cps	* *	Determine material strains, directions of strains, spatial distribution, amplitudes and frequencies of vibrations. Objectives 2, 8, 10
	Pressure Vessel Flange	Strain	2 2	0-500 cps 0-5 cps	* *	Determine material strains, directions of strains, spatial distribution, amplitudes and frequencies of vibrations. Objectives 2, 8, 10

Table II (Cont.)

INSTRUMENTATION LIST

SUB-ASSEMBLY	COMPONENT	MEASURAND	QUANTITY	FREQUENCY RESPONSE	ESTIMATED SENSOR RANGE	OBJECTIVES OF MEASUREMENT
PRESSURE VESSEL (Continued)	Control Rod Boss	Strain	4	0-5 cps	*	Determine material strains directions of strains. Objectives 2, 10
		Temperature	1	0-5 cps	*	Determine Material temperature. Objectives 3, 10
	Instrument Port Boss	Temperature	1	0-5 cps	*	Determine Material temperature. Objectives 3, 10
	Pressure Vessel AFT Flange	Temperature	6	0-5 cps	*	Determine material temperature, spatial distribution. Objectives 3, 6, 10
	Pressure Vessel External Wall	Temperature	3	0-5 cps	*	Determine material temperatures. Objectives 3, 10
	Pressure Vessel Forward Flange	Temperature	3	0-5 cps	*	Determine material temperatures. Objectives 3, 10
	Dome Flange	Temperature	3	0-5 cps	*	Determine material temperatures. Objectives 3, 10
	Dome	Temperature	1	0-5 cps	*	Determine material temperature. Objectives 3, 10
		Acceleration	3	0-1000 cps	*	Determine amplitudes and frequencies of vibrations. Objectives 3, 2, 10

* - NOT AVAILABLE