LIQUID ROCKET PLANT

FINAL TEST REPORT
MECHANICAL IRRADIATION TEST
3/L003
TURBOPUMP BEARING SET

Report 1.9.5-6E 23 April 1964

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

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MECHANICAL IRRADIATION TEST
3/L003
TURBOPUMP BEARING SET

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ABSTRACT

Nonlubricated, hydrogen-cooled roller- and ball-bearing assemblies were operated at cryogenic temperatures in a nuclear radiation field. The bearings are candidate NERVA turbopump bearing sets.

Two sets of AGC PN 290156-109 roller bearings and one pair of AGC PN 287812-19 ball bearings were tested. The roller bearing rollers, inner races, and outer races were made of Mod 440C steel; the cage material was polytetrafluoroethene laminated fabric. The ball bearing assemblies used Mod 440C (HTST) balls, inner races and outer races, and fluorinated ethylene propylene laminated fabric cages.

The bearings were operated within a temperature range of -423 to -300°F at 24,000 rpm under 2000 lb radial and axial loads. The measured integrated neutron fluxes to which the bearing tester was exposed ranged from 1.9×10^{12} to 9.3×10^{13} n/cm^2 (E > 2.9 Mev). Measured gamma doses ranged from 5.8×10^{6} to 1.1×10^{8} ergs/gm(c).

A posttest visual examination of the bearings showed no evidence of degradation.

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APPENDIXES

I. INTRODUCTION

A series of irradiation tests is being conducted on development models of NERVA nuclear rocket engine components to investigate operability under anticipated environmental conditions. This report describes the third in a series of irradiation tests on NERVA turbopump bearing assemblies (References 1 and 2).

The NERVA rocket engine utilizes an atomic reactor to heat liquid hydrogen. Because of weight considerations, the reactor will be only partially shielded, requiring operation of the engine components, such as the turbopump, in a moderate nuclear-radiation field. The turbopump is used to feed the liquid hydrogen to the reactor. The bearing assemblies used in the turbopump will have to withstand a combined cryogenic and nuclear-radiation environment. To avoid the problems associated with the use of lubricants in such an environment, Aerojet-General is presently developing nonlubricated, hydrogen-cooled bearings for the NERVA turbopump assembly.

The test utilized the Aerospace System Test Reactor (ASTR) at the Nuclear Aerospace Research Facility (NARF), operated for the Air Force by the General Dynamics Corporation at Fort Worth, Texas. Prior to the irradiation tests, developmental testing of the candidate bearing assemblies was performed in Aerojet-General non-nuclear cryogenic facilities at Sacramento, California.

II. EXPERIMENT IDENTIFICATION

A. TEST PLAN REFERENCE:

3/L003, Turbopump Assembly (TPA) Bearing Sets

B. SPONSOR:

Aerojet-General Corporation
NERVA Rocket Operations
Liquid Rocket Plant
for
AEC-NASA Contract SNP-1

II, Experiment Identification (cont.)

C. TEST FACILITIES

1. Pre-Irradiation Tests

Aerojet-General Corporation
Liquid Rocket Plant
Sacramento, California

2. Irradiation Tests

General Dynamics Corporation (GD/FW)
NARF-ASTR
Forth Worth, Texas

3. Post-Irradiation Examination

Aerojet-General Corporation
Liquid Rocket Plant
Sacramento, California

D. TEST HISTORY

The following tests were conducted:

1. Pre-Irradiation Test

354 sec duration on 11 October 1963

Reference: AGC RMR No. 0125
Sub-Subtask 1.2.4
Date: 29 October 1963
WOREL 0718-21-295

II, D, Test History (cont.)

2. Pre-Irradiation Checkout Test

Run 1: 5 sec duration, 23 October 1963
Run 2: 3 sec duration, 23 October 1963

3. Irradiation Test

300 sec duration, 24 October 1963

E. BEARING TESTER IDENTIFICATION

PN 263500-9, SN 0000004

F. BEARING IDENTIFICATION

Location	Type	PN	SN
Loader (pump) end	Roller Bearing 16 Elements, Armalon Medium Profile Cage	290156-109	A-34
Thrust Bearing (one pair)	Ball Bearing 12 Elements, Armalon cage, split inner race	287812-19	208A & B
Motor (turbine) End	Roller Bearing 16 Elements, Armalon Medium-Profile Cage	290156-109	A-33

III. PURPOSE OF THE EXPERIMENT

The purpose of the experiment was to demonstrate that the candidate bearing assemblies will operate under cryogenic temperatures at design speed and loads of 24,000 rpm and 2000 lb in a nuclear-radiation field for a duration of 10 min.

IV. TEST SYSTEM DESCRIPTION

The test system was the same as that used for Test 3/L002 (Reference 2). The major system subassemblies consisted of storage vessels for liquid hydrogen, liquid nitrogen, gaseous hydrogen, gaseous nitrogen, and gaseous helium; gas distribution systems; transfer lines; instrumentation; data acquisition units and the test pallet with its associated control components; and the bearing tester.

The bearing tester consisted of a NERVA Mark III turbopump power transmission (cooled by hydrogen at cryogenic temperatures) with a bearing shaft accommodating the hydrogen-cooled motor on one end, the pneumatically operated radial and axial load devices on the other end, and the bearings in the center section. The 2-pole motor is rated at 50 hp and operates on 208 v, 400 cycle, three-phase power. Radial and axial loads were applied to the shaft by pressurizing the radial and axial load chambers with GH_2 regulated at the load-control pallet. Figure A-10 shows a sketch of the bearing tester.

Two sets of roller bearings and one pair of ball bearings (thrust bearings) were tested. The candidate bearings were all of the SAE 210 size. The identities and descriptions of the bearings are listed in Section II, E.

The bearing tester was mounted within the test-pallet containment vessel (Figures A-1 through A-6). Also mounted on the test pallet were stop valves, filters, helium pressure regulators, and instrumentation. During the test, the pallet was located in the outside ASTR tank test-cell; the center line of the bearing-tester shaft was coincident with the center line through the front face of the reactor void chamber. The containment vessel (removed in the pictures) maintains an inert helium atmosphere around the bearing tester to alleviate any fire or explosion potential in the event of hydrogen leakage.

The load-control pallet regulated the pressures in the axial and radial load chambers. Gas-regulation components mounted on this pallet included solenoid-controlled regulators and valves, filters, rupture diaphrams, and safety relief valves.

IV, Test System Description (cont.)

This unit was located outside the biological shield to remove it from the high-intensity nuclear-radiation field. Remote-controlled regulators permitted the loads to be increased and decreased from the control room simultaneously with the startup and shutdown of the bearing tester. Figures A-8 and 9 show the top assembly drawing and photographs of the load-control pallet.

V. TEST PROCEDURE

The complete test procedure is found in Reference 3. Briefly, the test procedure had the following steps:

1. The test system was checked for component operation, leakage, and electrical calibration. This was followed by a system purge.

2. A flow checkout with liquid nitrogen was conducted.

3. The Dewar vessel was filled with liquid hydrogen and a system cooldown was conducted with liquid hydrogen.

4. Upon reaching a cooldown temperature of approximately -400°F, the bearing tester was turned on and operated for 600 sec.

5. At the end of 600 sec, the bearing tester was shut off, and the reactor was "scrammed."

6. The bearing tester was removed from the test stand and returned to Aerojet-General.

VI. NUCLEAR MEASUREMENTS

The incident-integrated neutron fluxes and gamma doses to which the test pallet was exposed were measured at ten locations within the containment vessel.

VI, Nuclear Measurements (cont.)

Each packet contained aluminum, phosphorus, and sulfur neutron detectors; and nitrous oxide, chemical, and cobalt-glass gamma detectors that were mounted on 3-1/2 by 3-in. aluminum holders. The location of each packet and the measured integrated neutron fluxes and gamma doses are presented in Figure B-1. A detailed report of the dosimetry data is given in Reference 3.

VII. TEST RESULTS

Data from the two checkout runs and the irradiation run are plotted in Figures C-1 through D-8.

A. CHECKOUT RUNS

Two 10-sec checkout runs were attempted on 23 October 1963. Run 1 was stopped 5 sec after FS_1 when the bearing-tester speed (NTPB) failed to register. Another test, Run 2, was made with the axial and radial loads removed to reduce the starting torque. After 3 sec, Run 2 was stopped when the motor speed again failed to register. The trouble was later found to be a faulty connection in the instrumentation patchboard. The Dewar LH_2 supply pressure, the bearing-tester hydrogen coolant inlet pressure, and the orifice inlet pressure are illustrated in Figure C-1. The pressure drop through the orifice ranged between 5 to 10 psi and averaged around 8 psi. Pressures in the radial and axial load chamber and in the bearing-tester loading cavity are illustrated in Figures C-2 and C-3 respectively. The pressures of the bearing housing and the bearing-tester motor housing are illustrated in Figure C-4.

Figure C-5 gives the temperature at the inlet to the bearing tester and at the outside diameters of the outer race of the loader-end roller bearing and the motor-end roller bearing. The split-race ball-bearing temperature and the bearing-tester hydrogen outlet temperature are given in Figure C-6. A sudden increase of the ball-bearing temperature is noted in both runs; this peaked at -43°F, approximately 2-sec after FS_1 before decreasing. Posttest inspection revealed wear on the

VII, A, Checkout Runs (cont.)

swaged thermocouple, indicating possible rotation of the outer ball bearing race. No wear marks were observed on the thermocouples used for the roller bearings.

Starting current of the motor reached a maximum of 265 amp for Run 1 and 262 amp for Run 2, as shown in Figure C-7. The long current-decay period (20-sec) is a function of the RC time constant in the measuring circuit.

B. IRRADIATION TEST

The Irradiation Test was conducted on 24 October 1963 for 10 min at 10 MW reactor power level. The bearing tester performed satisfactorily throughout the test. The orifice bypass valve (OPBV) was opened at 7 min, 13 sec after FS_1, when a sudden increase of the TSB temperature was observed. Opening the OPBV increased the mass-flow rate, which had the effect of decreasing the rate of temperature increase. Table D-1, Appendix D, lists the sequence of major events that occurred during the 10-min irradiation run. The integrated neutron fluxes and gamma doses to which the test components were exposed during the test are presented in Appendix B.

The pressures in the liquid hydrogen Dewar vessel and at the orifice inlet and outlet are illustrated in Figure D-1. Between FS_1 and FS_2 the pressure differential across the orifice ranged between 5.5 psi and 13.5 psi with an average of 9 psi. Figure D-2 illustrates the pressures in the bearing housing and the bearing-tester motor housing. Pressures in the radial and axial load devices are shown in Figure D-3; and pressures within the bearing-tester load cavity are illustrated in Figures D-3 and D-4, respectively.

Plots of the inlet and outlet temperatures of the hydrogen coolant flowing through the bearing tester are shown in Figure D-5. Resistance temperature transducers (RTT's) measured the coolant inlet and outlet temperatures of the bearing tester. The fact TLSH, the upstream measurement point, at times indicated a higher temperature than at TLDH, the downstream measurement location, is not fully understood.

VII, B, Irradiation Test (cont.)

One possible explanation for the apparent temperature reversal between FS_1+8 and FS_1+10 min is that after the orifice bypass valve (OPBV) was opened, the flow rate decreased through the orifice leg of the parallel flow system and a resulting increase in temperature at the TLSH location occurred. The temperature reversal before FS_1 has no apparent explanation.

Figure D-6 shows plots of the bearing temperatures. The temperatures were sensed by swaged thermocouples held against the OD of the outer race of each bearing assembly. In general, the bearing temperatures followed the variations in the coolant inlet temperature. One notable exception is in the rapid temperature increase of the ball bearing (TSB) immediately after FS_1. TSB, the temperature of the ball bearing increased to -66°F immediately after FS_1, remaining there for 3 sec before decreasing to its original value. This same temperature spike was observed on both checkout tests. Posttest examination revealed wear marks on the thermocouple, which confirmed the hypothesis that the outer race of the ball bearing was turning with the bearing-tester shaft during the first few seconds of shaft rotation. As was noted earlier, the orifice bypass valve was opened at FS_1+7 min and 13 sec when TSB showed a sudden temperature increase. Posttest examination of the data revealed that the coolant inlet temperature increased over this same period. It is believed that no abnormal bearing operation occurred at this time, but that the bearing temperature merely reflected the increase in the coolant temperature.

An anomaly exists between the thermocouple readings and the RTT readings. The thermocouples register lower temperatures than the RTT's. The reason for this anomaly, especially for the coolant inlet temperature (TLSH) has not been determined.

Figures D-7 and D-8 show plots of the speed and current of the bearing-tester motor, which were normal throughout the test.

VII, Test Results (cont.)

C. POST-IRRADIATION BEARING EXAMINATION

After the bearing tester was removed from the test pallet and returned to the Aerojet-General Sacramento Plant, it was disassembled and inspected. Figure A-10 shows the tester after disassembly. Visual examination revealed that the bearings were in excellent condition (Ref 4).

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

It is concluded that the bearings operated successfully during all phases of the irradiation test. All test values were well within the maximum and minimum limits established for the test. A comparison of the maximum and minimum limits established for the test and the test results follow:

Function	Allowable Limits	Test Results Maximum/Minimum
TRB-1	<-50°F	-357°F/-406°F
TSB	<-50°F	-395°F/-423°F
TRB-2	<-50°F	-333°F/-390°F
PLDH	>150 psig	225 psig/209 psig
PGH_2DT	235 psig max	227 psig/215 psig
NTPB	25,000 rpm max	24,000 rpm
IM (run current)	<100 amp	53 amps/42 amp

The test demonstrated that the candidate bearings will operate successfully for 600 sec in a radiation environment consisting of 1.9×10^{12} to 9.3×10^{13} n/cm^2 (E> 2.9 Mev) and gamma doses ranging from 5.8×10^6 to 1.1×10^8 ergs/gm(c).

VIII, Conclusions and Recommendations (cont.)

B. RECOMMENDATIONS

1. Calibration procedures for all instruments should be included in the test procedures for those future irradiation tests that require more definitive data.

2. The effects of temperature cycling on pressure transducers should be investigated.

3. Consideration should be given to monitoring the temperatures of all pressure transducers to observe any readings outside the temperature-compensated range. Pretest analysis should be conducted to predict temperatures and enable the use of transducers with suitable accuracy.

4. A log showing all instrumentation units used in each data channel and all calibration data should be recorded by the facility contractor and sent to the test contractor as part of the data package.

5. Pursue further investigation of nuclear radiation effects on hydrogen-cooled test systems.

REFERENCES

1. Final Test Report, Mechanical Irradiation Test 3/L001, Turbopump Bearing Set, Aerojet-General Report 1.9.5-1E, Volume 1, February 1964.

2. Final Test Report, Mechanical Irradiation Test 3/L002, Turbopump Bearing Set, Aerojet-General Report 1.9.5-5E, 20 March 1964.

3. Nerva Components Irradiation Program. Vol 6: ASTR Test 3. General Dynamics/Fort Worth Report F2K-170-6, 20 December 1963.

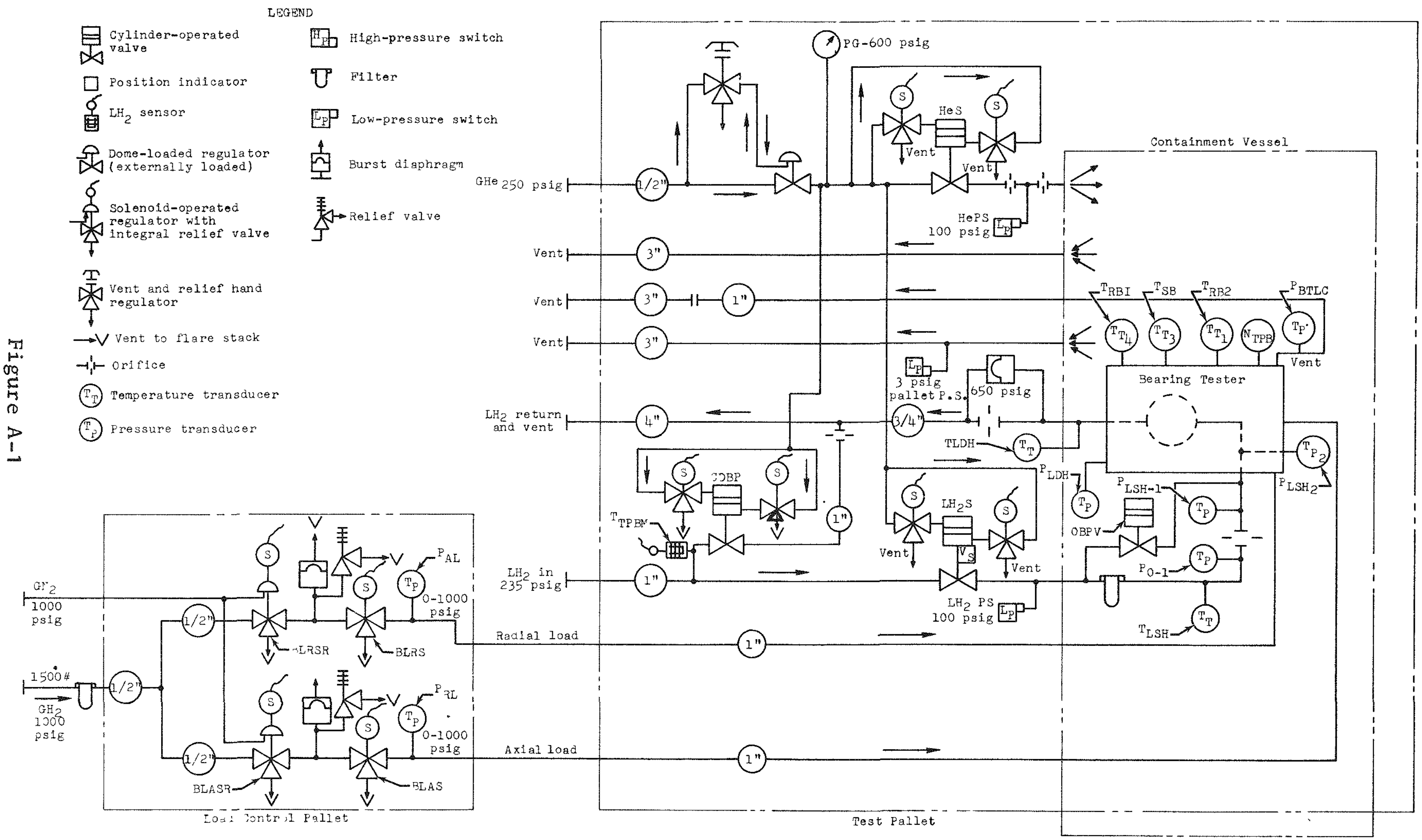
4. Nerva Turbopump Bearing and Tester MIT903 Test Report--Radiation Effects, Aerojet-General Report 1.2.4-64-M-005, (to be published).

APPENDIX A

PHOTOGRAPHS AND DRAWINGS OF MECHANICAL IRRADIATION TEST 3/L003 AND THE FACILITY AT GENERAL DYNAMICS, FORT WORTH

FIGURE LIST

Figure A-1



No. 903 Mechanical Test Pallet--Hydraulic Flow Schematic

NOTES:

1 REMOVE ALL BURRS AND SHARP EDGES
2 INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327
3 FORM, FLARE AND ASSEMBLE PER AGC-46097
4 TORQUE BOLTS #10-24 TO 15-20 IN-LBS, 1/4-20 TO 60-80 IN-LBS, 5/16-18 TO 120-140 IN-LBS, 3/8-16 TO 200-250 IN-LBS
5 INSTALL PER AGC-STD 4002
6 SEE DWG NO 295717 FOR ELECTRICAL SCHEM DIAG AND HYD DWG NO 295680.
7 CLEAN PER AGC-46350 AS FOLLOWS
   (a) INTERIOR PLUMBING SYSTEM LEVEL G
   (b) EXTERIOR SURFACES LEVEL H
8 PRESERVE AND PACKAGE PER AGC-46387, CLASS I
9 APPLY A LIGHT COAT OF ANTI-SEIZE COMPOUND TO THREADS AT ASSY
10 CLASSIFICATION OF CHARACTERISTICS PER MIL-W-9411 DENOTED BY (CRITICAL), (MAJOR), AND NO SYMBOL (MINOR)
11 SILVER SOLDER PER MIL-B-7883
12 PROOF TEST AT 375±25 PSIG, LEAK TEST AT 250±25 PSIG WITH AIR OR NITROGEN UNDER WATER FOR 2 MINUTES. NO LEAKAGE PERMITTED
13 PROOF TEST AT 2250±50 PSIG, LEAK TEST AT 1500±50 PSIG WITH AIR OR NITROGEN UNDER WATER FOR 2 MINUTES NO LEAKAGE PERMITTED.
14 PROOF TEST AT 225±25 PSIG, LEAK TEST AT 150±25 PSIG WITH AIR OR NITROGEN UNDER WATER FOR 2 MINUTES NO LEAKAGE PERMITTED
15 COML PROD PROCURED UNDER ANOTHER P/N NOT ACCEPTABLE UNLESS APPROVED BY ENGR.
16 COML PROD SEE SOURCE CONTROL DWG 294901 THRU 294978
17 END TO BE TRIMMED AND FLARED ON ASSEMBLY

QTY REQD -9	SYM	CODE IDENT NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
F				SILVER SOLDER		QQ-S 561		–	117
AK				ANTI-SEIZE COMPOUND		AGC-44068		–	116
1			AN929-20C	CAP				2 4/B	115
1			AN929-16C	↕				2 4/B	114
			AN92[illegible] 1C	CAP				3 3/D	113
2			AN824-4C	TEE				3 4/B	112
								3 3/A	111
2	V	98625	54973 10	SEAL				3 3/A	110
1	V	57187	PL 732T[illegible] 125-350	TRANSDUCER				3 3/D	109
1	V	92215	VSF [illegible] -N-20	SEAL				2 4/B	108
16	V	↕	VSF-1015 -N-16	↕				2 2/C	107
10	V		VSF-1015 -N-12					2 4/C	106
4	V		VSF-1015 -N-10					2 2/C	105
27	V	92215	VSF-1015 -N-4	SEAL				3 4/A	104
5	V	15687	PT 25 SP 0 350	TRANSDUCER				3 3/D	103
2	V	13881	F-82-4	VALVE, SOLENOID				3 1/C	102
1	V	07107	32-2475	FILTER ASSY				3 4/D	101
1	V	13881	DWG NO 0794	3/4" VALVE				3 4/D	100
1	V	12179	VD 261 0006 0020	SEAL, METAL				2 4/B	99
1	V	12179	VD 261 0006 0016	↕				3 4/D	98
1	V	12179	VD26 0006 0012					2 4/C	97
1	V	12179	VD26-0006 -0004	SEAL, METAL				3 2/C	96
	V	96985	COML PROD 4-37 108	90° ELBOW				3 2/D	95
								–	94
2			W-500 600 A20	GASKET				3 3/D	93

QTY REQD -9	SYM	CODE IDENT NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
2			295672-17	SUPPORT				2 3/C	92
1			-35	TUBE ASSY	MAKE FROM 295787-9			3 3/B	91
10			NAS609 -C6-16	BOLT				3 4/D	90
8			NAS609 -C4-20	↕				2 3/A	89
24			NAS609 -C5-16					2 4/D	88
17			NAS609 -C4-10	BOLT				3 1/C	87
1			NAS424-20C	COUPLING				2 4/B	86
1			-33	TUBE ASSY	MAKE FROM 295786-9			2 3/C	85
2			295785-9	TUBE				3 3/B	84
4			AN4C-11A	BOLT				2 4/C	83
57			MS35338 -82	WASHER				2 3/B	82
40			MS35338 -83	↕				2 4/D	81
10			MS35338 -84	WASHER				2 3/A	80
6			MS20364 -820	NUT				3 2/A	79
1			AN919-29C	REDUCER				2 3/D	78
1			AN919-25C	↕				2 4/C	77
4			AN919-23C					3 3/D	76
1			AN919-22C					2 2/C	75
1			AN919-20C					3 3/A	74
1			AN919 13C	REDUCER				3 2/A	73
8			AN960C4 16	WASHER				3 2/C	72
2			AN833-12C	ELBOW				2 3/B	71
2			AN833-20C	↕				2 4/B	70
4			AN833-16C	ELBOW				2 2/B	69
4			AN4C-31A	BOLT				3 1/C	68
12			AN960C816	WASHER				3 2/A	67
1			AN6289-4C	NUT				3 2/C	66
1			AN924-20C	↕				2 4/B	65
3			AN924-16C					2 4/B	64
1			AN924-12C					2 3/B	63
20			AN315C -4R-					2 [illegible]	62
1			AN6289-20C					2 4/B	61
1			AN924-8C					2 3/B	60
1			AN6289-16C					3 4/D	59
1			AN6289 12C	NUT				2 4/C	58
6			AN8 C17A	BOLT				3 2/B	57
1			A51429 2	PLATE, IDENT				2 3/D	56
1			A51149 16	RESTRICTOR				2 3/D	55
12			AN4C26	BOLT				2 3/B	54
32			A51026-518-18	BOLT				3 2/B	53
1			AN832-8C	UNION				2 3/C	52
2			AN815-16C	↕				3 4/D	51
2			AN815-10C					2 2/D	50
6			AN815-4C	UNION				2 3/A	49
1			AN938C10	TEE				2 2/D	48
1			AN824-16C	↕				2 2/A	47
1			AN804-4C	TEE				3 2/C	46

QTY REQD -9	SYM	CODE IDENT NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
2			295780-	BRACKET				3 1/C	45
1			295784-15	TUBE ASSY				3 3/B	44
2			295757-1	BRACKET				2 4/C	43
1			294923	SEAL				2 4/C	42
1			294922	↕				3 4/D	41
2			29492.					3 3/A	40
3			294920					2 2/D	39
1			294919					2 3/D	38
6			294916	SEAL				2 3/A	37
1			295782-9	TUBE ASSY				3 2/D	36
1			295781-9	↕				3 2/D	35
1			295779 9					3 2/C	34
1			295760-9					3 2/B	33
1			295754-9	TUBE ASSY				2 3/D	32
			295753-9	ELBOW, SPECIAL				3 3/D	31
1			295750-1	ELBOW				3 3/A	30
1			263500-79	TESTER ASSY				3 3/D	29
			295736-9	CONNECTOR ASSY, ELECTRICAL				[illegible]	28
2			295664-9	TUBE ASSY				3 3/B	27
1			295681 9	PLATE, BASE				3 3/A	26
1			295783-1	BRACKET				3 4/B	25
1			29567[illegible]	GASKET				3 3/B	24
10			295672-13	SUPPORT				2 4/C	23
			295 71-9	PLATE				2 4/D	22
			295[illegible]0 9	BRACKET				2 3/A	21
1			[illegible] 9	TUBE ASSY				2 3/B	20
			[illegible]-6	[illegible]				2 3/B	19
1			[illegible]	GASKET				2 4/B	18
1			276161-1	GASKET				2 2/C	17
1			295952 9	TUBE ASSY				3 2/B	16
1			295837 9	COVER				2 2/B	15
1			295716 9	THERMOCOUPLE				4 2/B	14
1			-31	TUBE ASSY	MAKE FROM 295759-9			3 3/D	13
1			-27	↕	2956[illegible]			3 4/B	12
1			-25		295685-9			3 4/D	11
1			-23		295752-9			3 4/C	10
1			-21		295756-9			3 1/A	9
1			-17		295755-9			3 3/A	8
1			-15		295751-9			2 2/D	7
1			-13		295668-9			3 4/D	6
1			-11		295667-9			3 2/B	5
1			-7		295666-9			3 4/A	4
1			-5		295664-9			3 3/A	3
1			-3		295663-9			3 3/A	2
1			-1	TUBE ASSY	MAKE FROM 295662-9			3 3/B	1

LIST OF MATERIALS

NERVA OPERATIONS

-9 | 295650 | NERVA

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES; DO NOT SCALE DRAWING

AEROJET-GENERAL CORPORATION

BEARING TESTER ASSY- RADIATION EFFECTS PALLET

05824 | E | 295660 | SHEET 1 OF 4

295660

No. 903 Mechanical Test Pallet--Top Assembly of Bearing Tester Section

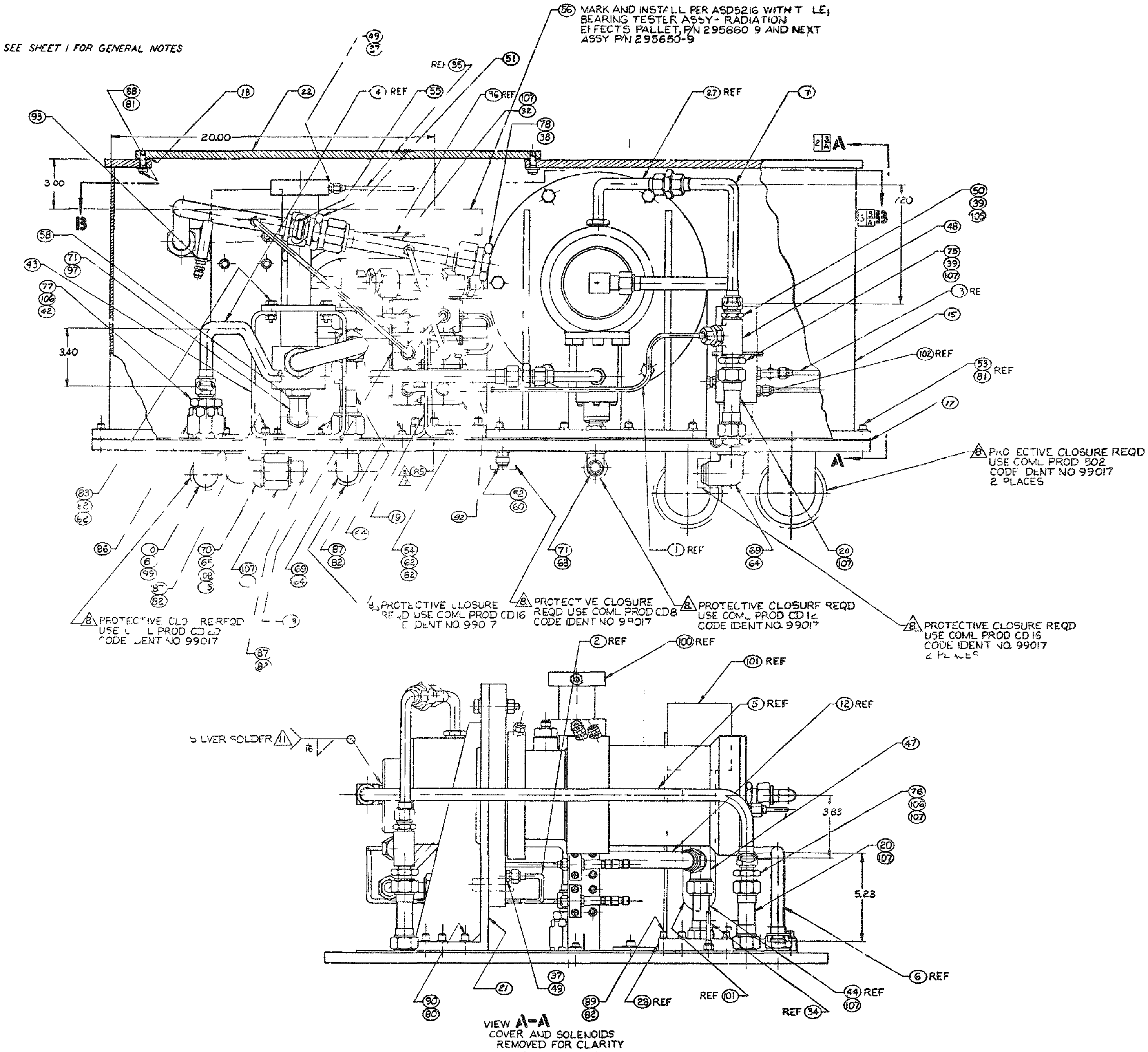
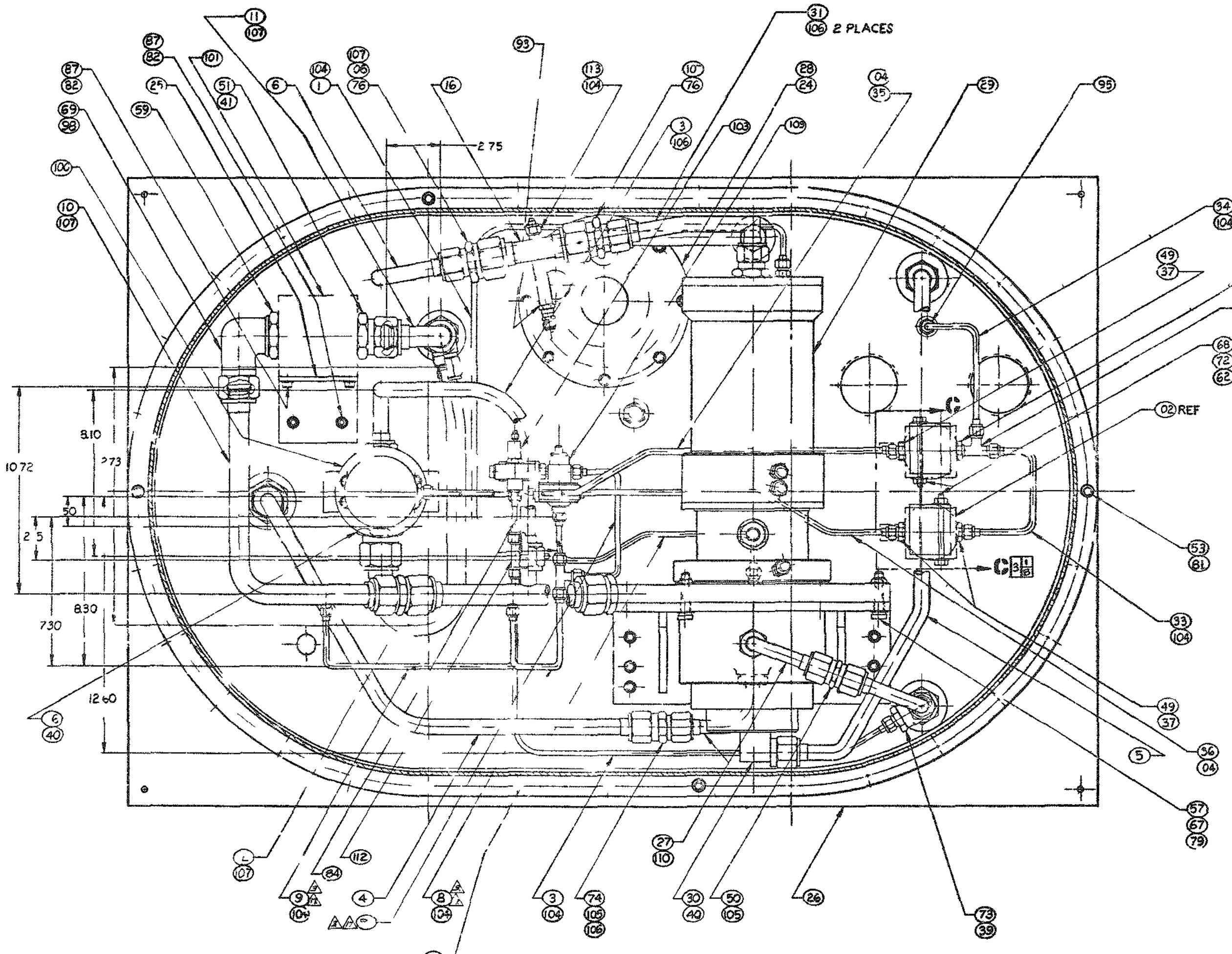


Figure A-2, Sheet 2 of 4

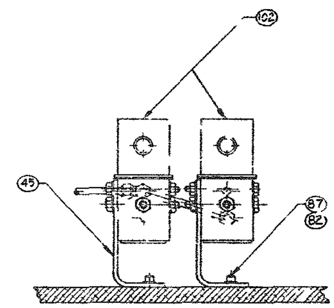
No. 903 Mechanical Test Pallet--Top Assembly of Bearing Tester Section

Figure A-2, Sheet 3 of 4

SEE SHEET 1 FOR GENERAL NOTES



SECTION B-B

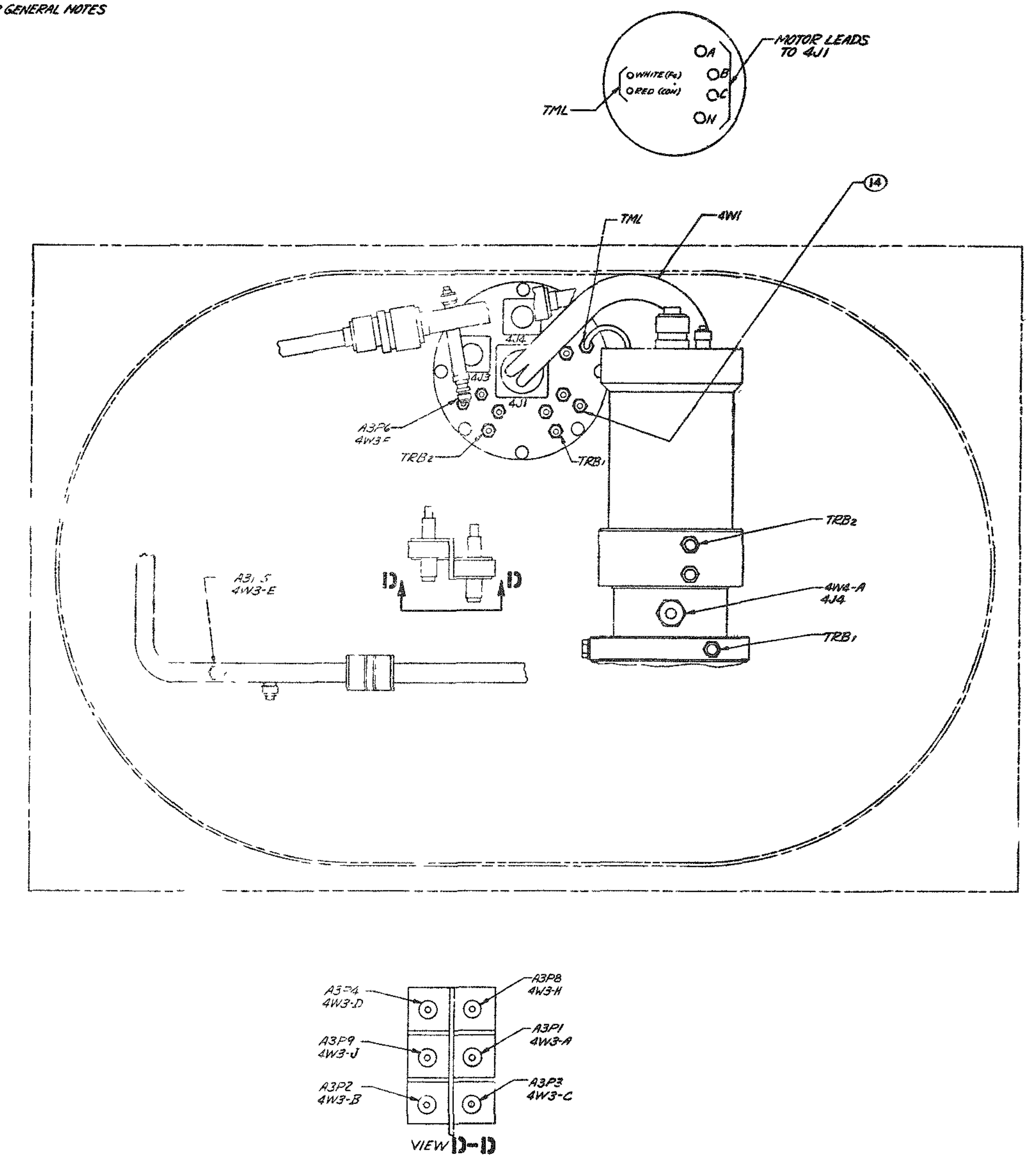


SECTION C-C ROTATED 90° C.W.

No. 903 Mechanical Test Pallet--Top Assembly of Bearing Tester Section

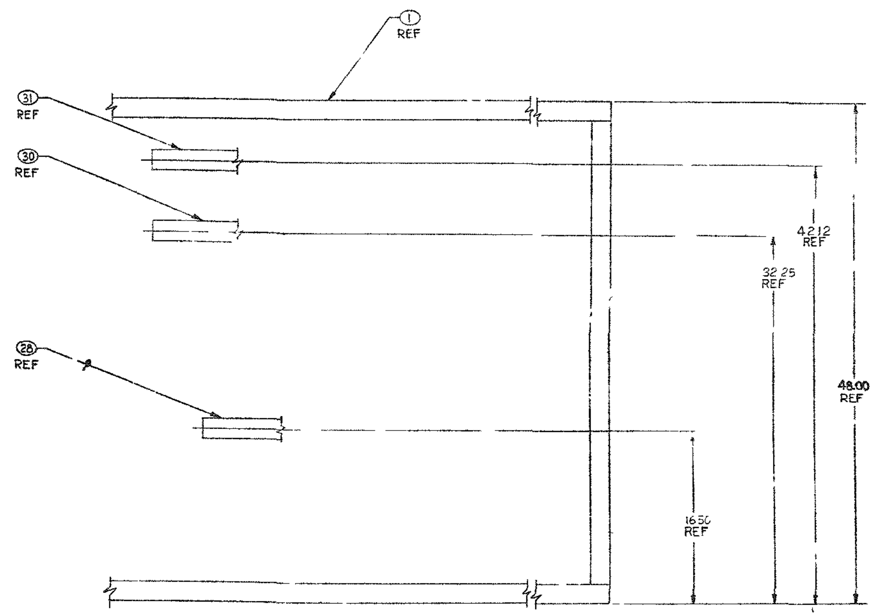
Figure A-2, Sheet 4 of 4

SEE SHEET 1 FOR GENERAL NOTES



No. 903 Mechanical Test Pallet--Top Assembly of Bearing Tester Section

NOTES:
1. REMOVE ALL BURRS & SHARP EDGES
2. INTERPRET DWG PER STDS PRESCRIBED IN MIL-D-70327
3. APPLY A LIGHT COAT OF ANTI-SEIZE COMPOUND TO THREADS AT ASSY
4. MARK PER ASD 5215C WITH PN 295650 & APPLICABLE DASH NO & SERIAL NO OF -9 ASSY.
5. FOR HYDRAULIC SCHEMATIC DIAGRAM SEE DWG NO 295680.
6. FOR ELECTRICAL SCHEMATIC DIAGRAM SEE DWG NO 295717
7. LOCATION OF HOLES TO BE ACCOMPLISHED AS SHOWN BY USING EXISTING HOLES ON DETAIL PART AS DRILL PILOT
8. CLEAN PER AGC-46350 AS FOLLOWS
   a. INTERIOR OF PLUMBING SYSTEM, LEVEL G
   b. EXTERIOR SURFACES, LEVEL H
9. PRESERVE AND PACKAGE PER AGC 46387, CLASS I
10. CLASSIFICATION OF CHARACTERISTICS PER MIL W-9411 DENOTED BY CRITICAL, MAJOR, & NO SYMBOL (MINOR)
11. ... PROD PROCURED UNDER ANOTHER PN NOT ACCEPTABLE UNLESS APPROVED BY ENGINEERING
12. ... ARE & ASSEMBLE PER AGC-46097
13. INSTALL PER AGC-STD-4002 EXCEPT USE LOX-SAFE LUBRICANT PER AGC 4405...
14. INSULATION TO BE TROWEL APPLIED TO INDICATED PLUMBING, TO DEPTH OF .50-2.00 INSULATION TO BE MIXED, APPLIED, AND DRIED PER MANUFACTURERS INSTRUCTIONS.
15. VAPOR BARRIER SEAL ALL INSULATION BY BRUSH APPLYING STABOND T-204 OVER INSULATION
16. VIEW C-C APPLIES TO VALVES 28, 30 & 31



PLAN VIEW SHOWING VALVE LOCATION

Figure A-3, Sheet 1 of 6

No. 903 Mechanical Test Pallet--Top Assembly

Figure A-3, Sheet 2 of 6

SEE SHEET 1 FOR NOTES

QTY	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.
6	AN929-4C	CAP	5	168
2	AN929-20C	CAP	6	167
1	AN929-16C	CAP	5	166
				165
2	AN938-4C	TEE	6	164
8	AN960C1216	WASHER	4	163
				162
				161
10	AN6289C4	NUT	5	160
2	AN919-23C	REDUCER	5	159
1	AN919-26C	REDUCER	5	158
				157
				156
	AN833-16C	ELBOW	6	155
6	AN833-4C	ELBOW	5	154
	AN827-4C	CROSS	6	153
				152
4	AN824-4C	TEE	6	151
				150
1	AN821-16C	ELBOW	6	149
				148
4	AN535-0-4	SCREW	4	147
1	AN815-8C	UNION	5	146
2	AN814-4C	PLUG	6	145
	AN815-12C	UNION	5	144
14	AN815-4C	UNION	5	143
1	AN815-16C	UNION	5	142
4	AN316C12R	NUT	4	141
4	AN315C6R	NUT	4	140
45	AN315C4R	NUT	5	139
56	AN315C3R	NUT	4	138
2	AN6C33A	BOLT	6	137
4	AN315C12R	NUT	4	136
				135
1	NAS1424[illegible]	COUPLING	5	134
				133
				132
	AS1407K 43C43	U-BOLT	5	131
2	AS1407K 38C43		5	130
3	AS1407K 33C38		5	129
	AS1407K 22C26	U-BOLT	5	128
				127
3	AS1407K 13C16	U-BOLT	5	126
27	AS1430-2	TAG	5	125
1	AS1419-2	NAMEPLATE	4	124
				123
				122
1	AS1149-120 -.120	RESTRICTOR	5	121
1	AS1149-6C -.350	RESTRICTOR	5	120
1	AS1155A C463	TUBE	5	119
1	AS1156A C443		6	118
				117
				116
1	276190-9		5	115
				114
	295[illegible]		5	113
	276166-9	TUBE	5	112
				111

QTY	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.
1	276164-9	TUBE	5 2/D	110
1	276163-9		6	109
1	295699-9		5 4/D	108
1	276161-9		5 4/D	107
				106
				105
1	276158-9		5 3/D	104
1	276157-29		5 3/D	103
1	276156-9		5 3/D	102
1	276152-10		4	101
1	276152-9	TUBE	5 3/D	100
				99
1	276150-3	BRACKET	5 4/D	98
1	276150-1	BRACKET	5 4/D	97
				96
				95
				94
				93
1	276151-9	TUBE	5 3/A	92
1	265752-159		5 3/B	91
1	276186-9		5 1/A	90
				89
				88
1	295758-9		2	87
1	255997-9		6 2/A	86
1	255996-9	TUBE	5 2/C	85
				84
				83
1	255968-19		5	82
1	255967-9		5 4/A	81
2	255961-9		3	80
1	255960-9		5	79
1	255959-19		5 1/B	78
1	255958-9	TUBE	5 1/C	77
				76
				75
				74
3	255957-1	BRACKET	6 4/A	73
	255954-9	ADAPTER	5 2/C	72
1	255953-9	ADAPTER	6 3/C	71
1	255945-9	ADAPTER	5 2/A	70
				69
				68
				67
1	255720-9	WIRING HARNESS	2/A	66
1	295726-9		3 4	65
1	295721-9		3	64
1	295728-9	WIRING HARNESS	3	63
				62
				61
1	255350-9	LIFTING FRAME	4 3/B	60
2	255823-9	TUBE	5 1/B	59
				58
				57
				56
				55
				54
				53
				52
				51
1	255602-111	TUBE	5 2/A	50
				49

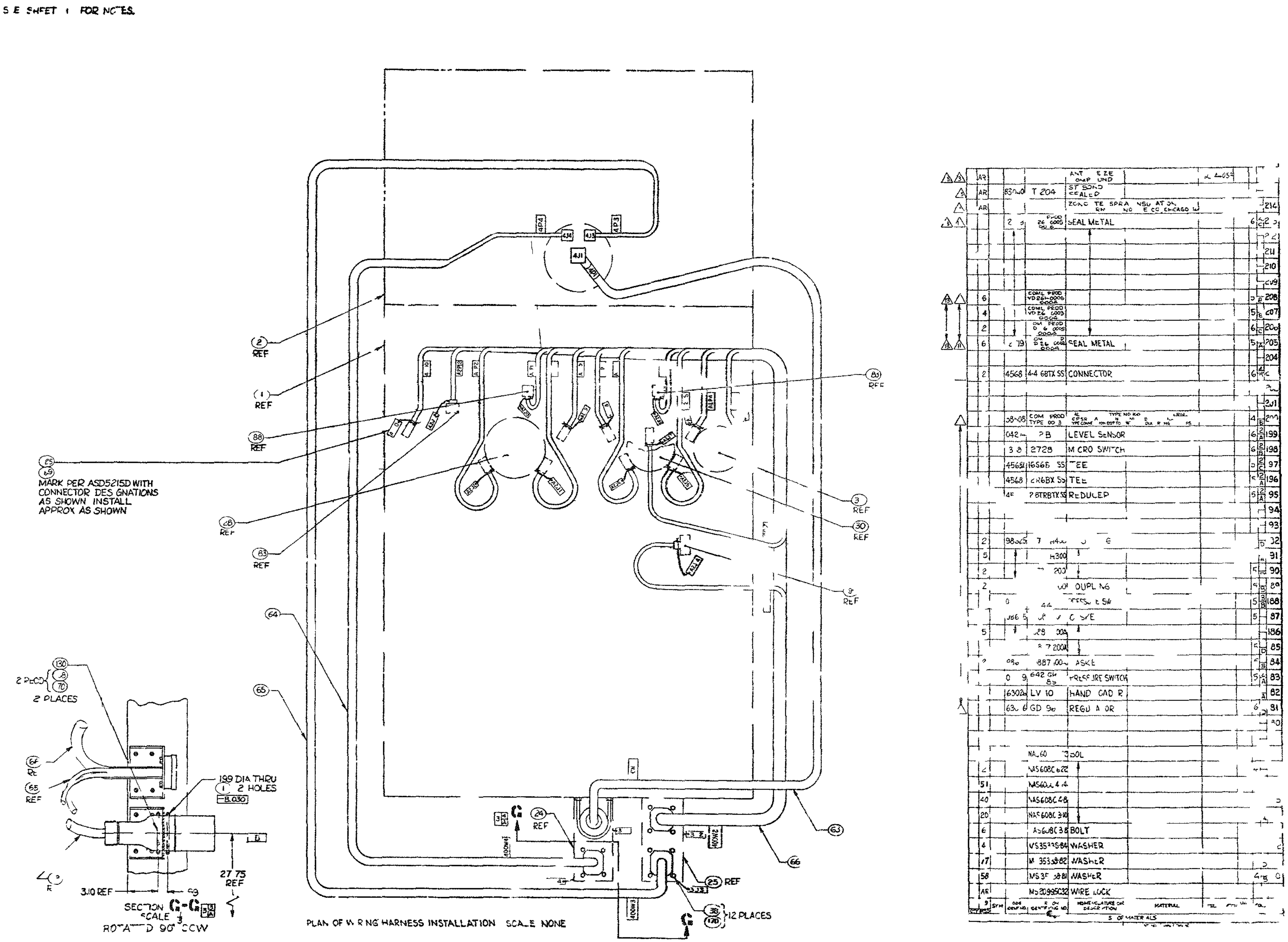
QTY	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.
1	255802-105	TUBE	5 1/?	48
1	-103		5 3/?	47
1	-101		5	46
1	-97		5 2/D	45
1	-95		5 2/D	44
1				43
1	-91		5	42
1	-87		6 2/A	41
1	-85		6 2/B	40
				39
1	-81		6 2/B	38
1	-77		6 2/A	37
				36
1	-73		5 2/A	35
1	-71	TUBE	6 2/B	34
				33
				32
1	-63	VALVE	5 3/D	31
1	-61	VALVE	5 3/D	30
				29
1	-55	VALVE	5 3/A	28
				27
				26
1	-	BRACKET	4 1/D	25
1	-45		4 1/C	24
				23
				22
				21
				20
				19
	-31		4 2/C	18
1	-27		4 3/B	17
	-25		6 2/D	16
				15
	-21		6 2/C	14
1	-17		6 2/D	13
1	-16		5 3/C	12
1	-15		5	11
1	-14		5	10
1	-13		5 3/B	9
				8
				7
1	-8		5 3/B	6
1	255[illegible]2-7	BRACKET		5
				4
				3
1	295660-9	CONTAINER	4 4/B	2
1	-1	MAKE FROM 255948-9 FRAME	4 3/C	1

LIST OF MATERIALS

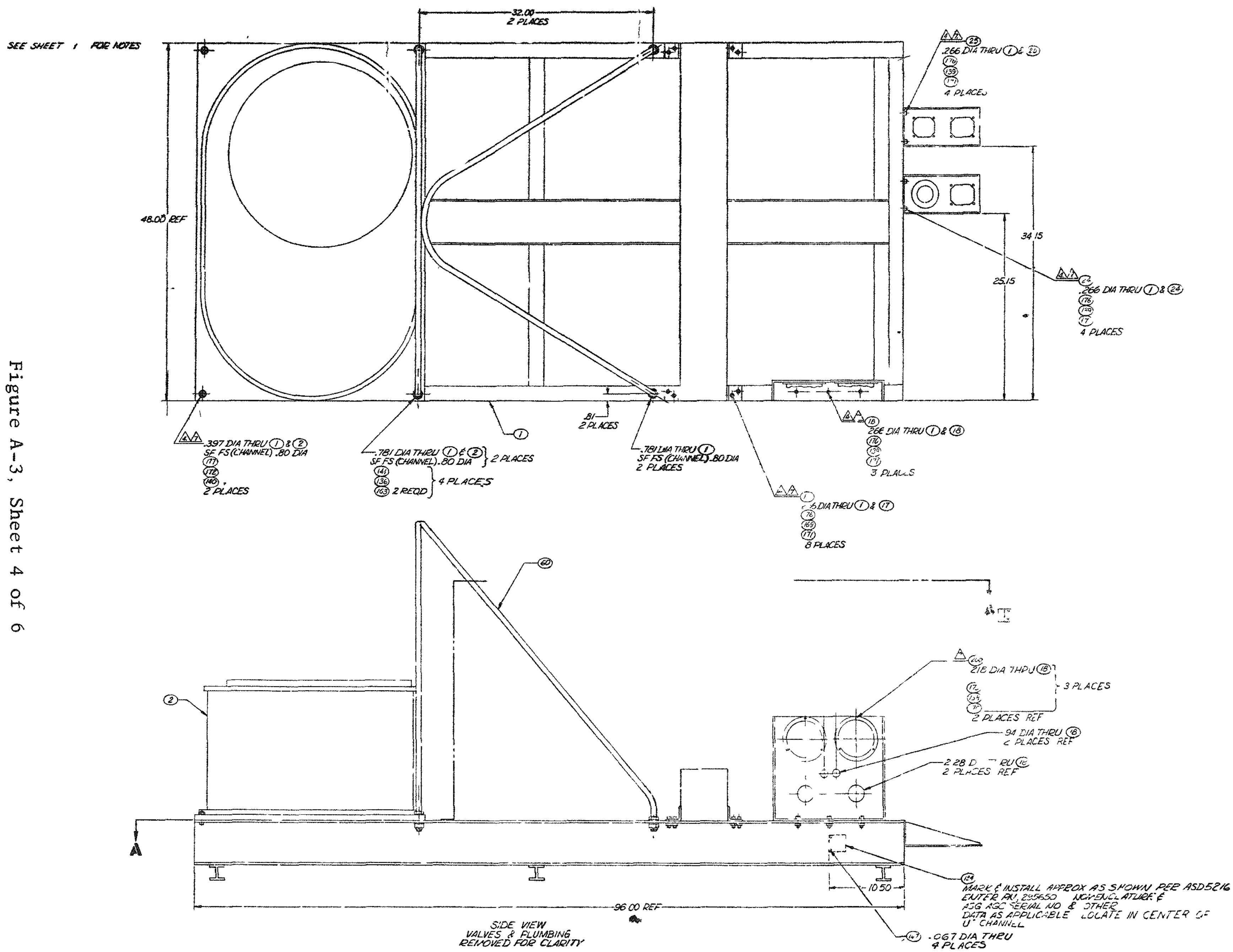
05824 E 29[illegible]650

No. 903 Mechanical Test Pallet--Top Assembly

Figure A-3, Sheet 3 of 6



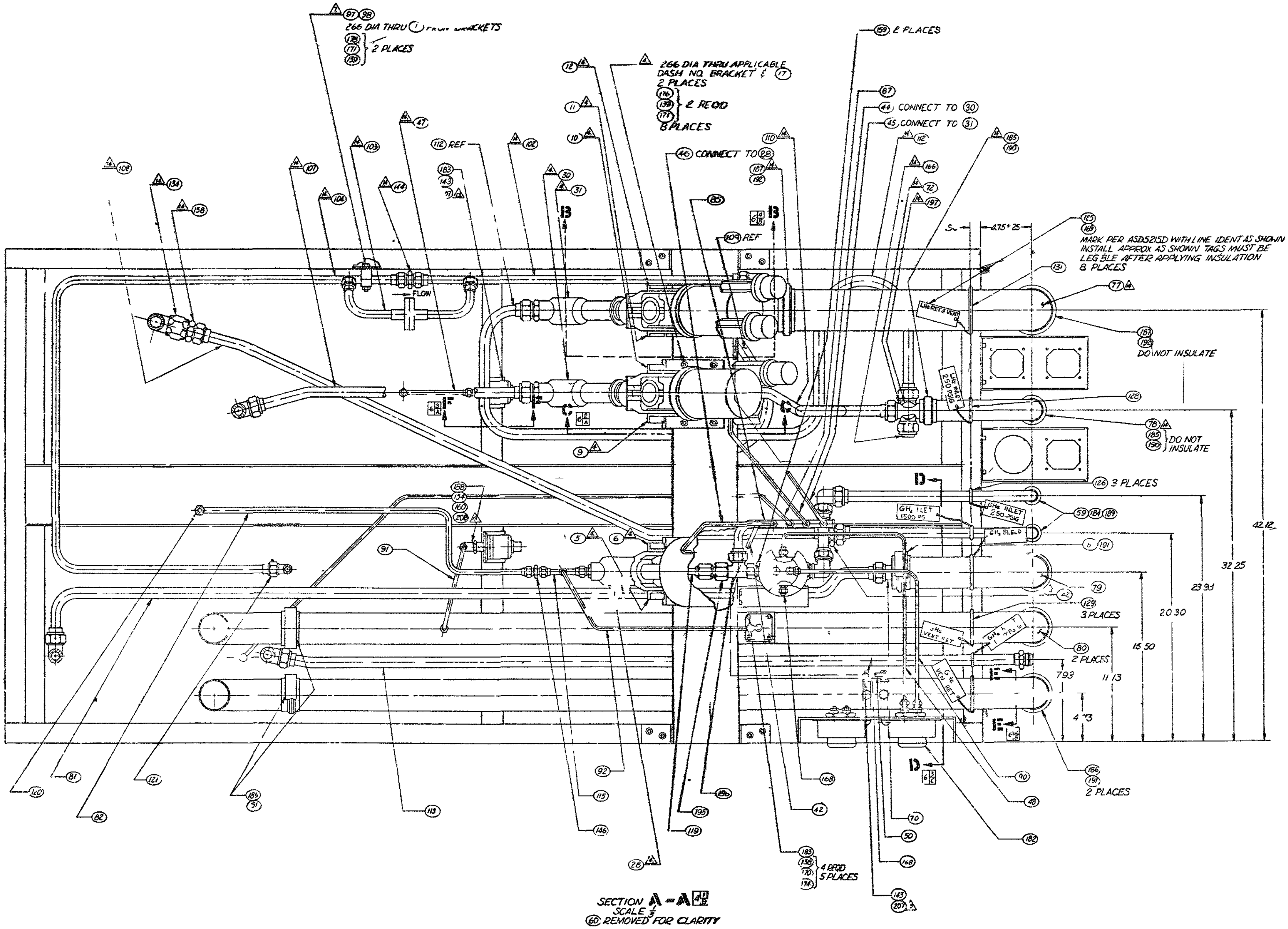
No. 903 Mechanical Test Pallet--Top Assembly



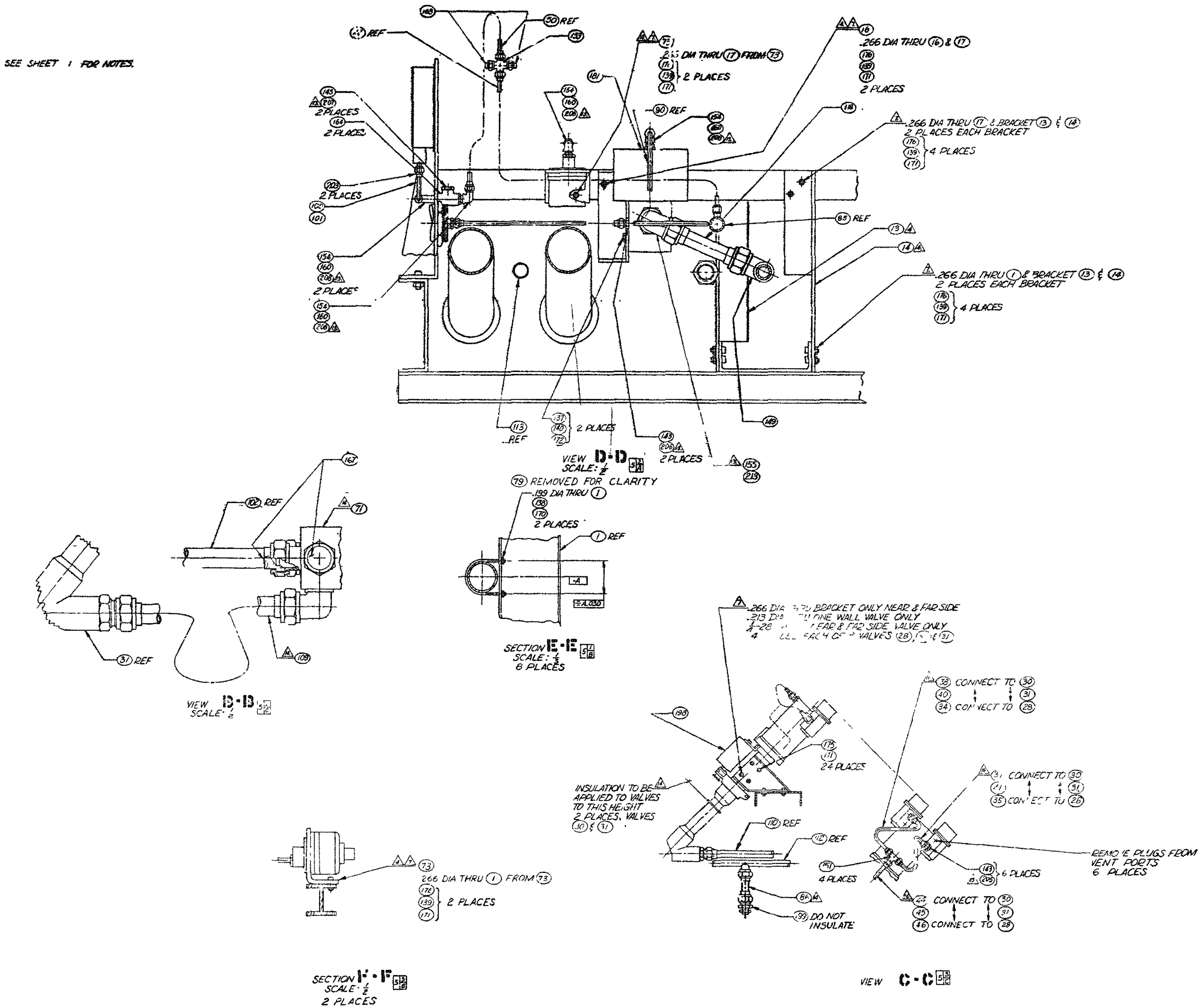
No. 903 Mechanical Test Pallet--Top Assembly

Figure A-3, Sheet 4 of 6

Figure A-3, Sheet 5 of 6



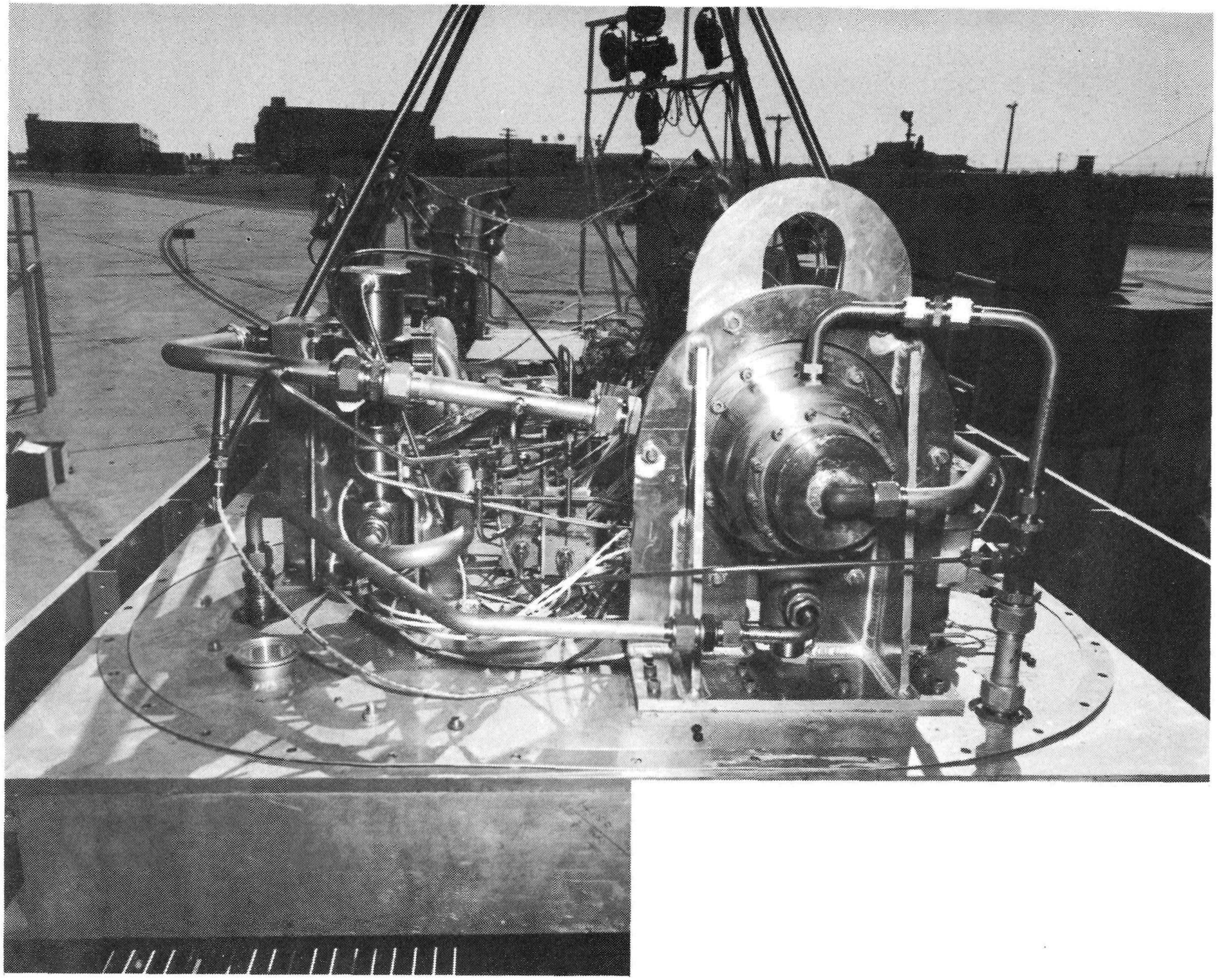
No. 903 Mechanical Test Pallet--Top Assembly



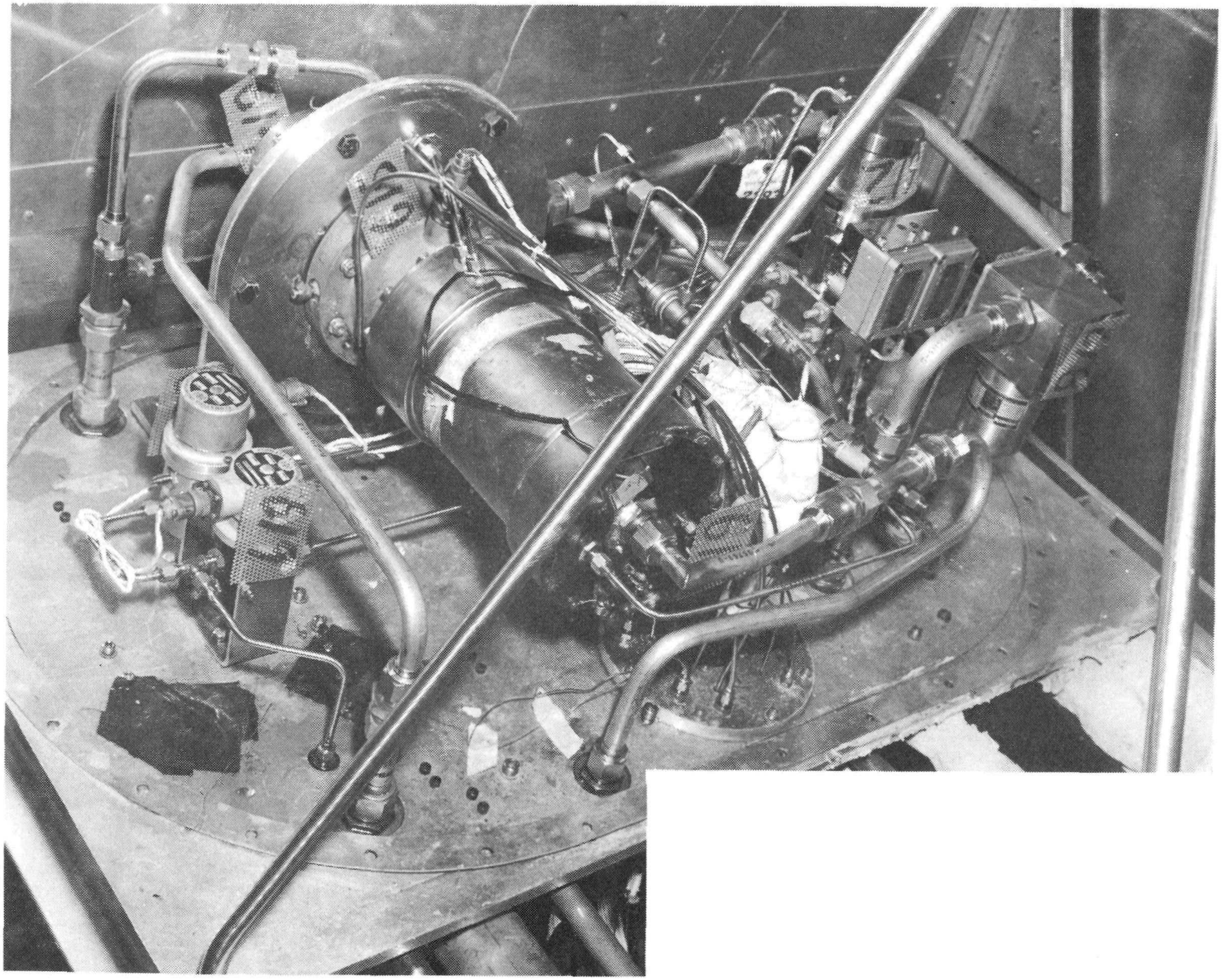
No. 903 Mechanical Test Pallet--Top Assembly

Figure A-3, Sheet 6 of 6

Figure A-4



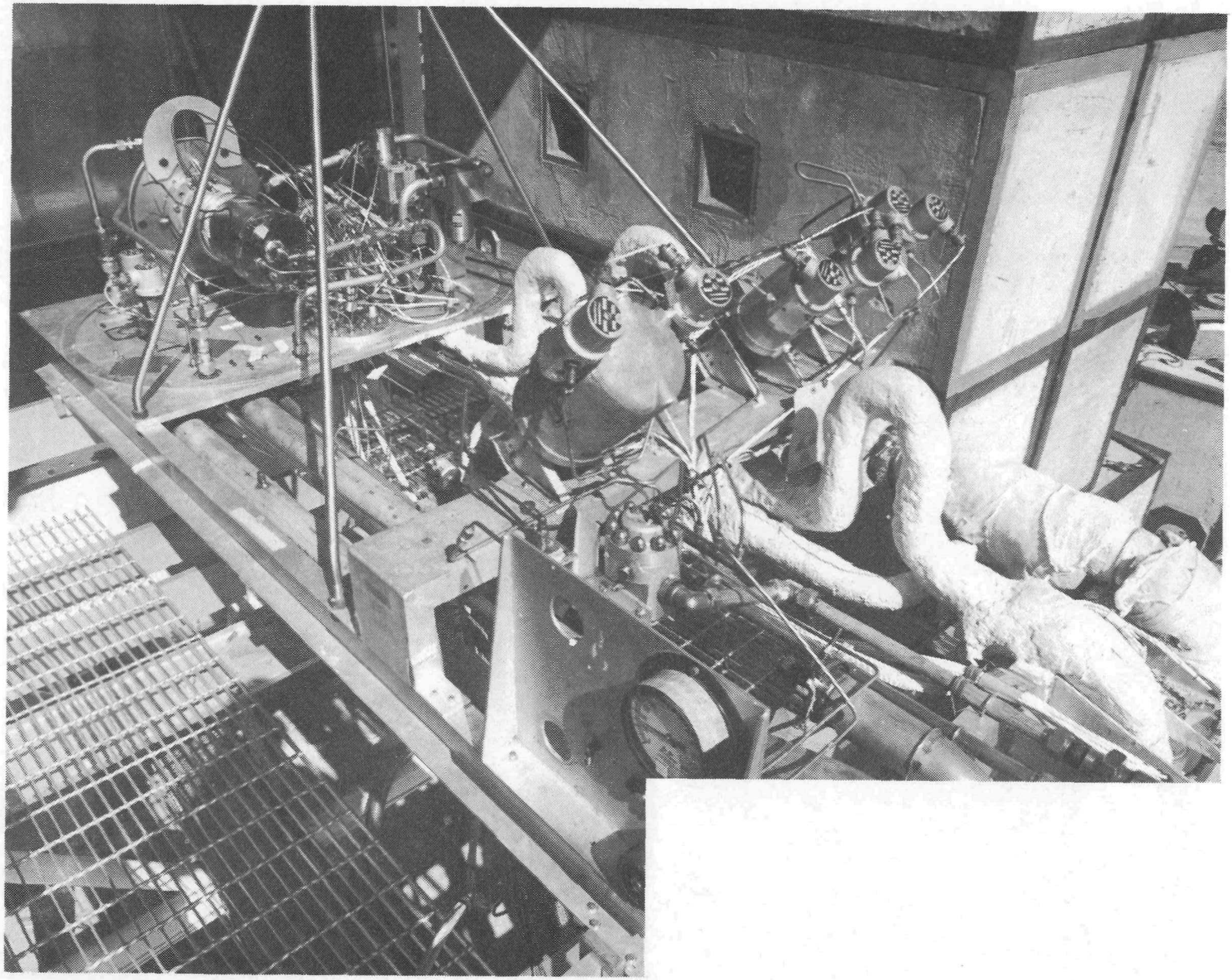
No. 903 Mechanical Test Pallet--Side Nearest ASTR Reactor



No. 903 Mechanical Test Pallet with Containment Vessel Removed
and Showing Dosimetry Pockets Installed

Figure A-5

Figure A-6



Overall View of No. 903 Mechanical Test Pallet

View Showing Test Pallet in Place within ASTR Outside Test Cell

Figure A-7

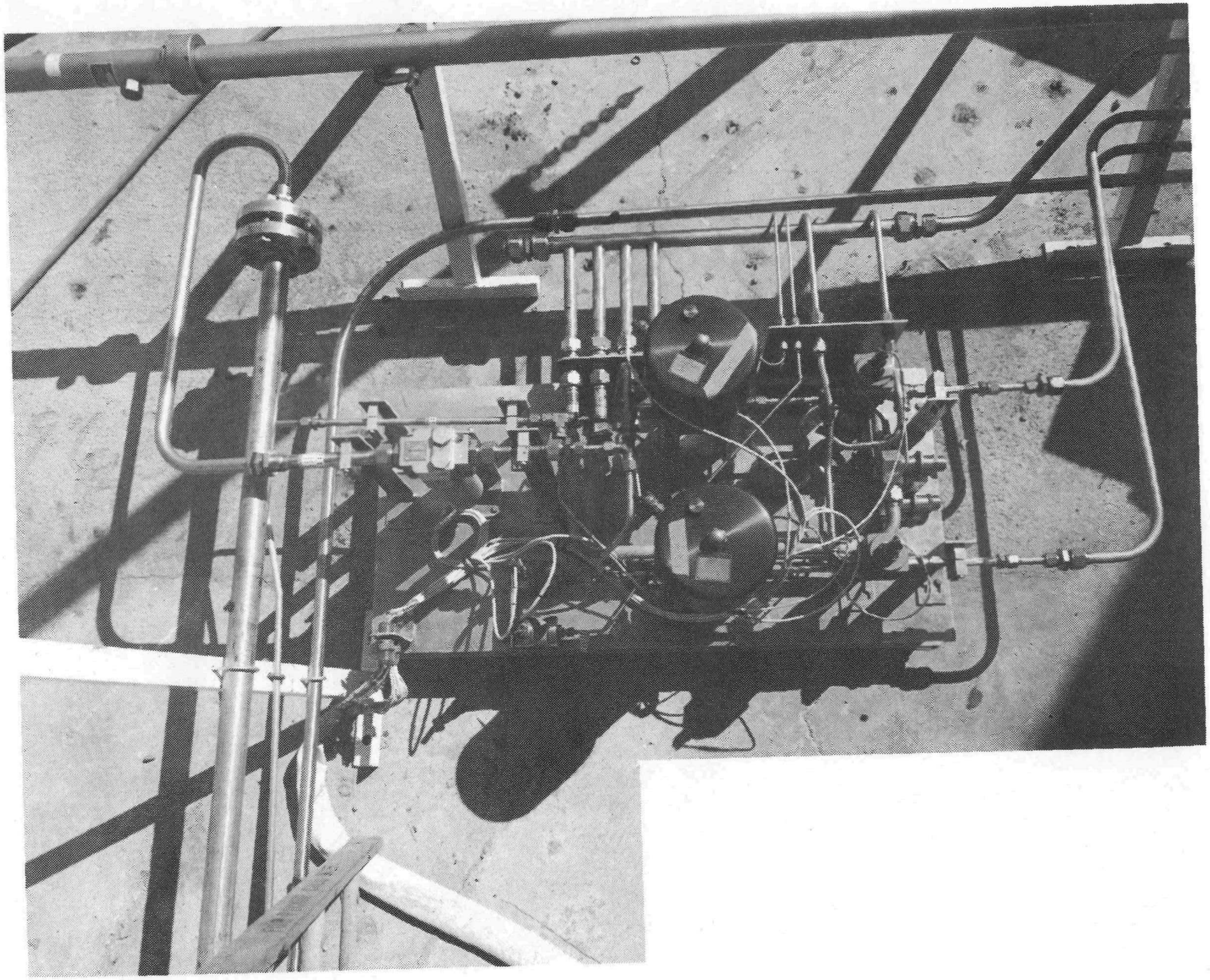


Figure A-8

View of Load Control Pallet

Figure A-9, Sheet 1 of 2

NOTES 1 -L) ALL E JRPS & SHARP EDGES
2 UT I PRET DRAWING PER STAUD-RD PRESCRIBED
J / L D 70327
G WL D PER ACC 46351
UTTRAUT IUSPECT WELD PER I I 6366 TYPE
OL L QUALITY PER VC S 7 4709 CLASS I
J F CAT OL OF CHARACTER ST LS ER MIL W9411
O I D BY (CRITICAL) (MAJOR) & NO SY BO (MINOR)
M C FIT & FLARE PER AGC 4609 INDICATED TUBES TO BE
E IDENTIFIED W TH PART NO 2956 O & T EIR RE IE T VE DASH NOS
ER ASP5215D
PROOF TEST AT 2250 ± 50 PSIG LEAK TEST AT 1500 ± 50 PSIG
. TH AIR OR HEL UM UNDER WATER FOR 2 M NUTE
NO EAKAGE PERM TTED
C N FER AGC46350 LEVEL H
INSTALL FITT NGS PER AND10064
N PER AGC46350 LEVEL G
O F TIVE CLOSURE P GD USE COML PROD ICT
NO CD 40 CODE IDENT NO 99017
OT UTVE C OSU R QL U E CO IL PROL KT
O D 80 COD O U NO 99017
OTECT VE CLOSU REQU D E COM PRODUCT
LO CD 60 CODE L NO 99017
RES RVE PRT V F R E C I AS II
A 438 AS A M LAT DI LL 2 ½ DA HOLE \ IOWN
DEVIATIONS NOT COVERED BY M L S D 12 DEF NED AS
B ULK ITEM
V VENDOR TEM
D SPE IFICATION/SOURCE CONTROL DRAW NG
7 OR ELECTRICAL W R NG DAGRAM EE DWG NO 295717

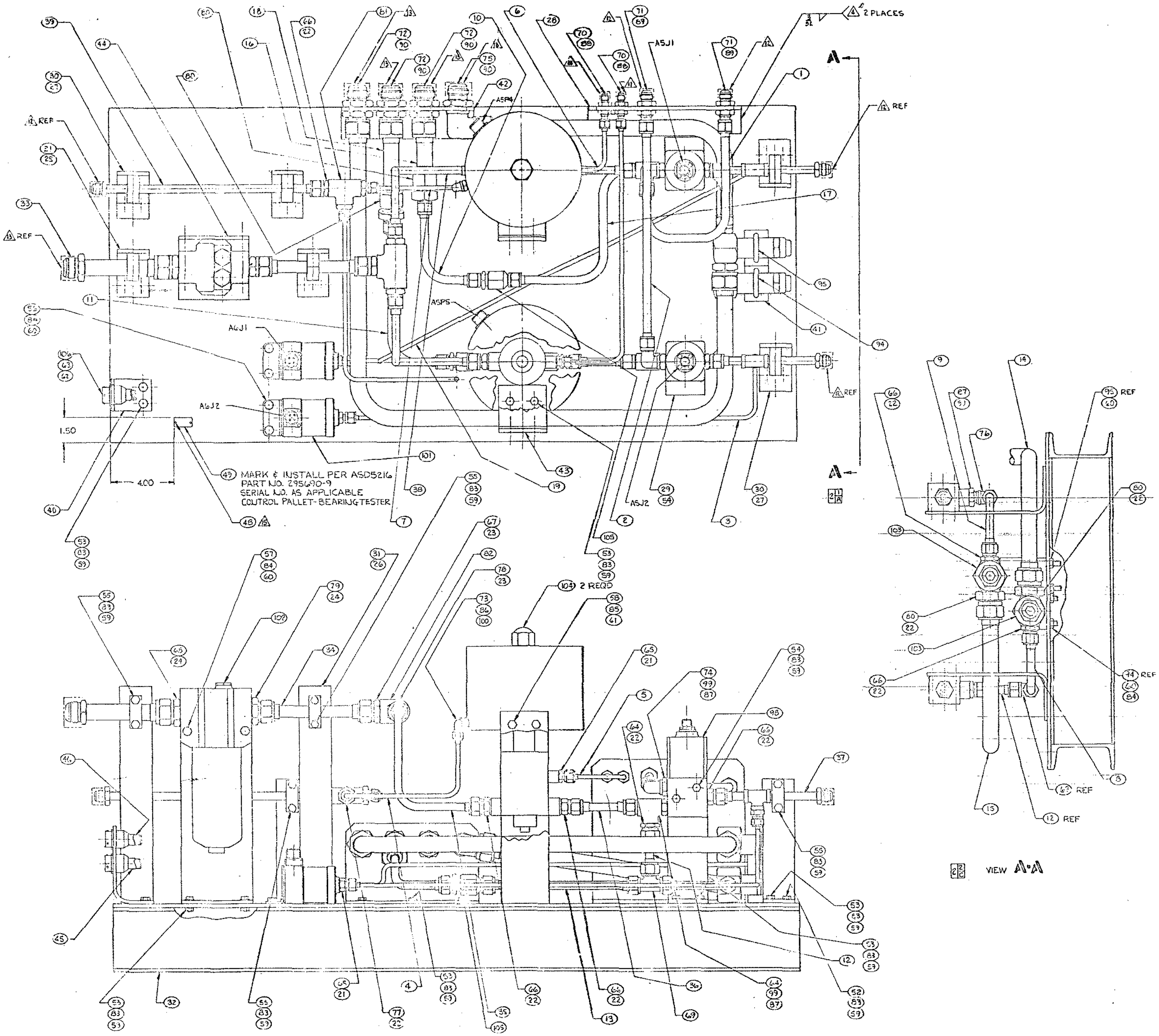
AR	B			WELD ROD	AL ALLOY 4043	QQ-R 566 TYPE I CL 43	2 2D	109
								108
								107
2	V	77870	PTOOP 6 265	ELECTRICAL CONNECTOR			2 4C	106
2	V	06370	305B	BURST DIAPHRAGM			2 2B	105
2	V	993	REDL6PI 403	R OR VALVE			2 2B	104
2	V	786	5349T 14 0	RELIEF VALVE			2 1B	103
1	V	32	PR420 4	FILTER ASSY			2 3B	102
2	V	0	206	T UCER			2 2C	101
2	V	2 79	VD761 OLC 04	SEAL			2 2B	100
5	V	2179	VD66 C 03	SEAL			2 2B	99
2	V	0	5/ CBL	VALVE			2 2C	98
								97
								96
1			3 5 0	UE T			2 1C	95
1			205 0 4	U BOLT			2 1C	94
								93
								92
								91
				NUT			2 3D	90
				NUT			2 2D	89
				NUT			2 2D	88
				NUT			2 2B	87

2			AN6289C4	NUT		2 2B	86
4			AN960C616L	WASHER		2 2B	85
10			AN960C516L	WASHER		2 4C	84
63			AN960C416L	WASHER		2 1A	83
1			AN938C12	TEE		2 2B	82
1			AN938C8	TEE		2 3D	81
4			AN919 29C	REDUCER		2 B	80
1			AN919 23C	REDUCER		3B	79
2			AN919 19C	REDUCER		2 2B	78
			AN919- 0C	REDUCER		2 3A	77
1			AN834 8C	TEE		2	76
1			AN833-16C	ELBOW		2 2D	75
2			AN833 8C	ELBOW		2 B	74
2			AN833-4C	ELBOW		2 2B	73
3			AN832 16C	UNION		2 3D	72
7			AN832 8C	UNION		2 4D	71
2			AN832 4C	UNION		2 2D	70
1			AN824 8C	TEE		2 2A	69
1			AN815 16C	UNION		2 3B	68
1			AN815 8C	UNION		2 2B	67
10			AN815 8C	UNION		2 2A	66
4			AN815 4C	UNION		2 2B	65
2			AN783 6C	TEE		2 2A	64
8			AN500C4	SCREW		2 4C	63
8			AN340C4	NUT		2 4C	62
4			AN3 5C 3	NUT		2 2B	61
10			AN3 C5R	NUT		2 C	60
44			AN3 5C4R	NUT		2 A	59
4			AN6C6	BOLT		2	58
2			AN C37	BOLT		2 F	57
4			AN5C 2	BOLT		2 4C	56
12			AN4C22	BOLT		2 2A	55
4			AN4C20	BOLT		2 2	54
23			AN4C5	BOLT		2 1A	53
7			AN4C10	BOLT		2 1A	52
							51
							50
1			AS1433	PLA IDENT		2 3	49
2			AS105	DR K W		2 3B	48
							47
1			29571 9	CABLE		2 4	46
1			2 57 8 9	CABLE		2 4	45
1			295777	BRACKET			44
2			295776	BRACKET		2	43
1			295774 1	BRACKET		2	42
1			295771 1	BRACKET		2	41

1			295770 1	BRACKET	2 4C	40
1			295764 9	TUBE ASSY	2 5	39
1			295697 9	TUBE ASSY	2 3C	38
2			29 9	TUBE ASSY	2 B	37
2			295694-9	TUBE ASSY	2 2A	36
1			295693 9	TUBE ASSY	2 2A	35
1			29569 9	TUBE ASSY	2 B	34
1			2956 9	TUBE ASSY	2 4D	33
1			295 1	PALLET	2 3A	32
2			295678-11	BRACKET	2 4D	31
4			295610-1	BRACKET	2 7C	30
2			295677-1	BRACKET	2 2C	29
1			295673 1	BRACKET	2 2D	28
8			295672 7	BLOCK	2 4D	27
2			295672 3	BLOCK	2 B	26
2			295672 1	BLOCK	2 1D	25
2	SCD		294909 1	SEAL	2 3	24
3	SCD		294908 1	SEAL	2 2B	23
12	SCD		294906-1	SEAL	2 1B	22
4	SCD		294903 1	SEAL	2 2B	21
						20
1			45	MAKE FROM 95778 9	2 2C	19
1			43	MAKE FROM 295775-9	2 3D	18
1			41	MAKE FROM 295773 9	2 1D	17
1			37	MAKE FROM 295772 9	2 3D	16
1			35	MAKE FROM 295768 9	2 A	15
1			3	MAKE FROM 295767 9	2 1C	14
1			31	M E ROM 9576 19	2 2A	13
1			27	M OM 29 9	2 1A	12
1			25	MAKE 0 1 9	2	11
1			23	29	2	10
1			21	9	1C	9
1			17	MAKE 9	2	8
1				M 3 29	2 3	7
1			13	MAKE M 3 19	2	6
1			11	9	D	5
1			7	MAKE OM 7 2 19		4
1			5	MAKE F 629		3
1			3	F 9 761 9		2
1					2	1

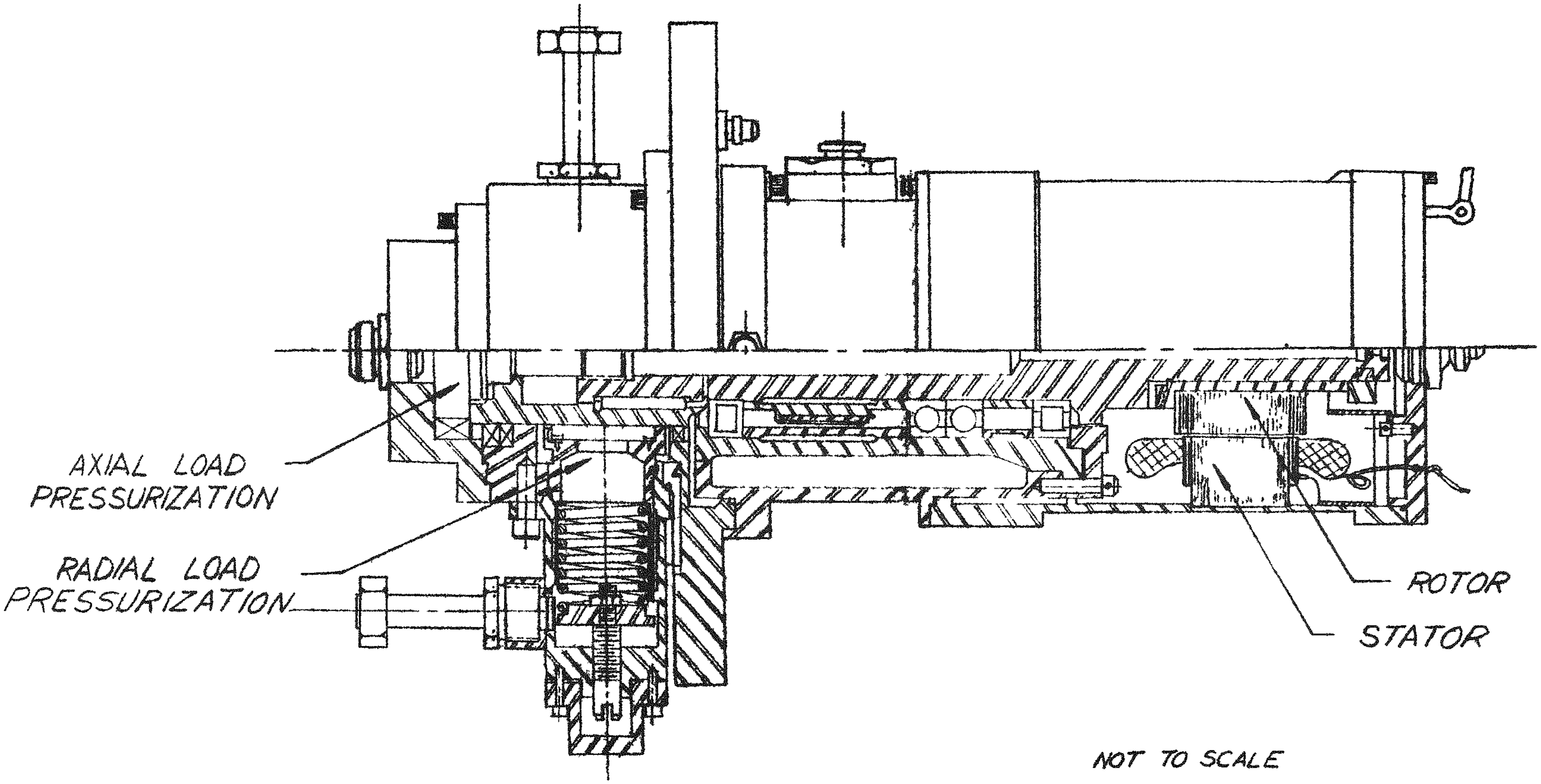
Top Assembly--Load Control Pallet

Figure A-9, Sheet 2 of 2



Top Assembly--Load Control Pallet

Figure A-10



Sketch of NERVA Refined Bearing Tester

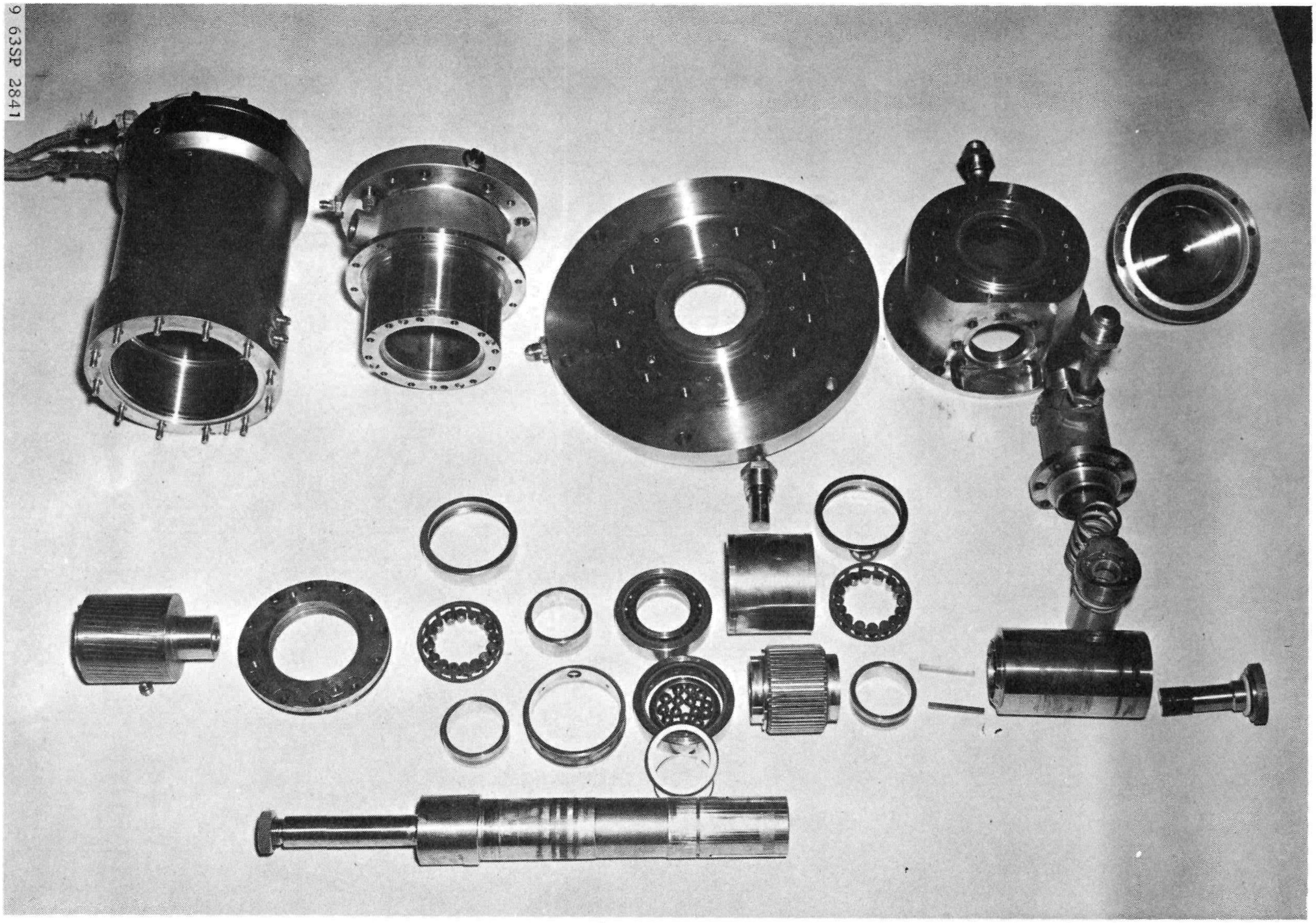


Figure A-11

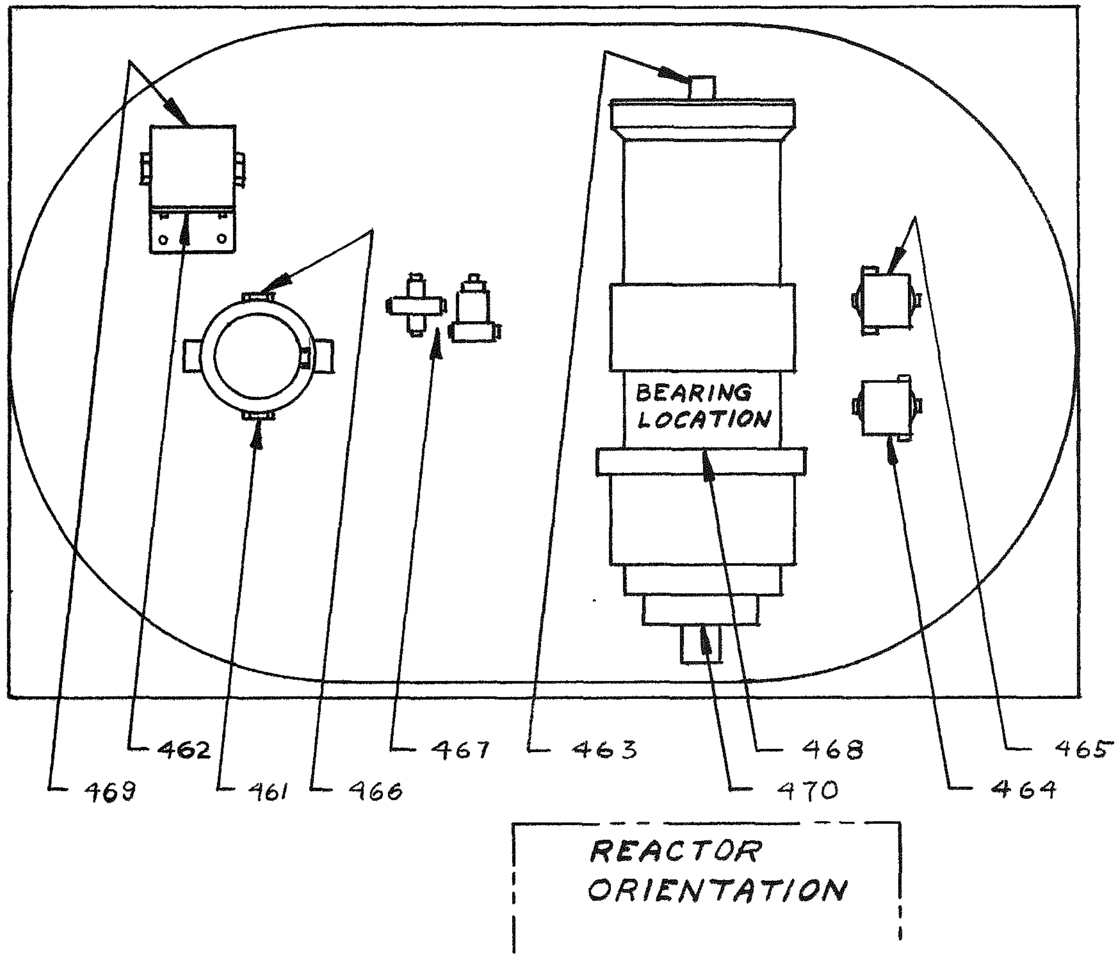
Bearing Tester PN 263500-69, SN 0000004 Disassembled after Irradiation Test
(Motor to the Left; Loading Devices to the Right)

APPENDIX B

DOSIMETRY MEASUREMENTS

TABLE B-1

DOSIMETRY DATA



DOSIMETRY PACKET NO.	INTEGRATED NEUTRON FLUX n/cm^2			GAMMA DOSE ergs/gm(C)
	E > 8.1 Mev	E > 2.9 Mev	E < .48 ev	
461	4.9×10^{11}	1.5×10^{13}	2.4×10^{12}	8.9×10^{7}
462	2.3×10^{11}	7.6×10^{12}	2.8×10^{12}	3.9×10^{7}
463	3.7×10^{10}	1.9×10^{12}	2.0×10^{12}	5.8×10^{6}
464	1.1×10^{12}	3.5×10^{13}	2.4×10^{12}	1.2×10^{8}
465	3.0×10^{11}	9.0×10^{12}	3.2×10^{12}	2.4×10^{7}
466	2.0×10^{11}	7.3×10^{12}	2.9×10^{12}	3.4×10^{7}
467	1.1×10^{12}	3.6×10^{13}	2.3×10^{12}	1.3×10^{8}
468	4.9×10^{11}	1.8×10^{13}	2.4×10^{12}	5.9×10^{7}
469	5.1×10^{10}	1.7×10^{12}	3.0×10^{12}	8.0×10^{6}
470	2.8×10^{12}	9.3×10^{13}	—	1.1×10^{8}

Table B-1

APPENDIX C

10-SEC CHECKOUT RUN

TABLE LIST

FIGURE LIST

Table C-1

TIME AND EVENT CORRELATION DURING THE 10-SEC CHECKOUT RUN

Time (sec)	Event
	Run 1
-898	Line and bearing-loop cool-down started
-717	P_{RL} set at 20 psi, P_{AL} at 300 psi
-528	CDBP closed
-411	Dewar pressure stabilized at 225 psi
-347	OBPV closed
0	Bearing motor turned on (no speed indication)
+5	Bearing motor turned off
+105	Bearing load pressures relieved
	Run 2
0	Bearing motor turned on (no speed indication)
+3	Bearing motor turned off
+93	LH_2 flow stopped

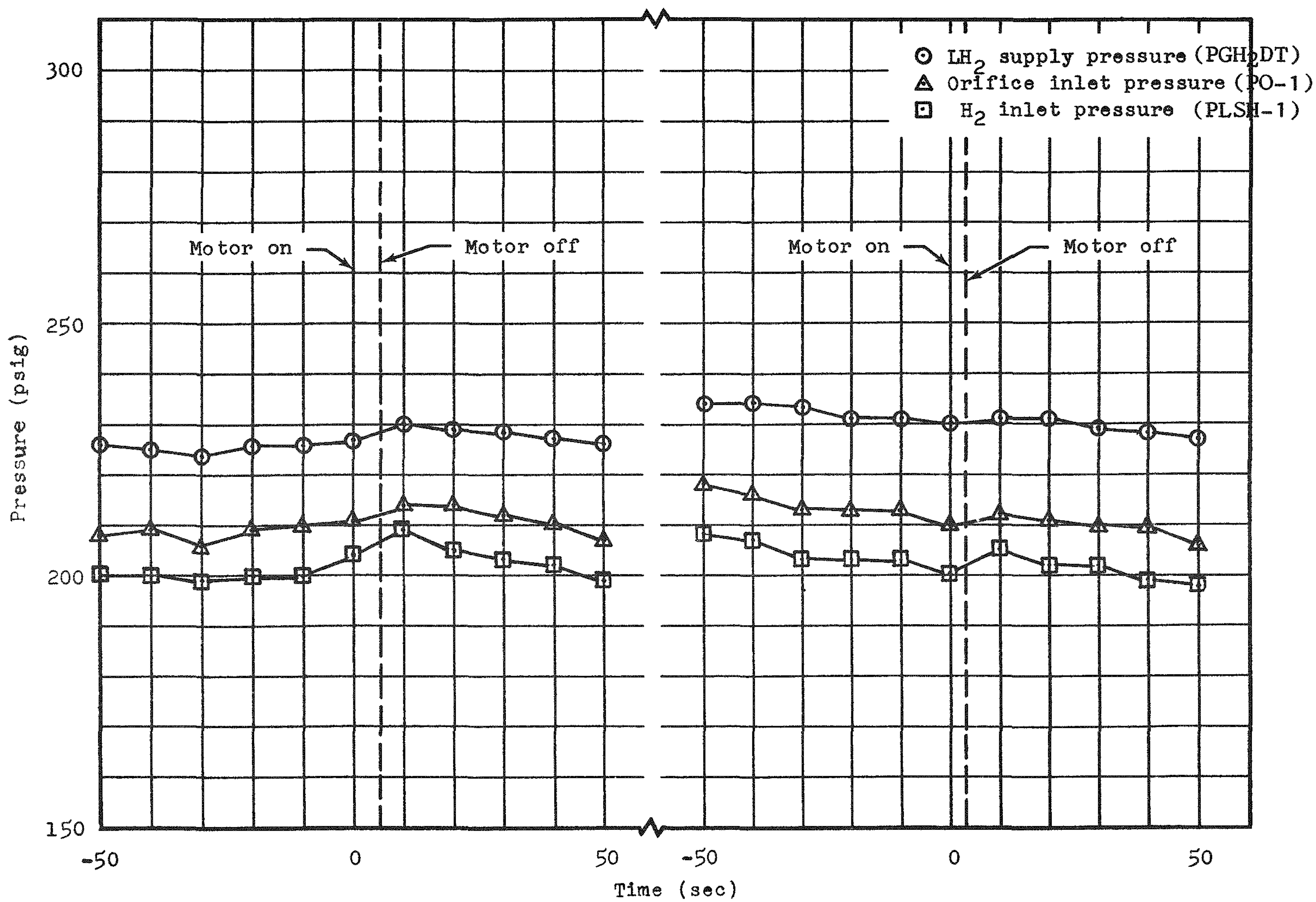


Figure C-1

Checkout Runs--Pressure of H_2 Supply at the Dewar, Bearing-Tester H_2 Inlet (PLSH), and the Orifice Inlet (PO-1)

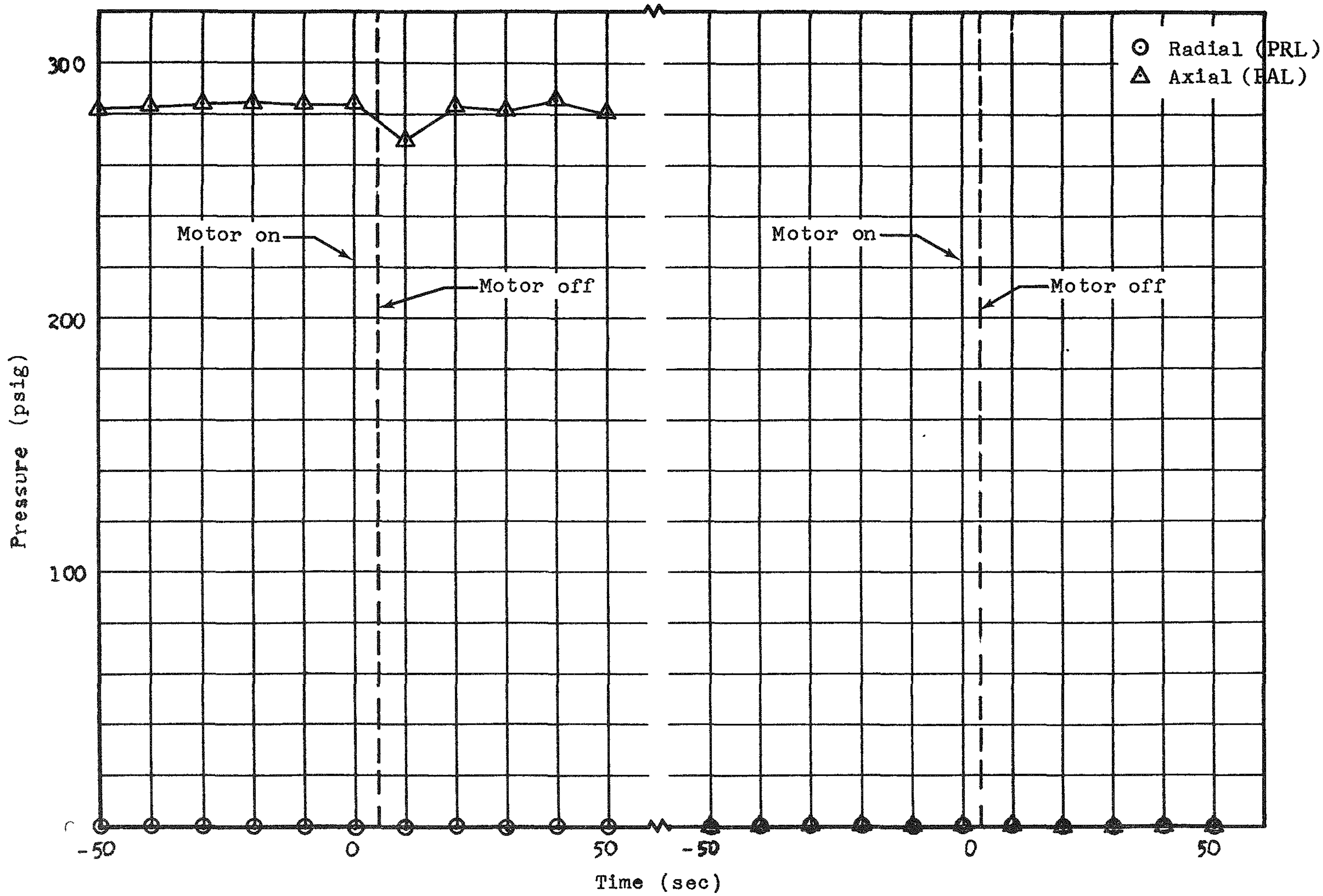
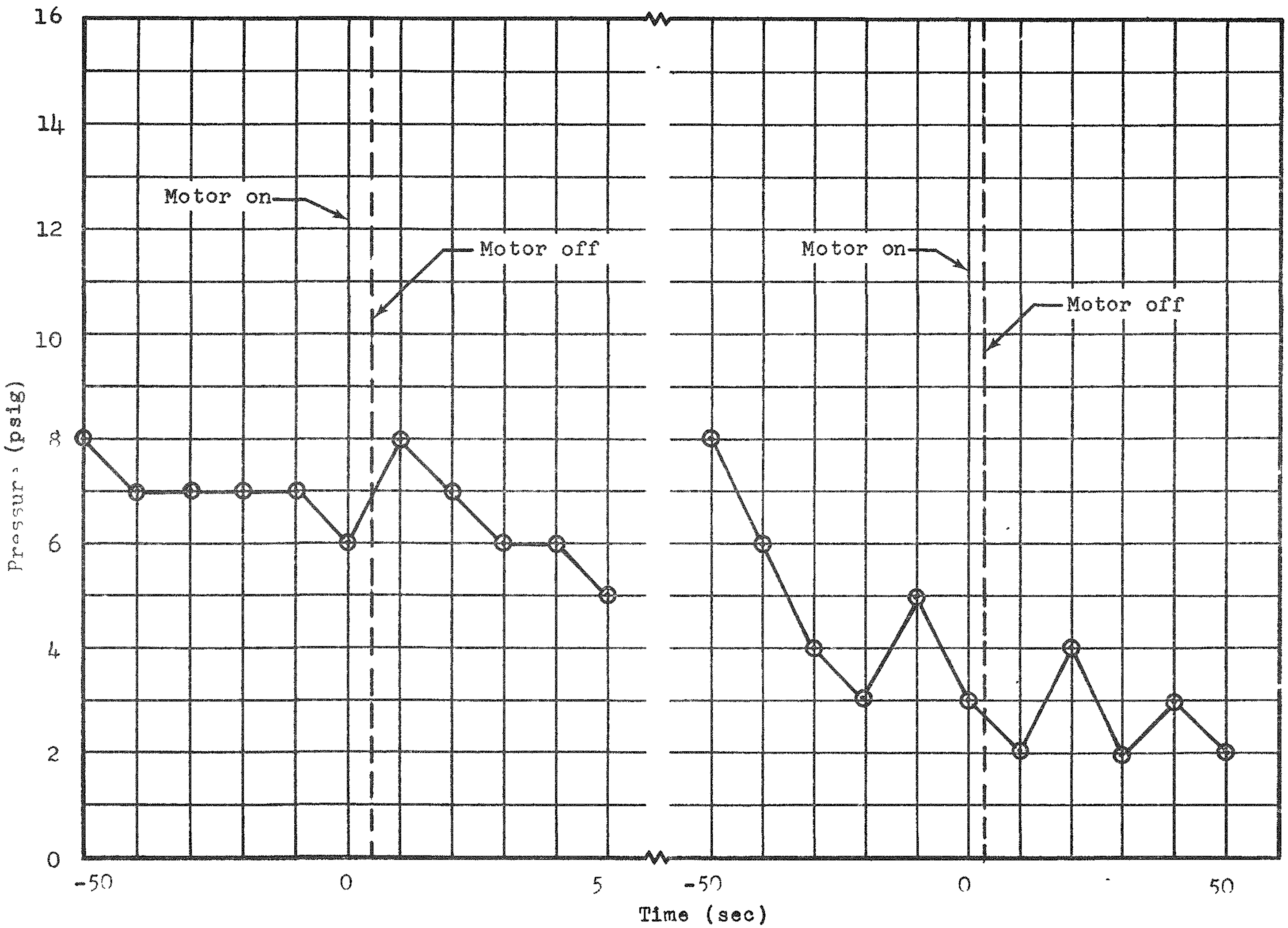


Figure C-2

Checkout Runs--Pressures of the Radial Load (PRL) and Axial Load (PAL)



Checkout Runs--Pressure in the Bearing-Tester Loading Cavity (PETLC)

Figure C-3

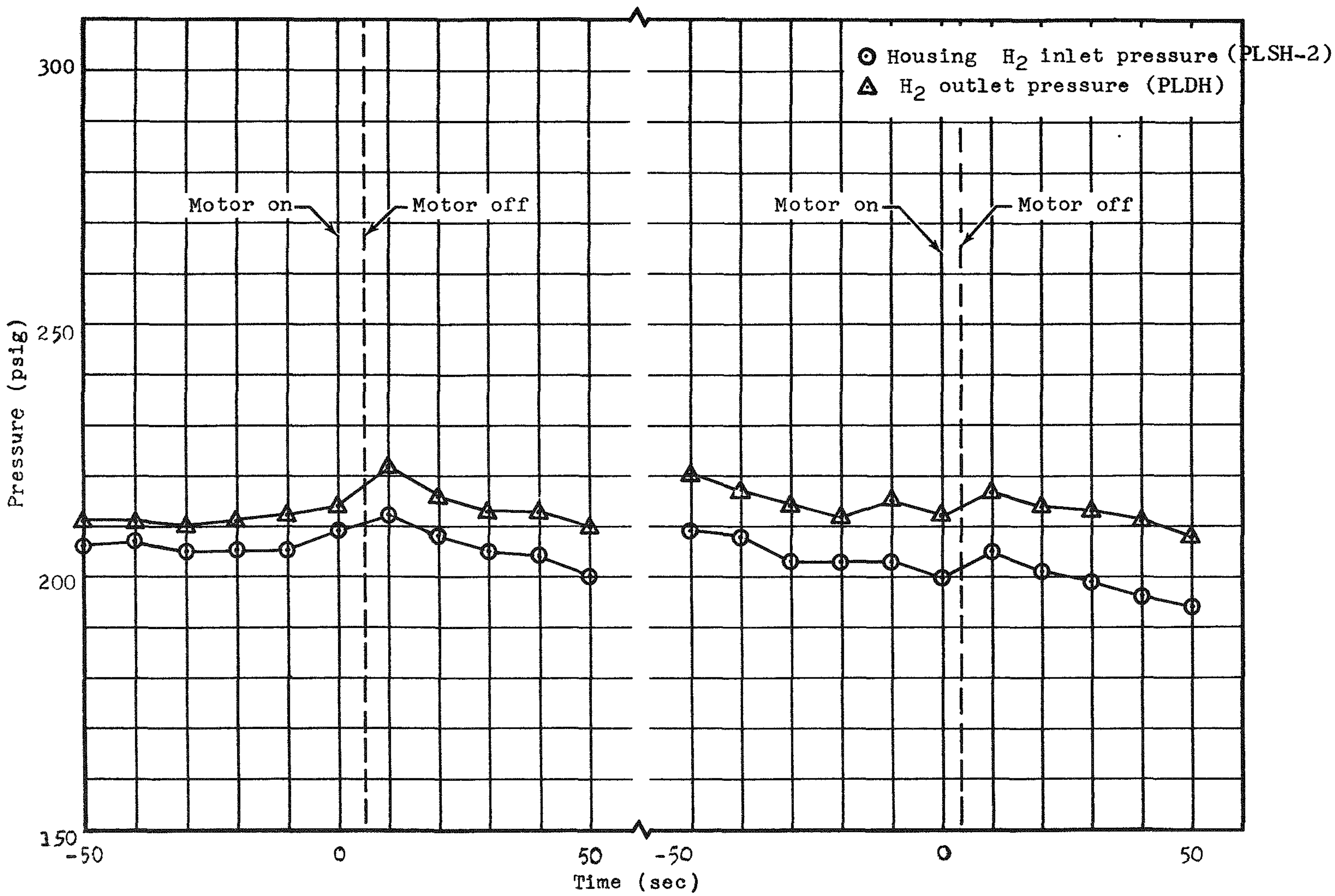
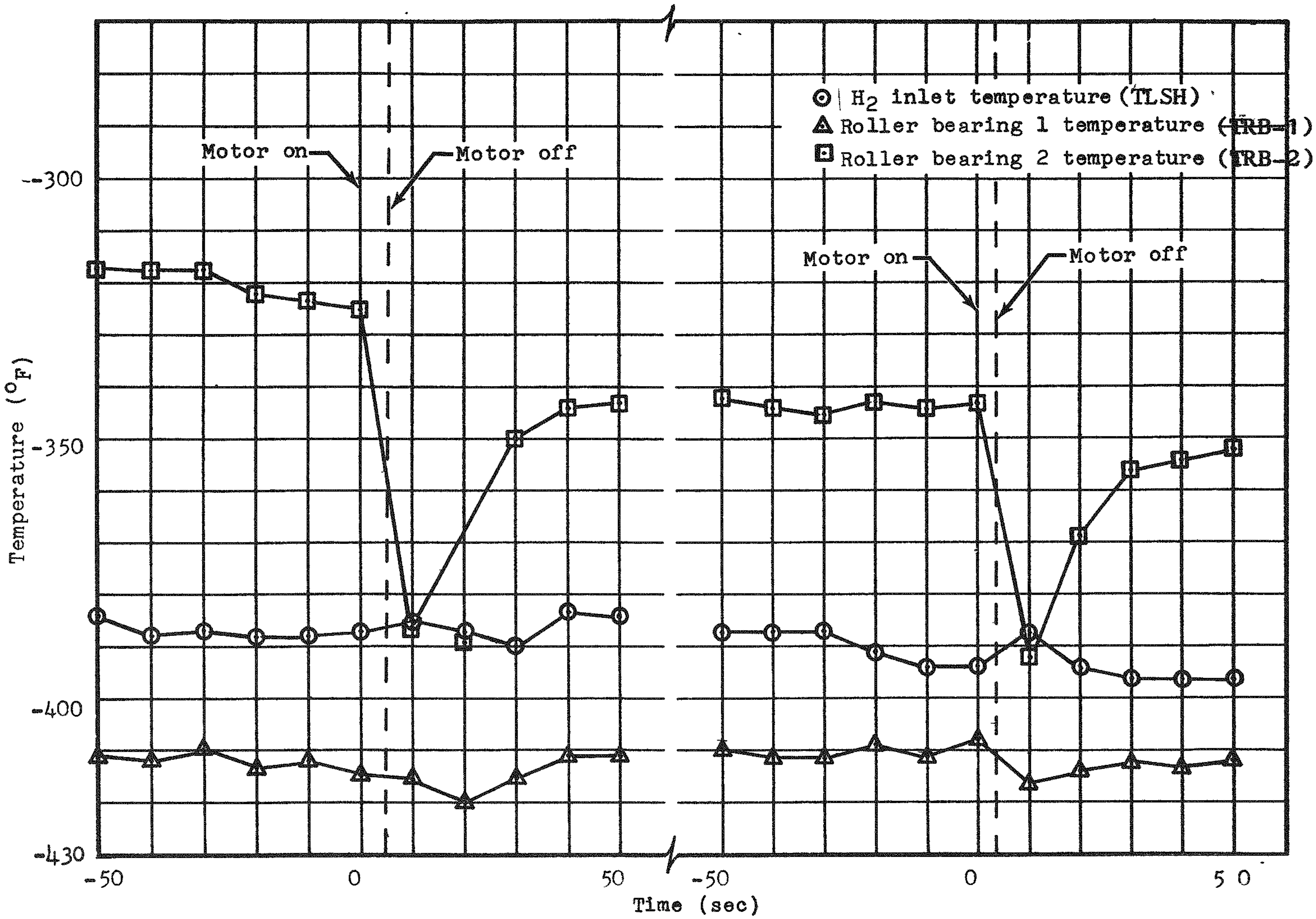


Figure C-4

Checkout Runs--Pressures of the Bearing Housing (PLSH-2) and Bearing-Tester Motor Housing (PLDH)



Checkout Runs--Temperatures of the Bearing-Tester Inlet (TLSH),
Loader-End Roller Bearing (TRB-2) and Motor-End Roller Bearing (TRB-1)

Figure C-5

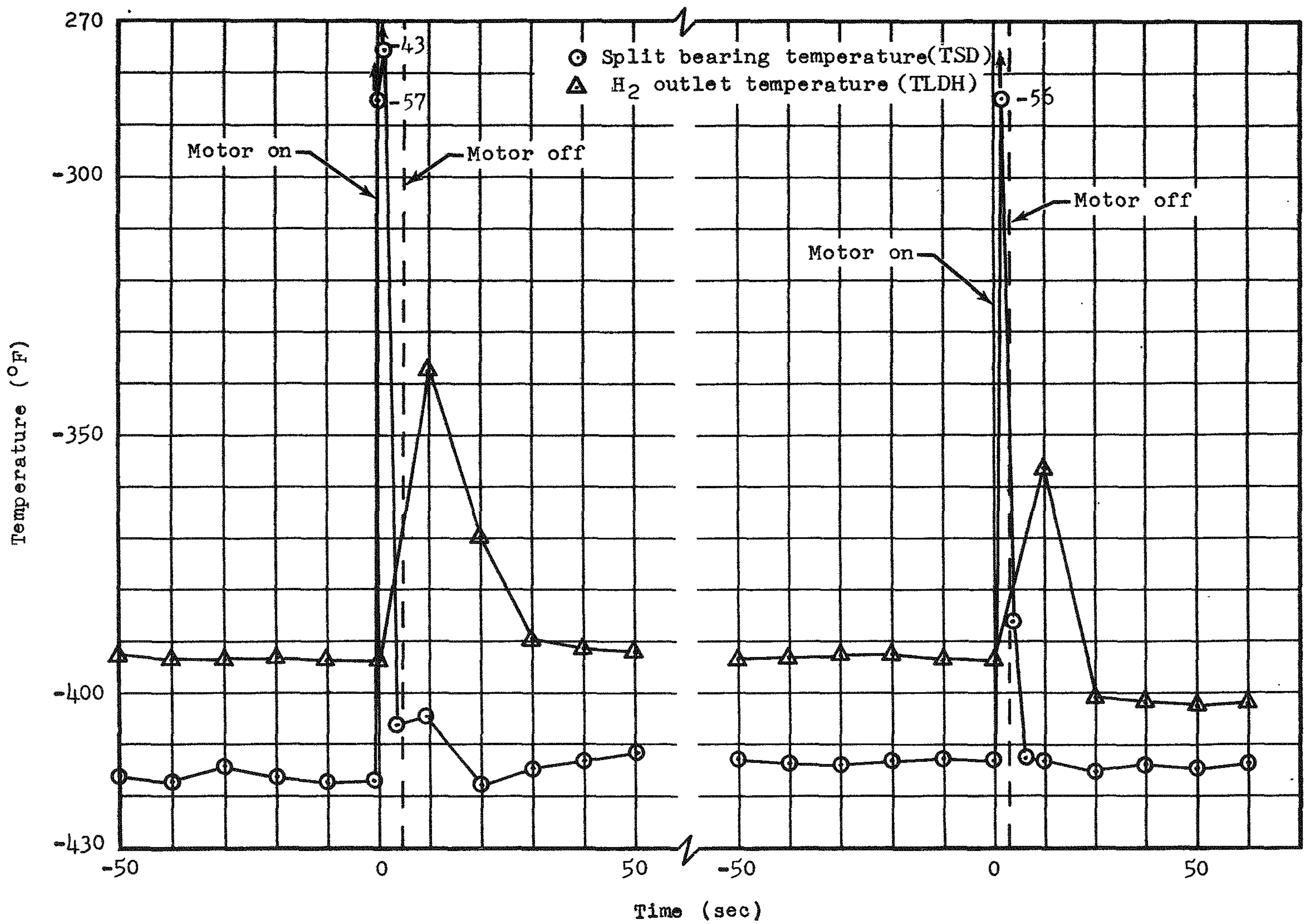
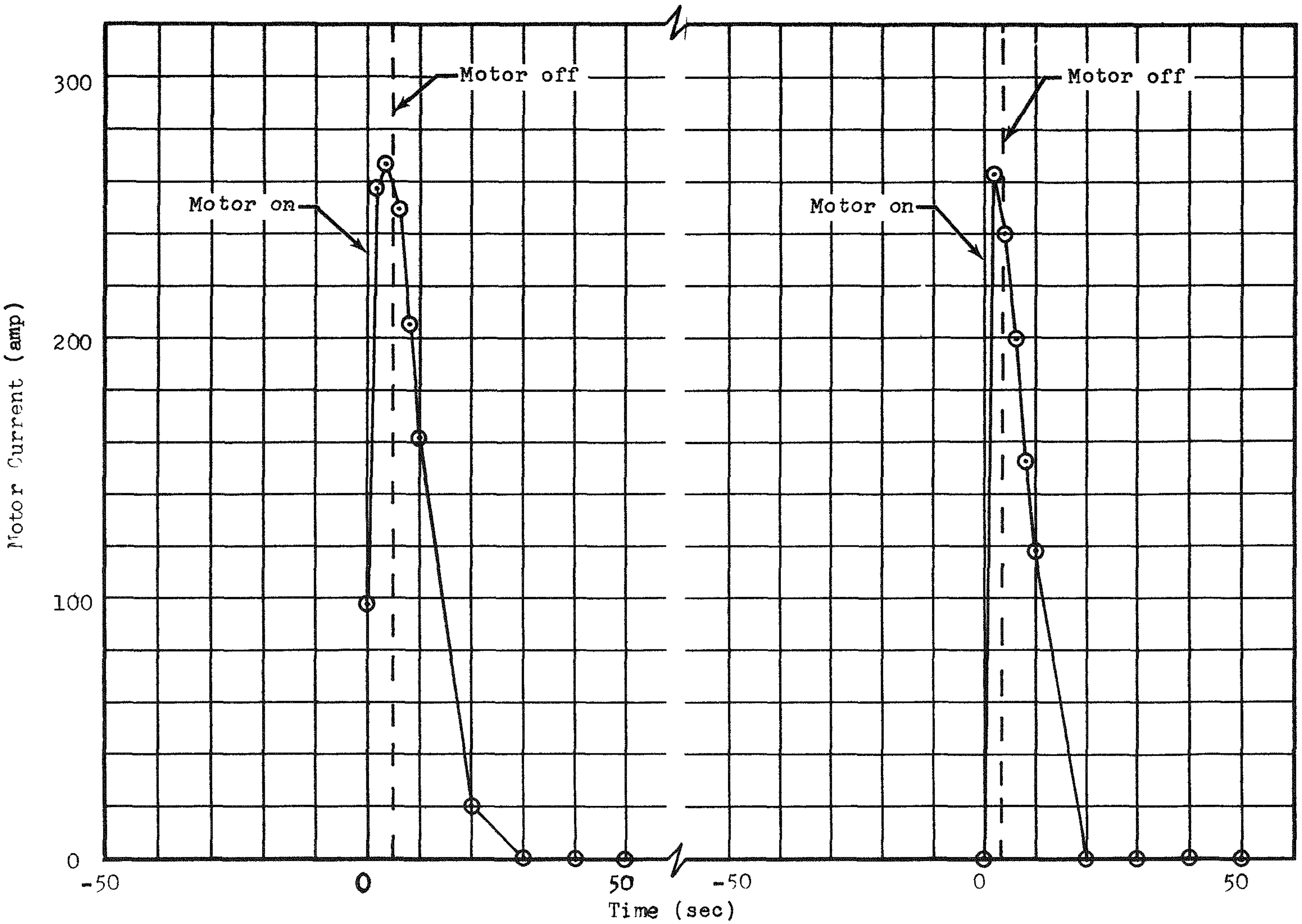


Figure C-6

Checkout Runs--Temperatures of the Split-Race Ball Bearing (TSB)
and Bearing-Tester Hydrogen Outlet (TLDH)

Figure C-7



Checkout Runs--Starting Current of the Bearing-Tester Motor (IM)

APPENDIX D

600-SEC IRRADIATION RUN

TABLE LIST

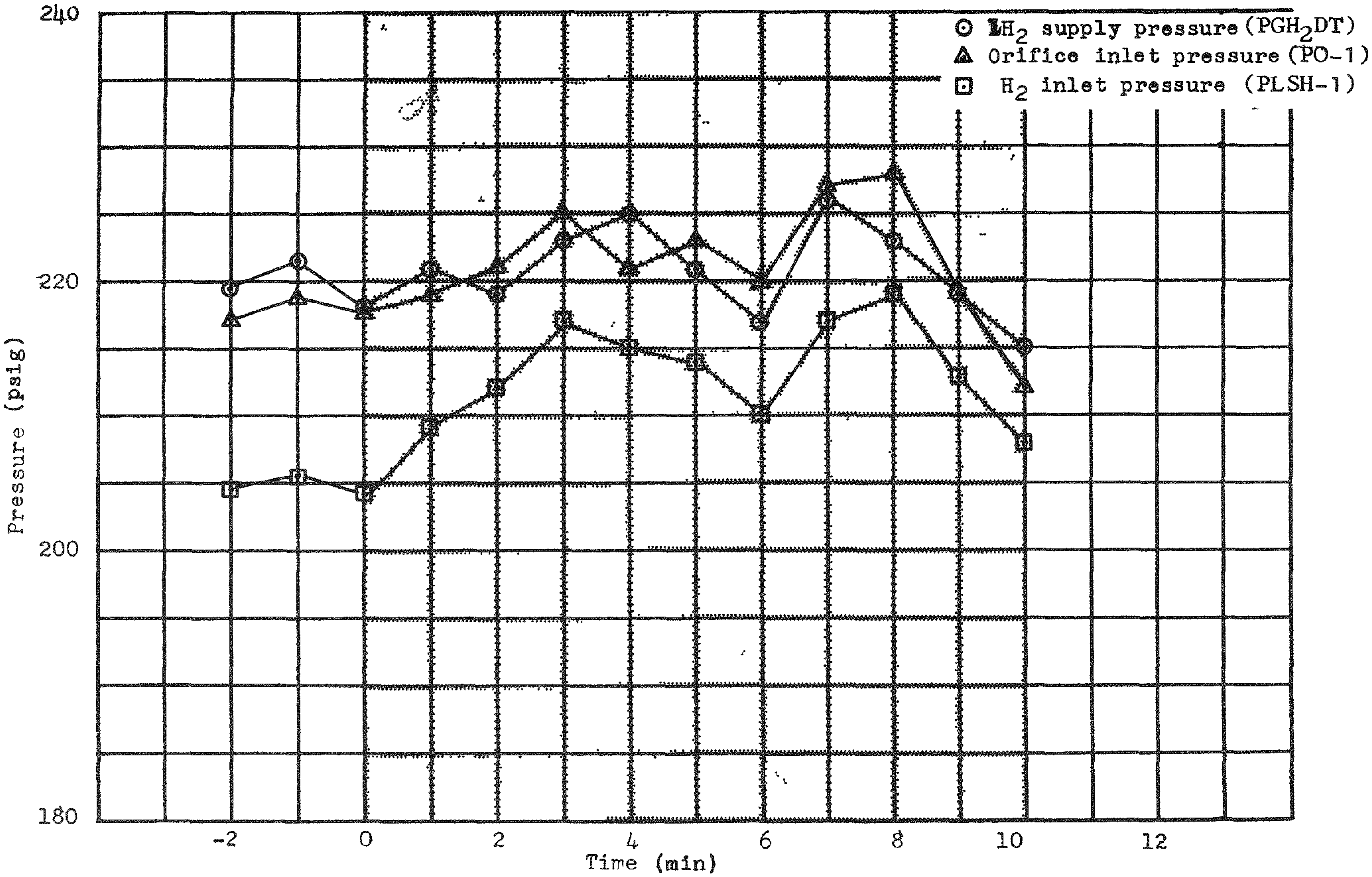
FIGURE LIST

Table D-1

SEQUENCE OF MAJOR EVENTS DURING THE 600-SEC IRRADIATION RUN

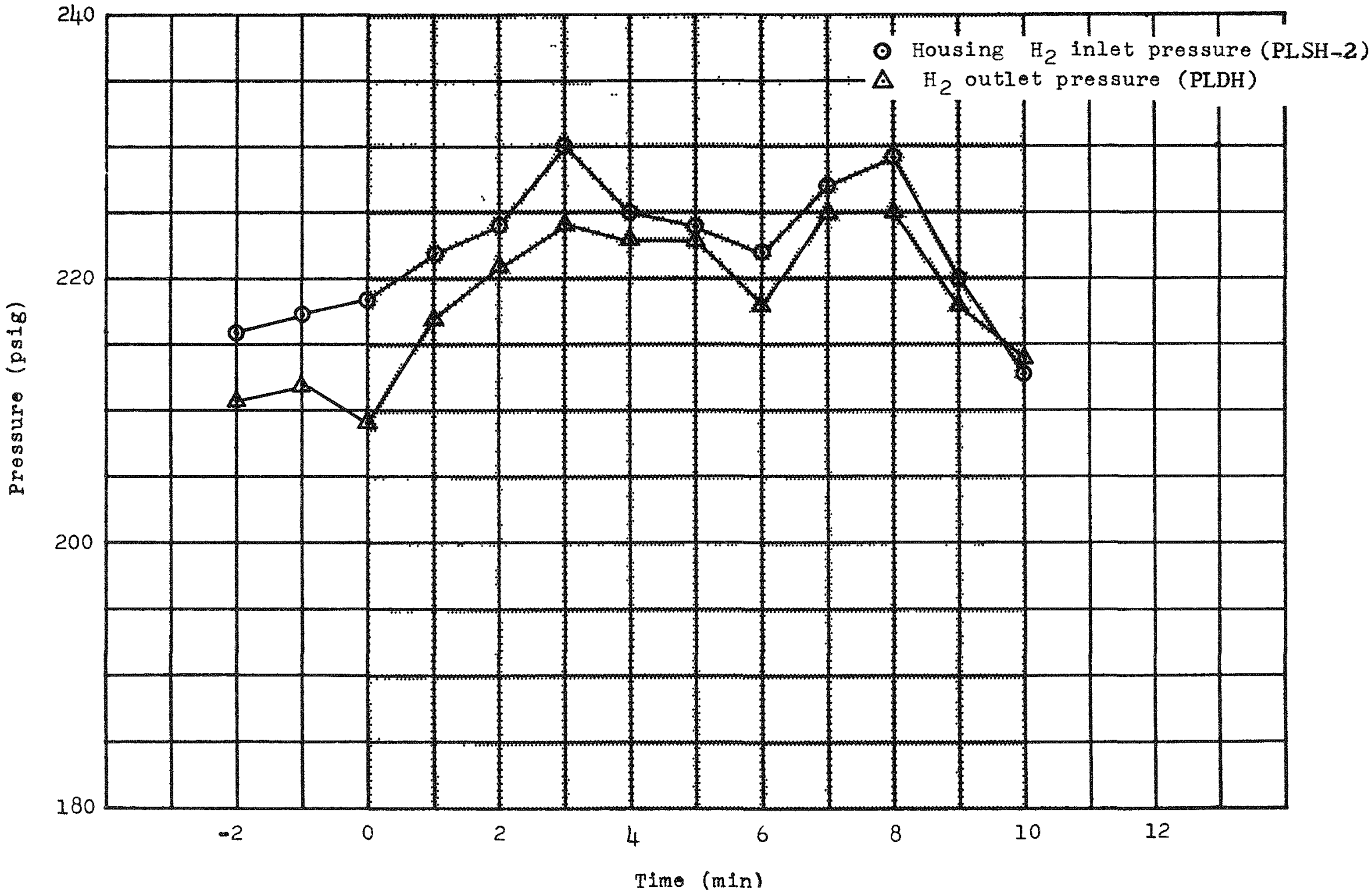
Time (sec)	Event
-1592	Line and bearing-loop cool-down started
-1436	P_{RL} set at 20 psi, P_{AL} at 300 psi
-1134	CDBP closed
-1011	ASTR stabilized at 10 watts
-869	Dewar pressure stabilized at 225 psig
-706	ASTR "scrammed"(zero power level)
-74	ASTR reached 10-kw power level
-48	ASTR reached 100-kw power level
-12	ASTR reached 5-Mw power level
0	ASTR reached 10-Mw power level, motor turned on
+14	P_{RL} set at 600 psig, P_{AL} at 500 psig
+431	T_{LDH} reached -275°F and dropping
+433	OBPV opened
+600	Reactor "scrammed", motor turned off
+608	Motor stopped (0 rpm)
+617	LH_2 flow stopped

Figure D-1



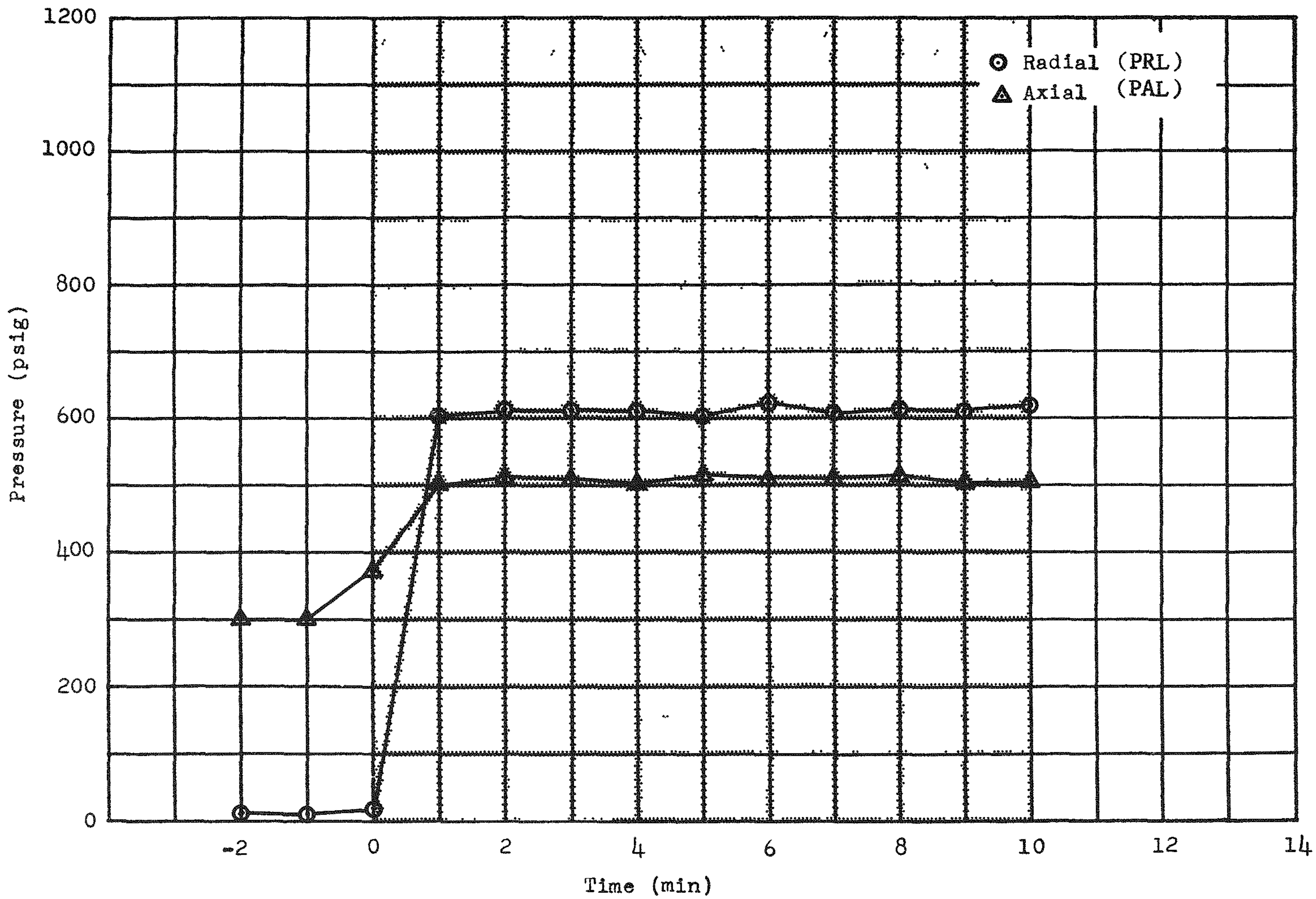
Irradiation Run--Pressure of LH_2 Supply at the Dewar (PGH_2DT) Bearing-Tester H_2 Inlet (PLSH-1), and the Orifice Inlet (PO-1)

Figure D-2



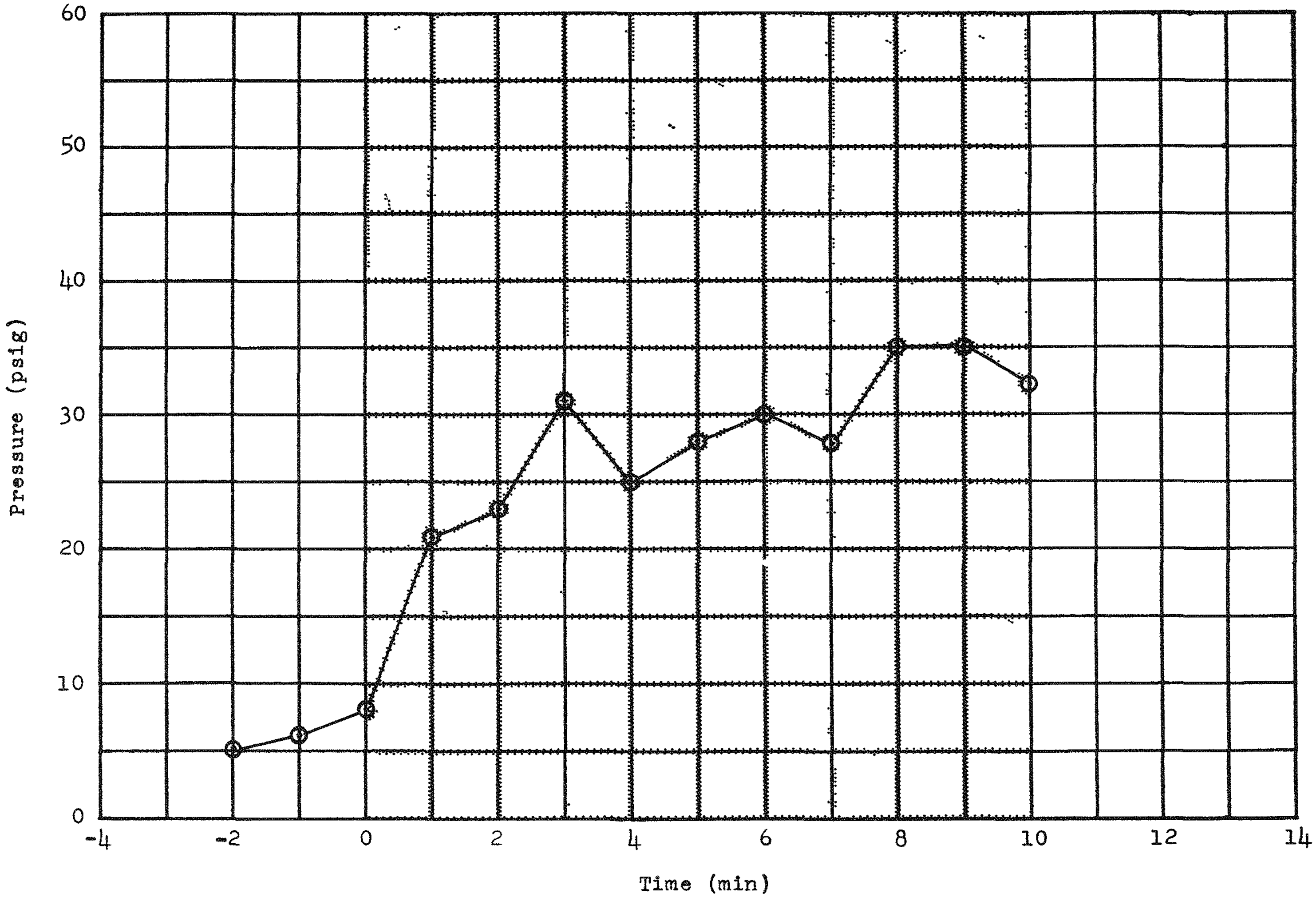
Irradiation Run--Pressures of the Bearing Housing (PLSH-2)
and Bearing-Tester Motor Housing (PLDH)

Figure D-3



Irradiation Run--Pressure of the Radial Load (PRL) and Axial Load (PAL)

Figure D-4



Irradiation Run--Pressure in the Bearing-Tester Loading Cavity (PBTLC)

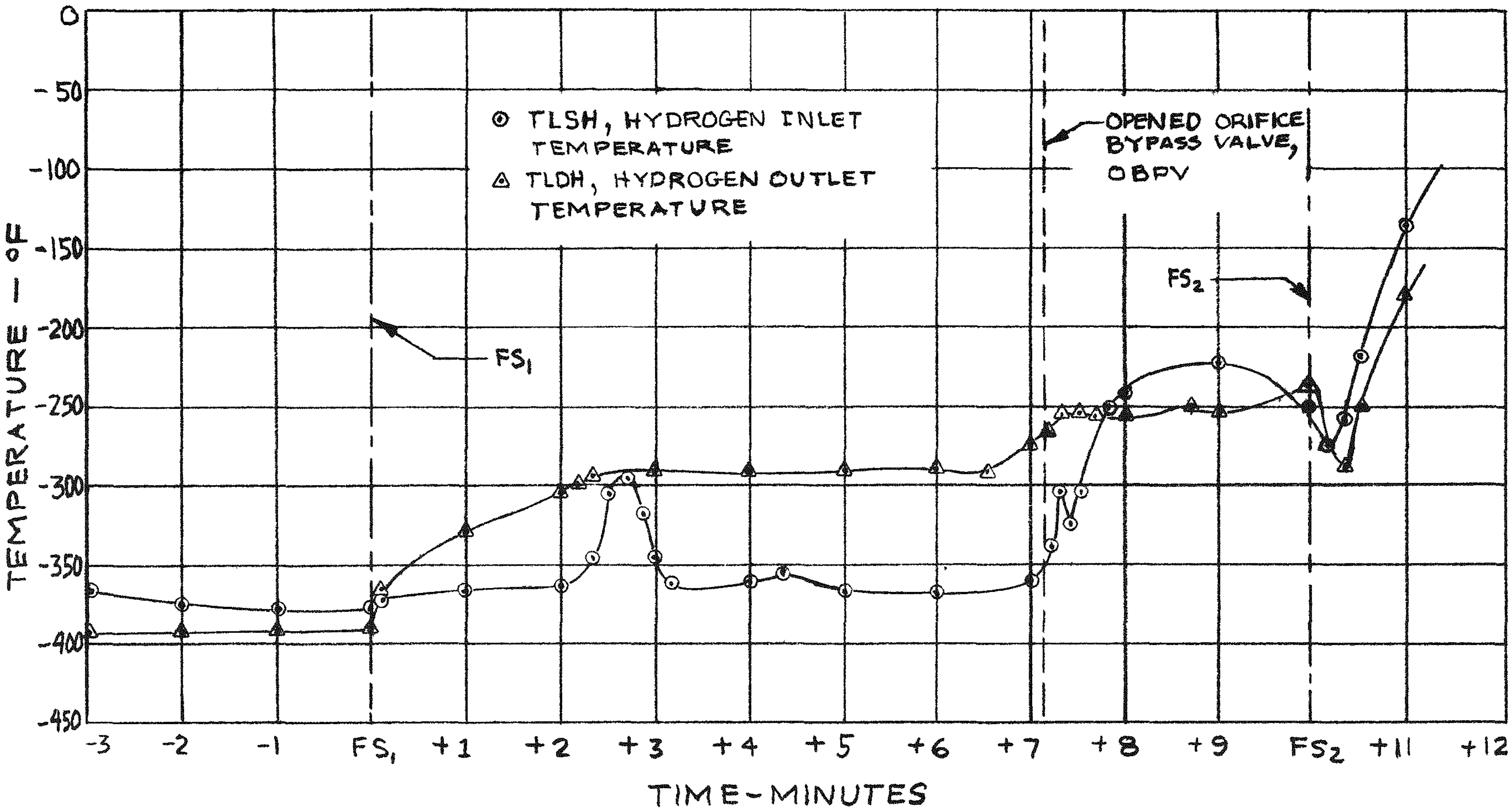
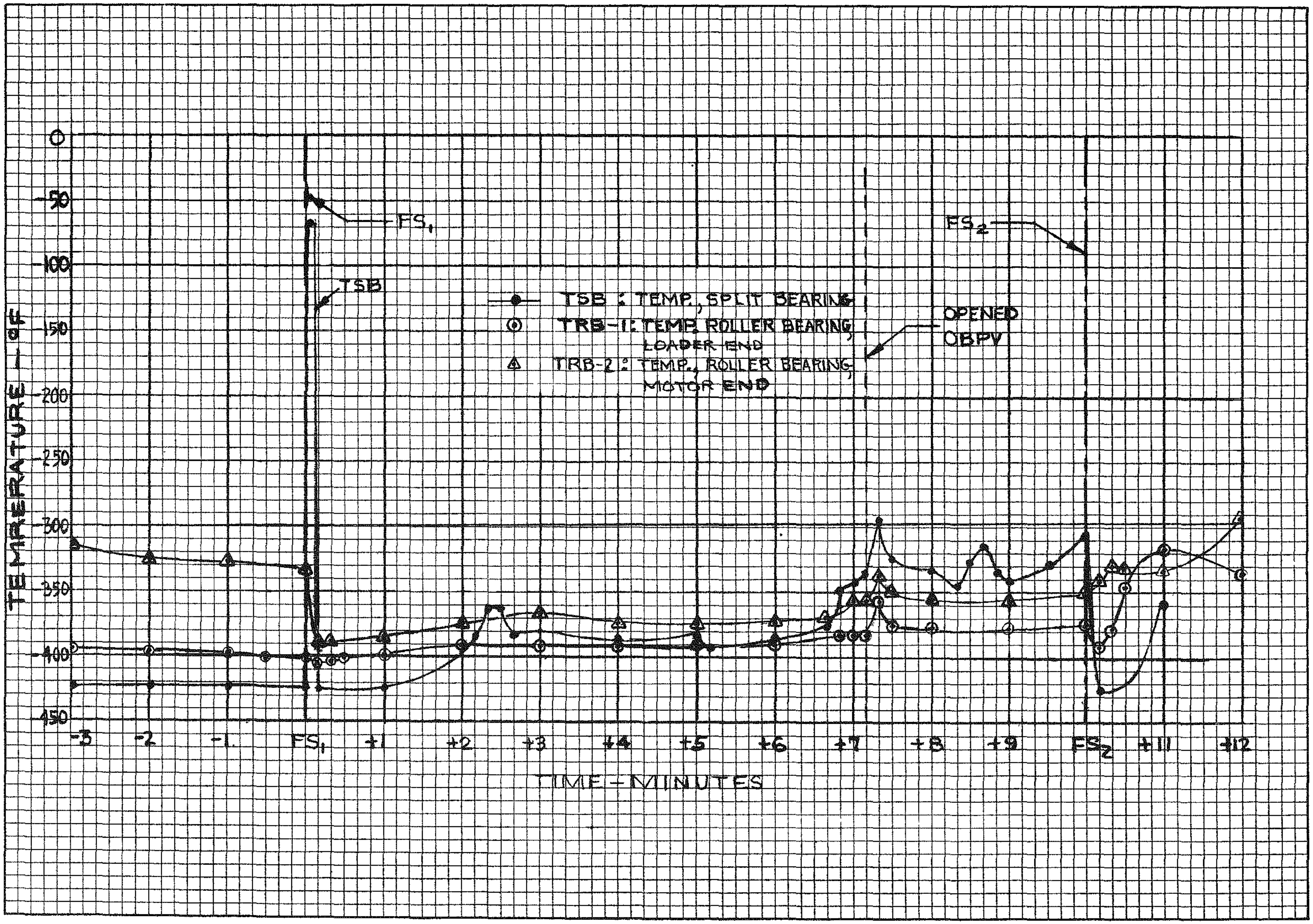


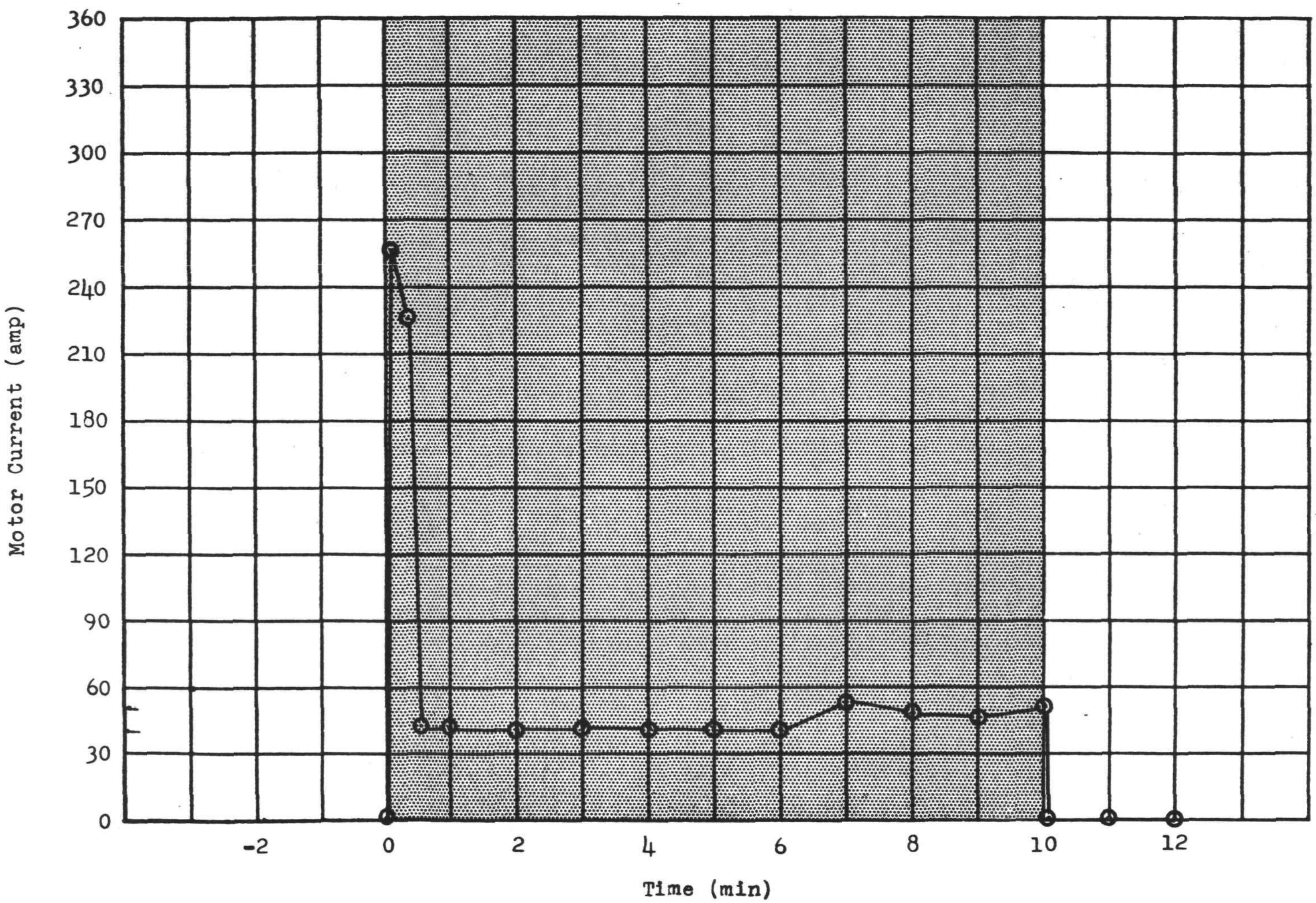
Figure D-5

Irradiation Run--Hydrogen Inlet and Outlet Temperatures vs Time

Figure D-6



Irradiation Run--Bearing Temperatures vs Time



Irradiation Run--Current of the Bearing-Tester Motor (IM)

Figure D-7

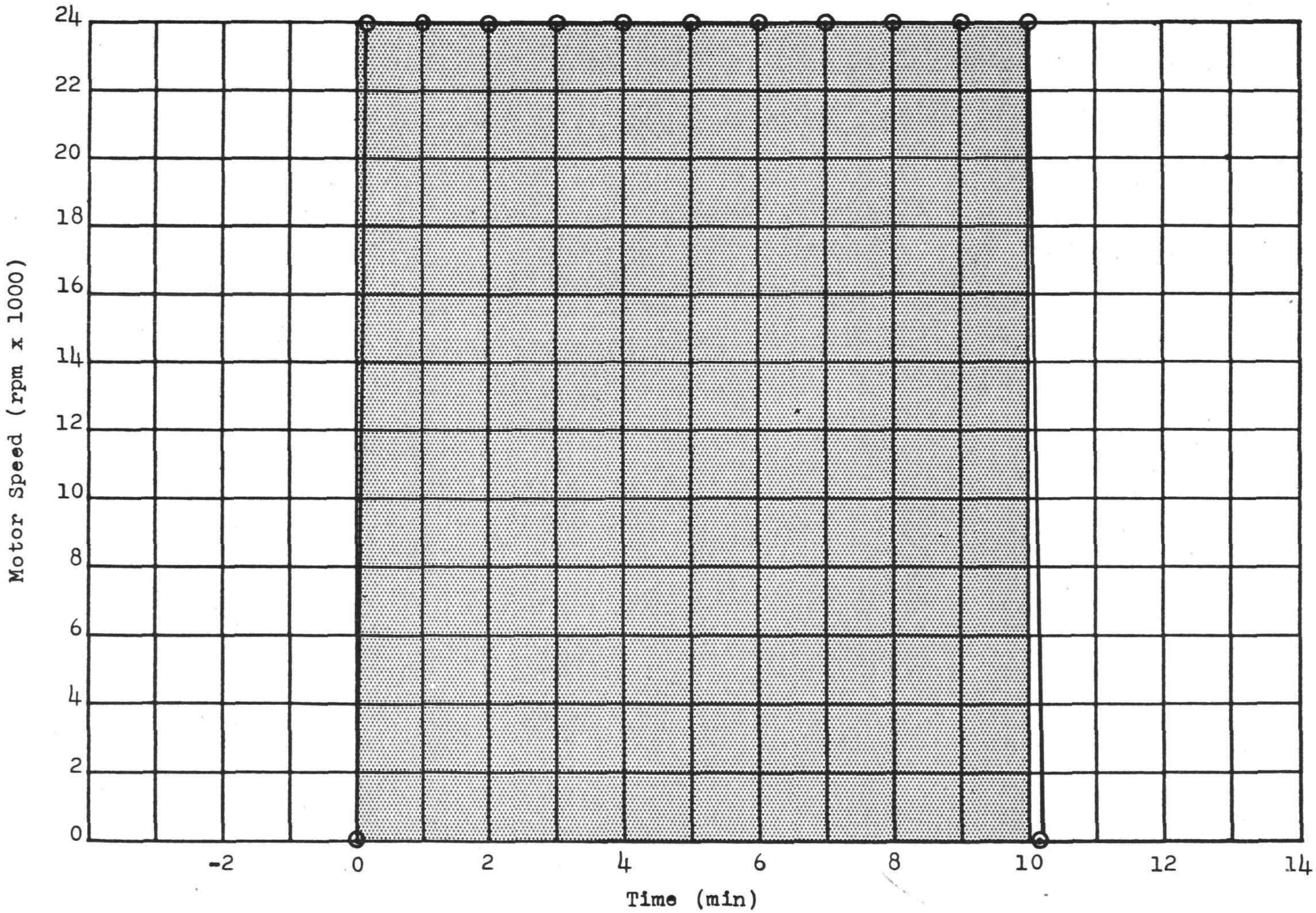


Figure D-8

Irradiation Run--Speed of the Bearing-Tester Motor (NTPB)

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