NUCLEAR ROCKET OPERATIONS

SACRAMENTO PLANT

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TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

SUMMARY REPORT CY '67
FOR PERIOD ENDING 30 SEPTEMBER 1967

NERVA PROGRAM CONTRACT SNP-1

NOVEMBER 1967

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AEROJET GENERAL

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AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY



Figure 2 - Test Configuration

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FOREWORD

The work described herein was conducted under, and in partial fulfillment of, Contract SNP-1 of the Space Nuclear Propulsion Office, a joint office of the National Aeronautics and Space Administration and the Atomic Energy Commission, with the Aerojet-General Corporation.

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I. INTRODUCTION

This document, the sixth summary report on the progress of the NERVA engine development program and its associated tasks, is submitted in partial fulfillment of Subtask 4.3 of Contract SNP-1 and covers Contract Year 1967 (1 October 1966 through 30 September 1967). The report has been prepared in sufficient detail to describe Contract Year 1967 progress. However, to minimize volume and repetition, reference has been made to previously submitted technical reports where feasible.

Work accomplished under Subcontract NP-1 to Westingnouse Astronuclear Laboratories (WANL) is covered in a separate summary report issued by WANL.

II. SUMMARY

A. PROGRAM HIGHLIGHTS

The major effort this year was directed toward mating XECF with ETS-1. Many of the program highlights pointed out in the three CY 67 quarterly progress reports involved delivery of the various items of NRX-A6, XECF, XE-1 and ETS-1 hardware to the test site, activation of the E-MAD hot and postmortem areas, and assembly of XECF in E-MAD. The frontispiece shows the movement of XECF to ETS-1. (The actual installation occurred 2 October 1967.) In addition, the third UTSM was authorized at mid-year and the cold and hot remote replacement program was defined.

The test specification for XE-1 was completed in May. All XE-1 hardware was completed during CY 67 and shipped to NRDS, where assembly was started in the E-MAD cold area. Assembly has been suspended pending resolution of problems associated with the discovery of a small quantity of fuel-element particles in the core, inner reflector, seal strip, and control drum housing. At the close of the period, laboratory investigation and further disassembly were planned. The problem is expected to be resolved in sufficient time for the engine to be ready for testing prior to ETS-1 availability.

The XE-2 nozzle was completed and prepared for shipment 12 weeks ahead of schedule.

An optimization program for the 200,000-lb thrust NERVA engine was completed in July 1967. Definition of this engine with drawings, specifications, and criteria documents will be accomplished with issuance of the PFRT Engine Design Requirements Baseline early in CY 68. This effort supported the preparation and submittal of a NERVA engine development program plan through PFRT (RN-DR-0103), detail program planning for CY 68, and the preparation of the input for the annual agency budgets.

At the conclusion of CY 67 the NRX-A6 Reactor was in final assembly for shipment to NRDS early in CY 68.

Overall Program Milestones upgraded as of the end of the period are presented in Figure 1.

B. ENGINE SYSTEMS

Primary effort on the NRX program during CY 67 was devoted to upgrading of the fuel endurance capability by WANL to ensure the achievement of the 60-min full-power full-duration objective for NRX-A6. As a result of this program and the consequent delay in assembling an NRX-A6 reactor, the NRX-A6 power test date was delayed from July 1967 to December 1967.

In support of the NRX-A6 test program, Aerojet completed shipment of all the required test article hardware to NRDS; WANL-Large, maintained and updated the interface control drawings, and participated in the preparation, review, and approval of the NRX-A6 test specification, operating procedures and safety documents. In addition, Aerojet personnel supported the pressure-vessel reactor assembly at WANL-Large for the NRX-A6 and XE-1 test articles.

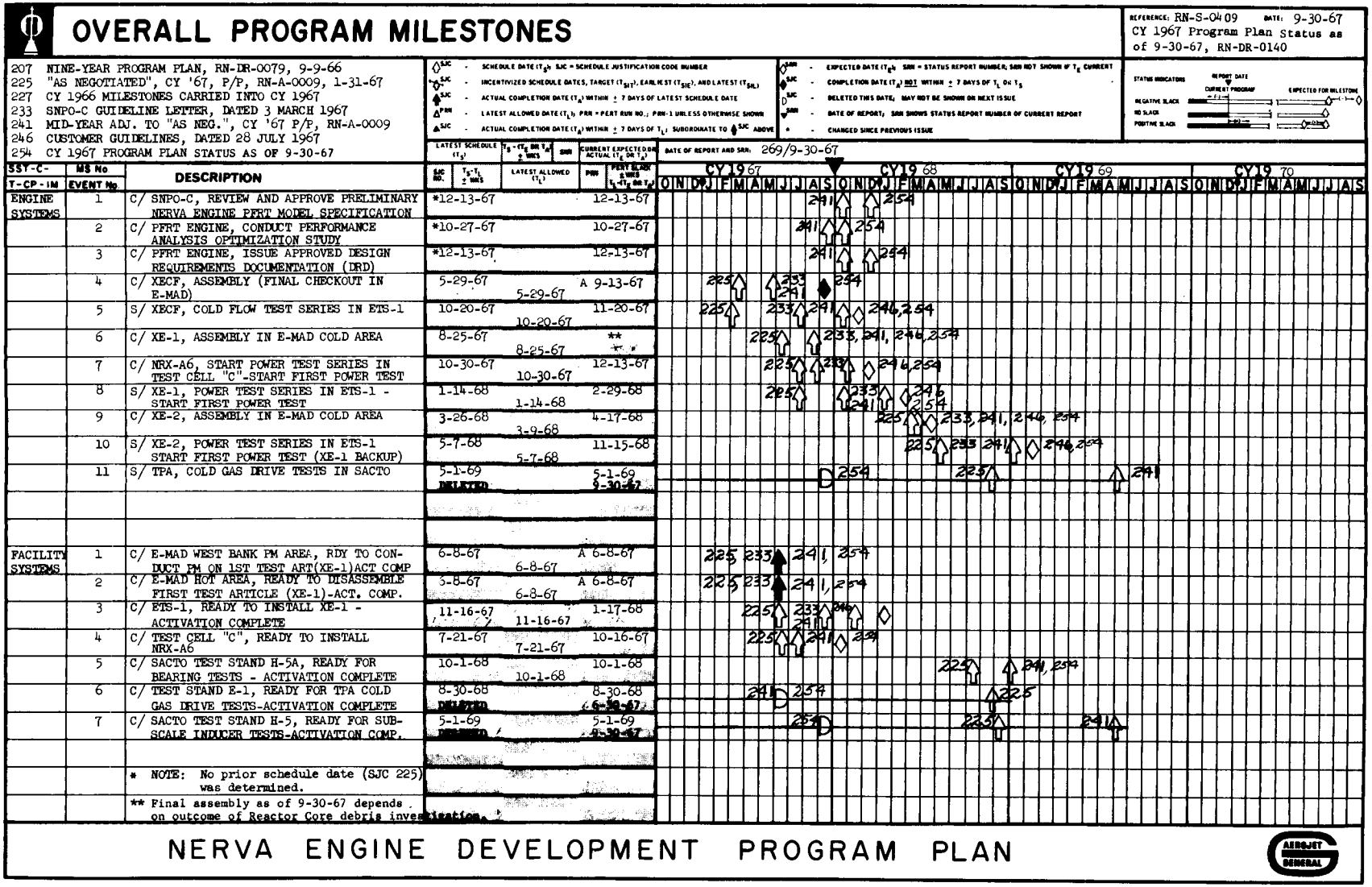


Figure 1 - NERVA Major Program Milestones

During the first three quarters of CY 67, significant effort was expended on design studies to uprate the NRX-type test articles in both power and temperature for NRX-A7. The studies, primarily in the areas of the reactor, pressure vessel and nozzle resulted in uprating of the NRX operating point to approximately 1500 Mw. A power test for a reactor test assembly of this power rating was scheduled for January 1969. However, redirection of the program during the last quarter of the contract year deleted NRX-A7 from the NERVA program.

At the beginning of the period, the XE-associated test articles, i.e., experimental engine cold flow (XECF) and experimental engines (XE-1 and XE-2), were in various stages of development. A majority of the components for XECF and XE-1 had been manufactured and were available for assembly. The NRX engine systems test (NRX/EST) during CY 66 had demonstrated the bootstrap start, restart, and stable operation of the hot-bleed cycle. Endurance capability had been demonstrated on both NRX/EST and NRX-A5 with accumulated time at rated power exceeding 30-min. The turbopump demonstration test program had been completed successfully, and nozzle performance on NRX/EST and NRX-A5 had demonstrated the suitability of the nozzle for use on XE-1. Remote assembly and disassembly features of the XE engine concept had been demonstrated at Sacramento by testing with the remote assembly and disassembly aid (RADA) and the weight and envelope mockup (WEMU) in conjunction with the engine-installation vehicle (EIV) and the manned control car (MCC). This work was continued during CY 67.

The cryogenic test program, which consisted of component cryogenic tests, was accomplished. The component tests demonstrated that on-mark connectors and electrical connectors functioned properly. The design of the installation and GN_2 purge in the UTS compartment minimized the formation of LN_2 lines. A drip pan/drain was provided atop the external shield to bleed off any LN_2. The tests demonstrated the adequacy of the design, since no deleterious effects were observed.

Assembly of the test stand adapter (TSA) was completed. The TSA was cryogenically tested in Sacramento, shipped to NRDS, checked out in E-MAD, and installed in ETS-1 to await testing of the XECF.

The XECF external shield was shipped to NRDS during the second quarter, and the XECF UTSM was completed and shipped during the third quarter. The XECF hardware was shipped to NTO, and assembly and checkout were completed the last of July; the test article was ready for installation in ETS-1 at the end of the contract year. Test predictions, issued in June, indicated that all the planned tests described in the XECF Test Specification (February 1967) were within the defined test parameter limits, and no unsafe conditions that could damage the test article or facility were indicated. Testing of the XECF is planned for November 1967.

All XE-1 hardware was completed and shipped to NRDS for final assembly. Test planning for the XE-1 was completed, and the test specification was issued in May. During assembly of the XE-1, at the point where the peripheral poison wires are pulled to install the nozzle, a problem was encountered. When the poison wire retention plate was removed from the pressure-vessel-and-reactor-assembly (PVARA), widespread particulate matter was detected over the aft end of the PVARA. Analysis indicated that the particulate matter was composed of graphite, NbC, and uranium; i.e., core material. Assembly was suspended until the cause of the problem could be determined. At the end of the contract year, a program of investigation and PVARA cleanup was being conducted.

Progress on the XE-2 hardware included completion of fabrication of the pressure vessel, lower thrust structure, turbine block valve, turbine power-control valve, turbine lines, pump discharge line, nozzle, and other miscellaneous hardware. All other hardware is being procured or is in some stage of fabrication. Final assembly of the XE-2 is planned during CY 68.

In support of the XE project, satisfactory performance of all mechanical support equipment required to remotely remove and replace the UTSM was demonstrated.

Nozzles for the technology engines, XE-1 and XE-2, were completed and accountability was transferred to the XE Project Manager. The backup nozzle for the NRX-A6 was transferred to the NRX Project Manager.

The XE-1 engine control system and the TSCS/TSS were successfully acceptance-tested at Aerojet-Sacramento and shipped to NRDS for installation in ETS-1. The equipment was installed and successfully checked out. A comprehensive updating modification program was then initiated, and various modification kits were installed and checked out. These changes were made to meet engine and facility requirements.

The common analog model for the XE-1 engine was agreed to have been correctly implemented at Aerojet and WANL, and the model was then used to design and evaluate the control system for normal, SCRAM, and emergency shutdown; conduct malfunction analysis and engine startup studies; and evaluate run profiles.

A test program was completed for qualification of the NT-D1 TPCV actuator for use in the technology-engine program; results of the various tests and recommendations were written and forwarded for publication.

Test predictions for the XECF test were issued. The XE engine cool-down systems have been defined, including the emergency cooldown. Malfunction studies of 25 different types of malfunctions were performed. A narrow-band data analysis program was prepared to perform the routine data reduction for ETS-1 data within two days after the test. Wide-band data analysis programs have been prepared for transfer-function analysis of steps, sines, and pseudo-random data; and a program has been prepared for power-spectral-density plots.

Line and valve components required for the XECF and XE-1 engine systems were shipped. Lines required for the XECF and XE-1 engine systems and the XE-1 upper thrust structure and lower thrust structures for XE-1 and XE-2 were shipped. The XE-2 pressure vessel was shipped, and analyses of the NRX-EST, A5, A6, A7, and the XE-1 pressure vessels were completed.

A NERVA engine parametric study was conducted early in CY 67 to assist in establishing the NERVA-engine thrust level. In addition, system-oriented zero-NPSP studies were conducted to establish the advantages of an engine system with a zero-NPSP capability. The results of these studies were presented to SNPO in December 1966.

Flight-safety studies were conducted during CY 67 that resulted in definition of an emergency cooldown system capable of maintaining system integrity after a loss-of-flow accident. Several issues of the MSFC NGTM specification were reviewed, and comments were forwarded to SNPO-C.

NERVA-control dynamic studies for the power range of engine operation were continued, and an analog computer model for the two-spool NERVA TPA inducer pump system was programed. Studies were made with the NERVA engine TAF digital program to determine the proper turbine power margin. Investigation and evaluation of various manufacturers for application of microcircuits in the NERVA flight-engine control system were conducted. A vendor search was also conducted for applicable electro-pneumatic servo actuators for use on the NERVA engine.

A preliminary NERVA-engine configuration-management plan was formulated. This plan was in general agreement with the Apollo Configuration Management Manual, NPC 500-1. A detailed test program was developed for NE-1 testing in ETS-1. This test description, along with the required modifications to ETS-1, was forwarded to SNPO-C in September 1967.

Design analysis of the pneumatic system required for NERVA was completed. Detail fabrication drawings were released, and a design review was completed on the NERVA propellant shutoff valve (PSOV). Preliminary analyses of the NERVA thrust structure and thrust-vector system was completed. Aluminum 7039 was recommended as the NERVA pressure-vessel material on the basis of material-development-program results, fabricability, and nuclear, thermodynamic, and structural analyses.

The nozzle jacket preliminary design was completed, and forging drawings were prepared. Nozzle coolant-tube design was conducted, and the optimum number of tubes was established. Nozzle design criteria and development plans were prepared.

A 7.00-in. internal-gimbal restrained-bellows assembly has been designed for use in the pump-discharge and emergency-cooldown-line assembly. NERVA-lines design criteria and development plans were prepared.

Design studies were conducted on major components of the skirt to identify and eliminate potential problem areas. Operating limits of the turbine-exhaust-cooled skirt extension were established.

For the NERVA engine, parametric studies were made of engine systems between 2900 and 5000 Mw. Detailed studies have been made of the 200,000-lb-thrust engine to optimize the components and the engine system. The requirements of a flight-safety system were analyzed. The engine system work was used to define the size of the NR system.

The transient digital program has been rewritten into FORTRAN IV and expanded to incorporate the new features of the NERVA engine, which include the inducer, nozzle skirt, and structural support system, as well as including analysis of the NRX, NR, and XE engines.

The analysis of the major error-producing factors in measurements systems was completed. A computer program was prepared to automatically produce and plot measurement-system uncertainty information for all diagnostic channels. The design and analysis of an advanced calorimeter were completed, and prototypes were fabricated and tested.

Primary performance criteria for the EPIC were generated, and a flame-spray technique was developed for cooling engine-mounted cables by conductive heat transfer.

C. SUPPORT SYSTEMS

Three radiation-effects tests were performed during CY 67. These were explosive-materials test 38/A001 (Phase I-A) at GETR, structural-materials test 37/R006 at GTR, and pressure-transducer test 23/R512 at the ASTR. In addition, analyses of test data were completed for instrument irradiation tests conducted during the last quarter of CY 66. Beyond these analyses, a portion of the CY 67 program was devoted to the preparation of reactor run GTR-21 at GD/FW. This run consists of thermal-conductivity tests 37/R018 and 37/R017 and TPA bearing-cage-materials test 37/R107. Analytical work in support of NERVA component design activities and preparation of radiation-effects reports summarizing the performance of NRX-A2, NRX-A3, EST, and NRX-A5 components was completed.

Coordination was maintained with NRO organizations, WANL, LASL (ACFI), NTO, SNPO-C, and various subcontractors to ensure proper integration of support equipment activities. This coordination involved reviewing and commenting on proposals, design criteria, specifications, procedures, special studies, and equipment change requests.

Support-equipment personnel were on hand at NRDS/E-MAD for initial use of the GSE during the RADA, WEMU, XECF, and XE-1 programs. Design was completed on modifications of four NRX items of support equipment for adaptation to NRX-A6. Fabrication of the modifications of two NRX items of support

equipment was conducted at NRDS; modification of the remaining two items will be completed in CY 68.

The Operational Support Plan for XE-1, Report RN-S-0190 (Volume II), was revised and issued in November 1966 and again in June 1967. Design-criteria documents for three items of XE support equipment were completed, and design or design modifications of 28 items of XE support equipment were completed.

Fabrication of 32 items of XE support equipment, including modifications, was completed, and the items were shipped to NRDS. Modifications of four items of XE support equipment for which design is complete are in various stages of fabrication or are to be fabricated, and all will be completed in CY 68. Two items of XE support equipment for which design is complete will be fabricated in CY 68. Twelve items of XE support equipment completed in CY 66, some of which were tested and used at Sacramento, were shipped to NRDS.

Operation and maintenance instructions were prepared and issued for nine items of XE support equipment, and reassembly, checkout, and acceptance tests were completed on the MCC/EIV/PM. Design, fabrication, and installation were completed on ten major modifications to the MCC and EIV. The end-item report for the POCMTS was completed.

Support was provided for the NERVA program by providing proposal input based on applicable specifications and guidelines. A preliminary checkout plan was prepared. Support was also provided in analyzing requirements for E/STS 2-3 where GSE interfaces were affected, and contacts were made with LASL and ACFI to ensure maximum use of Phoebus GSE in the NERVA program.

Reliability engineering personnel participated in the NERVA flight-safety presentation at SNPO-W on 19 July 1967. The presentation described the engine-system failure modes that would result in a loss-of-coolant accident, including a probability estimate for the critical time period wherein an

in-flight malfunction would result in a land impact during the suborbit phase of the 72-hr. lunar-transfer mission. Of the four engine system failure modes, one mode (steady-state failure causing loss of mission and immediate abort) is a catastrophic-type failure, which creates a flight safety problem if it occurs during the 11-sec African-window portion of the lunar-type mission or during the second engine start or steady-state operating phases. By using a custom-designed valve and regulator system, the probability of sudden loss of coolant flow is directly proportional to the estimated failure rate of the TPA (0.0014). The African-window probability of sudden loss of coolant flow was estimated to be 2.56 in 100,000 attempts.

The estimated engine-system failure probabilities were distributed as functions of engine operating phase for the two cycles of operation required for the lunar-type mission. The first cycle probability of success was estimated as 0.9873; that of the second cycle was estimated to be 0.9821. The mission probability of success was estimated to be 0.9694.

Because the low volume of test hardware and data virtually precludes the use of a statistical approach to the problem of obtaining an accurate assessment of engine system reliability, a unique approach has been developed by NRO and WANL that combines quantitative and qualitative assessments and provides an accurate assessment of reliability in accordance with the requirements of NPC 250-1.

Studies were conducted to evaluate the safety of nuclear rocket operation during the suborbit phase of the 72-hr. lunar-transfer mission. A reference mission and trajectory profile establishing the critical flight safety periods was defined. Auxiliary thrust system and delta-V requirements for controlled deep-ocean disposal were established. Nonnuclear-component response to a loss-of-coolant accident was defined, and emergency auxiliary cooling requirements and system concepts were presented.

Project support was provided throughout the contract year by Program Controls, Documentation Services, Fiscal Control, Quality Control and New Technology.

D. FACILITY SYSTEMS

At Sacramento, planning relative to Test Stands E-1, E-2, and E-3 was pursued throughout the contract year. The factors considered included varying relationships between the overhead run vessel and the pump inlet, the test schedule, and varying degrees of versatility in the instrumentation and controls systems.

A preferred method of heating hydrogen for the TPA turbine drive was selected, and a subcontract was awarded to Twyman Engineering Co. to design a hydrogen heat exchanger. However, the heater design effort and all other E Zone design efforts were terminated in September at SNPO-C direction.

NERVA component development testing was accomplished throughout the year in the Cryogenics Laboratory. The types of tests included bearings, valves, filters, insulation, metallic specimens, and an upper thrust structure.

NERVA technology engine development testing in Test Zone H was completed, and the facility was partially deactivated.

Coordination and assistance were provided on a continuous basis in support of ETS-1 activation and NES testing. This effort included development of the design criteria for the test diagnostic center, defining requirements for and procurement of television lighting power supply and plug components, sound-pressure transducers, stand heating, and instrumentation. Analysis and data reduction support was provided for NES testing, reliability studies, and the Greely Event.

The preliminary and final data system accuracy testing and data analysis were completed. The addendum test was completed, and the data are being analyzed.

The coolant water system of the NES duct satisfactorily passed proof testing and water flow testing of the system was completed; Report RN-S-0360, Steam Generator System Development Test Final Report, a contractual milestone item was issued; the steam generator system improvement program was completed, and the modification and additions were qualified by testing; Phase I of the NES design demonstration test program was completed using a temporary engine compartment, and the Phase II program using the permanent engine compartment was started.

Continuous support was provided for the design of facility modifications, procurement of modification kits, and analyses in support of ETS-1 activation:

Major activities consisted of the following:

1. Design and Procurement

   a. External engine fill-and-drain system
   b. Control-drum-actuator vent system
   c. Alternative cooldown path
   d. Cryogenic trap
   e. Thrust ring
   f. Engine-test-compartment (ETC) latches

2. Analyses

   a. (ETC) pressures and repressurization
   b. Duct-plume heating
   c. Failure-mode analysis

d. Steam-line dynamic analyses

e. Support for ETC repair and modification

Effort at ETS-1 was concentrated on the installation, modification, and activation of facility systems to satisfy safety and engine testing requirements for the NERVA program. After successful individual programs were conducted to improve the gas generator system, to check operational reliability of the engine test compartment, and to obtain operational data on the NES duct, experimental plans were successfully conducted with gaseous nitrogen that demonstrated inerting capability and successful operation of the combined NES subsystems. Problems related to the gaseous and cryogenic fluid systems were solved by converting valves from pneumatic to hydraulic actuation. As CY 67 ended ETS-1 was ready for the installation of XECF.

The E-MAD building was activated on 8 June 1967. However, work continued to prepare the hot cells and CDAE for the NRX-A6 and XE-1 posttest operations by the installation of special equipment.

Operator qualification programs were completed for the operation of remote handling equipment. Personnel and facility readiness was accomplished to support NRX-A6, XECF, and XE-1 assembly operations and to prepare for the disassembly and postoperative examinations.

In early 1965 various diffuser concepts were considered for the E/STS 2-3 facilities. A scaled-up ETS-1 type exhaust system was used as the reference point and various configurations were evaluated to reduce the overall height. This work led to a scale model test program designed to evaluate various diffuser L/D ratios, contraction ratios, contraction angles, elbow configurations, film cooling, preliminary water penetration and water mixing tests. Portions of this program were reported in the CY 66 Summary Technical Report, RN-A-0008; however, testing and analysis were completed in this contract year. As a direct result of this experimental and analytical effort and Aerojet recommendations, a diffuser system was selected by SNPO in January 1967.

This configuration had an entrance diameter of 126 in., an L/D ratio of 4, a contraction ratio of 1.9, a contraction half-angle of 4, a wet elbow, center-body ejector nozzles, and a turning deflector. A scale model of this selected diffuser was fabricated, and testing was initiated early in February 1967. Further testing of steam penetration has been completed in the NASA 6 by 9 ft wind tunnel at Lewis Research Center.

Analytical and experimental efforts were directed toward evaluating the 1:20 scale E/STS 2-3 selected NES system. These efforts were largely concentrated on (1) the diffuser without plenum elbow, (2) diffuser with plenum elbow and no water injection and (3) diffuser with plenum elbow and water injection. These wet and dry elbow experiments were conducted at the Von Karman Center test facilities of Aerojet-General Corporation in June 1967. The purposes of the tests were to increase understanding of the fluid-dynamic and heat transfer processes in a diffuser plenum system such as envisioned for E/STS 2-3 and to demonstrate that the plenum would be cooled by the water injection. These duct tests were conducted with 1:20 scale hardware that was instrumented to determine surface temperatures, static wall pressures, and total pressure of the gas stream, with or without the addition of water. The test equipment consisted of a contoured nozzle with a 40:1 expansion ratio in an air-tight enclosure, a second throat diffuser with a 4:1 length-to-diameter throat section, a water injection system at the exit of the diffuser designed to inject sufficient water to saturate the gas stream, followed by a plenum that included a deflector plate to aid in turning the exhaust gases.

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III. TECHNICAL DISCUSSION

A. ENGINE DEVELOPMENT (TASK 1)

1. Engine Systems (1.1)

a. Engine System Integration, Design, and Documentation (1.1.0)

(1) X-Engine Layout Drawing

The engine design was firm at the start of the year and hardware assembly was in process. Layout efforts were directed mainly toward the support of design investigations and resulting modifications brought about by hardware fabrication and assembly or associated test programs. Included in this category were such items as the layout of the insulated drain pan installed at the bottom of the UTS compartment, rerouting of the GN_2 purge system, redesign and rerouting of the control-drum-actuator vent system, and a study to determine the feasibility of remotely removing the TPA from the UTSM.

(2) X-Engine Assembly Drawings and Assembly Parts List

The final assembly drawings for the XECF engine, XE-1 engine, and the TSA were released in the early part of the year. The electrical installation drawings were released shortly thereafter. Modifications were continuously required as a result of actual hardware assembly efforts. When the assemblies were shipped to NTO, their as-built configurations were defined in their respective EIRs. Subsequent configuration changes occurring at NTO were initiated and controlled by the issuance of field change orders. The configurations of the major assemblies shipped to NTO were in accordance with the following:

Drawing Title	Drawing No.	Change Letter
Engine Assembly, XECF	1114000	B
Module Assembly, Lower XECF	1116957	C
Installation Kit, Instrumentation - Lower Module XECF	1117240	B
Engine Assembly, Nuclear XE-1	1116931	B
Module Assembly, Lower, Nuclear, XE-1	1117122	B
Installation Kit, Instrumentation - Lower Module XE-1	1117230	A
Upper Module Assembly (XE-1 & XECF)	1117061	R
Propellant Feed System and UTS Assembly (XE-1 and XECF)	1117060	H
Electrical Installation Kit, UTS	1117580	B
Instrumentation Installation Kit, UTS	1117220	A
Test Stand Adapter	1117088	G
Instrumentation Installation, TSA	1117210	B

(3) X-Engine Piping and Instrumentation Drawings

The piping and instrumentation drawings for XECF and XE-1 were updated and reissued twice during the report year. At the close of the year, these drawings were being updated to reflect the latest instrumentation and piping changes, as well as for inclusion of those facility details that directly affect engine operation.

AGC Specification AGC-90166, Termination Schedule, Control and Instrumentation Cable, XE, was issued in February 1967 and defines the engine and facility wiring terminations from the engine transducers to the north terminal room. Two revisions were made during the fourth quarter.

In conjunction with this specification, a formal procedure for making changes has been initiated to provide holders of the specification with up-to-date changes between official releases of the specification.

(4) X-Engine Measurements-Requirements Lists

The 14 September 1966 XE-1 measurement-requirements list (MRL) and the 13 December 1966 XECF MRL were submitted to, and approved by, SNPO-C. All subsequent changes to these documents have been controlled by using measurement change requests (MCRs). All MCRs that changed the intent of the MRL were submitted to SNPO-C for approval prior to convening of the Test Specification and Procedure Review Board (TS&PRB). Since that time, all changes have been processed through the TS&PRB.

The XECF and XE-1 MRLs have been updated and reissued two and four times, respectively, during the report year.

The XE-2 preliminary joint MRL was issued for review on 3 August 1967. The approved issue of this MRL will be issued during October 1967.

(5) X-Engine Interface Control

The interface-control-drawing (ICD) efforts were directed toward integration of the nuclear-subsystem and ETS-1 designs with the X-engine assembly. A major configuration change in the nuclear subsystem was one concerning the engine-mounted nuclear detector. The previous design, with a single LH_2-cooled detector assembly, was changed to one having three individually mounted detectors, plus the calorimeter, which are cooled by direct contact with the pressure-vessel dome.

The major interface configuration change concerning the ETS-1/X-engine ICD was that of changing the aluminum octagonal thrust ring to a steel circular ring. This change resulted in corresponding changes in the TSA/ETS-1 attachment design.

(6) TSA Development and Assembly

The test-stand-adapter (TSA) structure was received from the vendor at the start of the first quarter, and assembly of the TSA (to the configuration shown in Drawing 1117088) was initiated shortly thereafter at Sacramento. A design change was made during assembly of the unit to incorporate urethane insulation for the LH_2 lines and Refrasil Batt for the shield supply and vent lines, and the On-Mark connectors. The assembly was then used in the cryogenic test program at Sacramento. Assembly and checkout operations were completed during the third quarter, and the TSA was shipped to NTO. After E-MAD processing, the unit was installed into ETS-1. At this time, the PIL assembly was pressure-checked in an unrestrained condition, resulting in an elongated 1116021 bellows segment. To preclude recurrence of this elongation, a line-restraint design was initiated for the bellows segment. This hardware is presently being fabricated, and the design modification will be installed during the next report period.

(7) X-Engine Shield Development and Assembly

Fabrication of the XE-1 external shield was completed at AGC Fullerton in the first quarter, after completion of the XECF shield in the fourth quarter of CY 1966. Both units were assembled into their respective engine assemblies, with minor assembly modifications performed. Bellows were added to the supply- and vent-line segments of these units to facilitate assembly. The test proof pressure was increased from 24 to 39 psig as a result of pretest analysis. Both units successfully passed the increased proof-pressure test; minute leakage occurred around three studs on the XECF shield structure but was considered acceptable for engine testing. The units were disassembled from each engine and were shipped as an assembly to NTO. During leak check of the XECF shield at E-MAD, a seal could not be held on the two center-cover Marman flanges. Measurements disclosed that the covers had been distorted when welding was performed after the flanges were finished-machined. To eliminate the

leakage, O-ring seals were installed and will be used for XECF testing only. This problem was corrected on the XE-1 shield assembly by finish-machining the flanges after all welding had been performed.

To upgrade the XECF shield for XE-2 use, oversize Conoseals will first be tried to effect a seal. Should this attempt prove unsuccessful, the cover and flanges will be replaced if necessary. New hardware for this effort is presently being ordered.

(8) X-Engine Cooldown System

The cooldown sequences for the normal, scram, and energency shutdowns have been established by use of both the digital and analog computer models. The results of these analyses have been reviewed, and recommendations for improvements and changes have been made.

The ETS-1 facility experimental plans were reviewed, and recommendations were made that would check out the cooldown system. Also, information was coordinated to revise and update the digital and analog computer model on the basis of facility test results.

Recommendations for changes to make the facility compatible with the cooldown system were coordinated.

(9) X-Engine Pneumatic System

Fabrication of the pneumatic lines for the XECF and XE-1 UTSMs and the TSA was completed, and the lines were installed in their respective assemblies. Because matings of the UTSM and TSA in the engine-assembly and cryogenic-testing programs at Sacramento were conducted without benefit of the finer control capabilities of the EIV-MCC or OPS, distortion of a TSA pneumatic-line bellows occurred. At this time, a decision was made to replace all 2-in. bellows in the TSA lines with bellows of improved design.

The design and fabrication of the new bellows was completed, and the lines were reworked and reinstalled in the TSA assembly. Mechanical stops were added to the UTSM lines at the 18-in. remote interface to prevent bellows distortion during disengagement. Fabrication of the pneumatic lines for the XE-2 UTSM, initiated during the third quarter, incorporated the new bellows design.

During component cryogenic testing, it was disclosed that the On-Mark remote-interface connector had a low-temperature sealing limit of approximately -50°F. As a result, the control-drum-actuator vent-gas system was revised to route the vent gases through an external shield penetration and overboard into the ETC at the LTS periphery. This routing eliminated the On-Mark connector at the 18-in. remote interface. Development was initiated to replace the connector with an all-metal, remote-interface, compression seal connector capable of low-temperature sealing. This effort was curtailed in the fourth quarter due to budgetary limitations.

(10) X-Engine Component Cooling System

A water-circulation capability has been provided in the ETS-1 design to cool the external shield during extended engine testing if subsequent tests reveal this need. To recirculate the water, the shield fill-line size had to be increased from 1 in. to 2 in. in diameter. The change was incorporated in the X-engine UTSM and TSA lines.

(11) X-Engine Supports and Brackets

In addition to the supports and brackets found to be necessary during the engine-component and assembly design phases, engine assembly operations at Sacramento revealed the need for extra bracketry at various points. These brackets were required to provide a cleaner assembly (as in the case of providing additional clamps for the small UTSM flex lines) or to facilitate assembly or both. In the latter case, an additional lateral spring hanger

support was found to be necessary for the PDL in the UTSM to ensure alignment capabilities when mating with the lower module assembly. Design and fabrication of the initially required support bracketry, as well as additions, proceeded with no problems.

(12) X-Engine UTS Insulation System

Systems-analysis studies indicated the possibility of LN_2 formation in the UTSM compartment during engine testing, with the posttest cooldown period probably being the most severe period. As a result, action was initiated to protect those components considered susceptible to low temperatures and to reduce the potential of LN_2 formation. The LN_2 could be formed by the compartment GN_2 purge gas coming in contact with the LH_2 line surfaces.

In the UTSM and TSA designs, urethane insulation was added to the LH_2 lines. The bellows in these lines, along with the TPA and PIL in the UTSM, were not insulated. An insulated drain pan was incorporated at the 18-in. remote interface between the shield and UTSM. This drain pan is mounted on an insulated cylinder that encloses the control-drum-actuator area on the engine shield. The GN_2 purge distribution system was rerouted to initially introduce the purge gas into the annulus formed by this cylinder and the UTSM side wall. This point was selected for introducing the purge gas to maintain acceptable temperature levels at the transducers mounted on the shield top face and at the shield itself. The purge is then directed up through the UTSM compartment. A separate line is branched off from the purge supply line to an insulated compartment in the UTSM in which the UTSM transducers are housed. Local insulation or baffles, or both, were incorporated in such components as the On-Mark remote-interface connectors, shield supply and vent lines, and UTSM valves.

Cryogenic environmental testing was conducted at Sacramento under conditions expected during X-Engine testing. These tests were conducted on a component level with a simulated UTS segment and with the XECF

shield and UTSM and the TSA. The test results indicated that appropriate design measures had been incorporated to ensure satisfactory temperature levels in the UTSM compartment during XE testing.

(13) X-Engine Television System

The remote Kon-Tel TV systems were incorporated in the UTSM to provide remote viewing capability during engine testing. An accompanying lighting system was also incorporated. The TV-and-lighting system was used during the cryogenic testing at Sacramento with satisfactory viewing results. During checkout of the XECF UTSM in E-MAD at NTO, and after a minor correction to the lighting-system power supply, satisfactory remote viewing was again demonstrated.

(14) WEMU and RADA Development and Evaluation

Development testing of the TSA-UTS remote interface was completed utilizing the WEMU at Sacramento, and the final test report, RN-S-0340, was issued: X-Engine TSA/UTS Remote Interface Development, dated October 1966.

The WEMU, TSA design aid, and SETS-1 were sent to NTO for use in personnel training and in development of engine installation and removal procedures.

As a result of testing at Sacramento, some modifications were made to the WEMU and TSA remote interfaces after their arrival at NTO, for compatibility with the X-engine interfaces. In subsequent remote matings, the interface components worked satisfactorily.

The WEMU has been used with MCC-EIV to evaluate loads to which the X-Engine would be subjected during transportation between E-MAD and ETS-1. The condition of the RR track bed was also evaluated. The WEMU has been

loaded onto and unloaded from the EIV at E-MAD. Personnel have been trained in handling of the engine and in remote-checkout procedures by using the WEMU at E-MAD and SETS-1.

During the next quarter, the training program will continue to use the various pieces of remote-checkout equipment for application at Station 42.89, nozzle closure, turbine-exhaust-line closures, and overboard vent line. Fully remote cycles will be performed for final evaluation of the remote-installation capabilities of the engine and handling equipment.

The RADA engine was modified to be compatible with the X-engine configuration. This modification consisted of installing a new PDL with relocated bellows and new On-Mark connector guides at the 18-in. interface. In addition, mock-up actuators were installed on the top of the shield, with one actuator containing a remotely operated Marman clamp for testing of the appropriate remote wrench. Also, a mock-up of the actuator overboard vent line was added.

The engine holding stand, used in the hot bay of E-MAD to support the engine during remote operations, was tested and found to require the addition of remotely operated supports for the lower half of the propellant lines. These supports were added and were satisfactorily tested.

The positioning head, used to pick up the UTS with the OPS, was tested and found to be built to the configuration of an outdated UTS. The positioning head was reworked, tested, and found to be satisfactory.

During CY 66, remote wrenches were provided for the remote Marman clamps at the Station-185.14 interface and for the UTS-to-shield nuts. Testing showed these wrenches to be inadequate, so new wrenches were designed, built, tested on the RADA engine, and found to be satisfactory.

The propellant-line alignment fixtures were tested and found to be satisfactory.

The RADA engine was the first piece of hardware in the E-MAD hot bay that allowed realistic use of the hot-bay equipment and facilities. During the initial tests on the RADA engine, a number of minor problems with the OPS WMHS and turntable occurred and were corrected. The RADA engine was used in the training program for hot-bay equipment operators.

During RADA testing, three major revisions have been made to the remote operating procedure (RADA P-3) as a direct result of experience gained during testing. The procedure developed will be used as a basis for writing XE operating procedures.

One fully remote cycle has been accomplished on the RADA engine. Several problems occurred with the GSE and engine components and are being evaluated for correction prior to additional cycles. Three more remote cycles are to be performed to complete the RADA test program in CY 68.

In summary, testing on the RADA engine has progressed to the point where a high degree of confidence has been gained for removing and replacing the UTSM of an XE engine. Also, the RADA engine has been a very useful tool for initial checkout of hot-bay equipment and for familiarization in handling XE-type hardware.

(15) Cryogenic Testing of UTS, TSA, and External Shield

A cryogenic test program was conducted to demonstrate the adequacy of the X-engines in their operating environments. The program was conducted in three phases. The first phase was concerned with testing at the component level; i.e., testing of the On-Mark and electrical remote-interface connectors, the pedestal-adapter Omega seal, the glass-fiber insulation board

used in the insulating shield, and the insulation of the liquid-hydrogen lines. In the second phase, a 30° segment mock-up of the UTS and shield was tested to obtain preliminary environmental test data. The third phase was a full-scale environmental demonstration test using the XECF shield, upper thrust structure module (UTSM), and test-stand adapter (TSA).

The first-phase testing revealed no problems except that the On-Mark connector could not maintain pressure sealing at temperatures below -50°F. The gaseous-hydrogen pneumatic-vent-line On-Mark connection at the shield-UTS interface was the one connector for which this problem would cause concern. This unit was therefore replaced with hard plumbing that routes vent gas through a penetration in the shield and vents it overboard in the lower-thrust-structure (LTS) area.

The adequacy of the engine-system design to provide operational integrity in the expected XE testing environment is considered to have been satisfactorily demonstrated by the second- and third-phase testing. Figure 2 shows the test configuration at AGC-Sacramento. Detailed information on all the tests is available in RN-S-0426, Final Report, XE Cryogenic Test Program.

(16) XECF Assembly

Assembly of the XECF at Sacramento was completed in May 1967. The engine was subsequently disassembled, shipped to NTO, and reassembled for testing. Assembly at Sacramento included checking of the fit of the UTSM to the lower module, the TSA, and the XE-1 lower module. Complete assembly at Sacramento provided the opportunity to correct several problems with the fit of components and several potential problems with remote interfaces. Figure 3 shows the XECF during assembly at AGC-Sacramento.



Figure 2 - Test Configuration

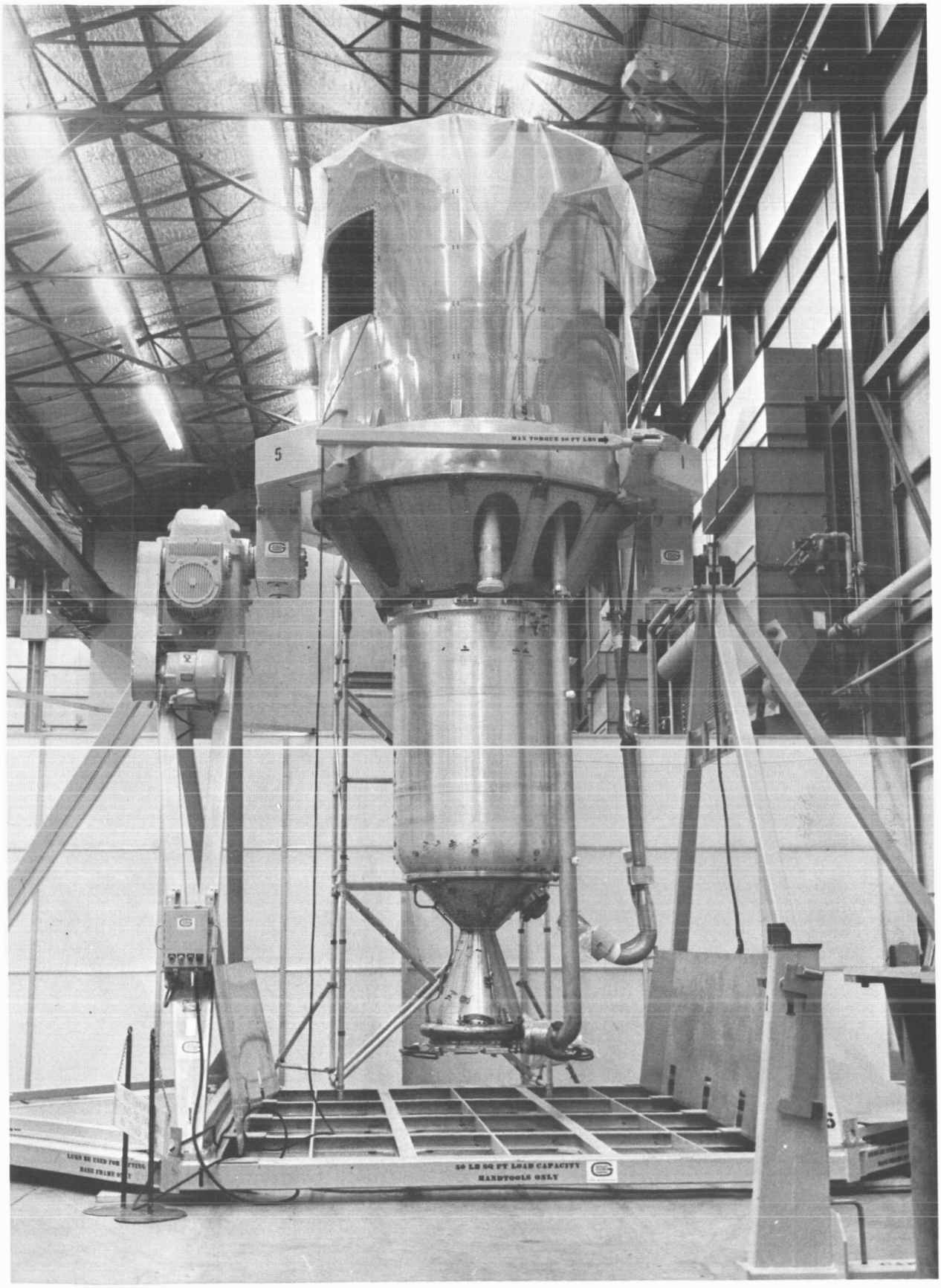


Figure 3 - XECF Assembly at Aerojet-Sacramento

(17) XE-1 Assembly

Assembly of the XE-1 UTSM at Sacramento was completed. The XECF and XE-1 UTSMs were checked for fit to the XECF lower module, and both UTSMs were checked for fit with the TSA. The units were subsequently disassembled and shipped to NTO to be assembled for testing.

(18) XE-2 Fabrication

Assembly of the XE-2 UTSM is to begin at Sacramento in November 1967. This date is compatible with a scheduled date of 1 May 1968 for completion of the XE-2 engine for testing. Scheduled delivery of all UTSM components is at present satisfactory for meeting the 1 May date.

(19) Shipment Coordination

All components and assemblies for the XECF and XE-1 were shipped to NTO. Shipments were in accordance with procedures and packaging that specified special requirements for protection of the parts.

The upper-thrust-structure modules were shipped in a horizontal position by using a special shipping container that contained shock mounts to minimize road shocks. Impact recorders mounted on the units showed that shocks were held to a satisfactory level. Figure 4 shows the XE-1 UTSM as it was being prepared for shipment from AGC-Sacramento.

The PVARAs were shipped by rail using normal procedures and equipment supplied by WANL. The XECF PVARA was shipped from Sacramento, and the XE-1 was shipped from Large, Pennsylvania.

Hardware and components for XE-2 will be shipped in CY 68.

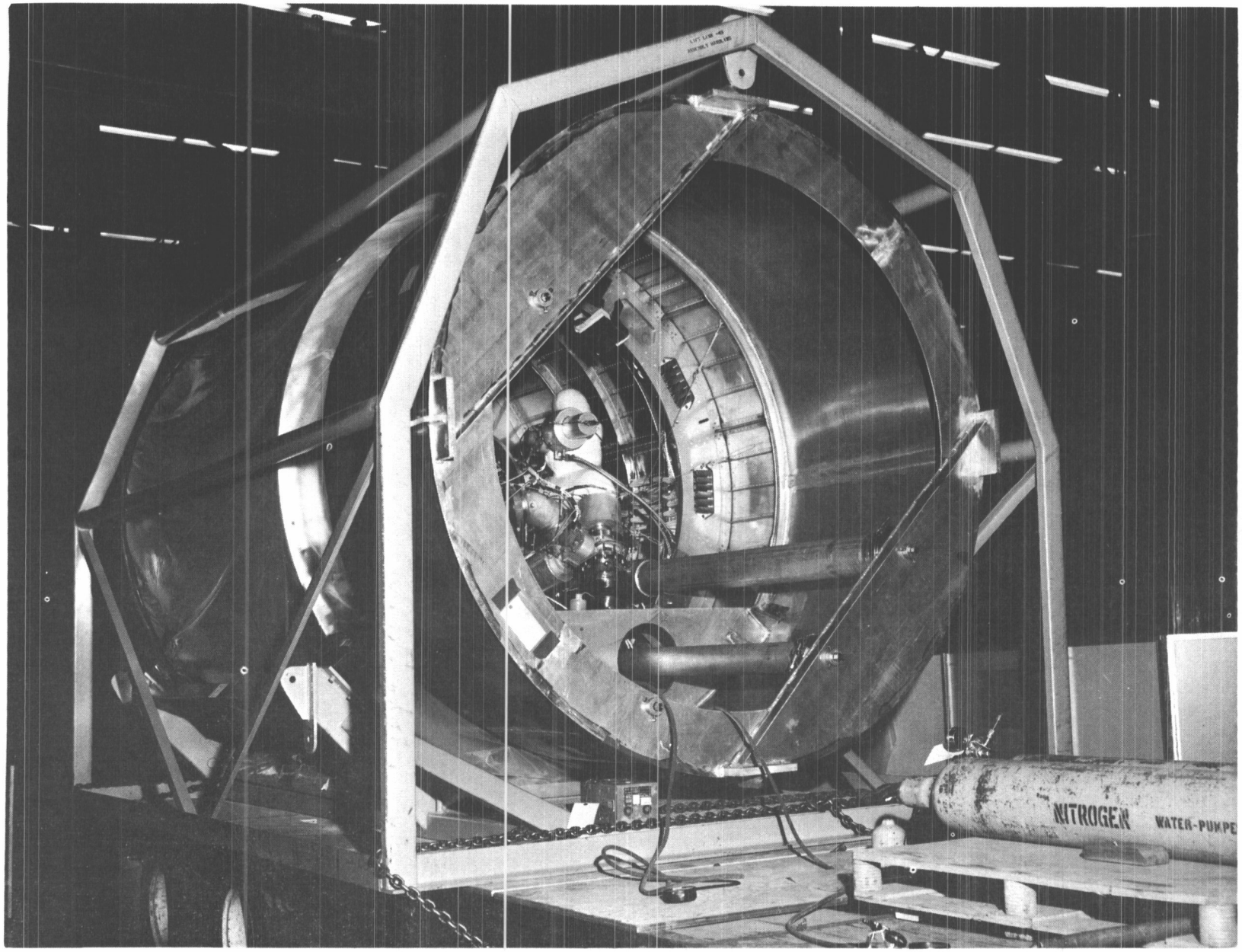


Figure 4 - XE-1 UTSM Prepared for Shipment

b. NERVA Engine System Design and Integration (1.1.1)

(1) A parametric study was conducted early in CY 67 to determine the effects of engine thrust level and chamber pressure on overall engine-system weight and performance.

Six basic engine systems were evaluated that included three variations in chamber pressure and two variations in thrust level. The engines were identified as follows:

Engine	Power Level, Mw	Chamber Pressure, psia
A	5,000	625
B	5,000	525
C	5,000	450
D	4,000	625
E	4,000	525
F	4,000	450

All engines were assumed to operate at a chamber temperature of 4500°R.

Preliminary component designs were sufficient to define the component performance characteristics and weights.

The significant results of this study are shown below:

Engine	Thrust lb	T_c, °R	P_c, psia	Pump H, psi	I_{sp}, sec	Weight, lb
A	246K	4500	625	1270	822.5	34,454
B	245	4500	525	1141	825.3	34,564
C	244	4500	450	1052	827.3	34,756
D	196	4500	625	1301	822.5	28,531
E	196	4500	525	1166	824.8	28,538
F	196	4500	450	1082	826.5	28,665

From these results, it was concluded that (a) for variations in engine thrust level, the variation in I_{sp} is insignificant; however, the weight variation is significant; and (b) for variations in chamber pressure, the lower chamber pressures give higher engine performance with a small effect on weight.

Details of this study were presented to SNPO in a December 1966 meeting.

(2) NERVA Engine Optimization Program

The optimization program involved the study of trade-offs among various factors that influence the system and component designs. The principal factors that were evaluated to define the engine system included reliability, specific impulse, weight, development cost, development time, and total program fabrication cost.

An initial preliminary system design was established that would meet the performance requirements for a 200,000-lb thrust at chamber conditions of 4500°R temperature and 625-psia pressure. The component designers then proceeded to develop sufficient preliminary alternative designs to define the weights and operating characteristics that would satisfy the system requirements.

The performance of the various component designs was weighed against reliability, weight, development cost, and time.

From this iterative process, the current reference-engine design has evolved. The design-state-point schedule for the reference NERVA engine is shown in Table 1.

TABLE 1

NERVA ENGINE (100% Power)

Engine: Pc = 625 psia; Tc = 4500°R; Thrust = 199,925 lb; Impulse = 823 sec; Power Level = 4178 Mw; TPCV = 35.2 degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm	6,020	16,605	6,020	16,605
Power, Mw	.674	19.88	.674	19.91
Efficiency, %	57.7	69.9	16.75	63.2
NPSP, psi	0			
Quality, %				

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	243		35	38	
Inducer Inlet	243		35	38	
Pump Inlet	243		67	41	
Pump Leakage	1.03		1281	55	
Pump Outlet	242		1281	55	
Structure Support	32		809	212	
Structure Bypass	17		809	55	
Nozzle Manifold Inlet	128		1281	55	
Nozzle Outlet	118		875	192	
Bolt Coolant	10		875	55	
Skirt Outlet	77		880	159	
Reflector Inlet	188		878	180	
Reflector Outlet	188		807	235	
Periph. Shield Outlet	188		807	235	
Support Plate Inlet	188		803	237	
Central-Shield Inlet	237		799	234	
Core Inlet	237		775	260	
Core Outlet	237		625	4500	

TABLE 1 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	230		625	4500	
Diluent Bleed Inlet	8.1		878	180	
Diluent Bleed Outlet	8.1		878	180	
Hot Bleed	3.6		625	4500	
Mixing-Ring Outlet	11.7		609	1660	
TPCV Inlet	11.7		599	1660	
Main-Turbine Inlet	11.7		462	1660	
Inducer-Turbine Inlet	11.7		64	1217	
Inducer-Turbine Outlet	12.73		48	1120.6	
Skirt Extension Inlet	12.73		30	1120.6	
Skirt Extension Outlet	12.73		8.0	1663	

The engine consists of the following principal components:

a. Centrifugal pump plus inducer
b. Three-stage main turbine plus inducer turbine
c. Seven-inch pump discharge line
d. Two technology-engine-size hot-bleed ports
e. Two technology-engine-size TPCVs and TBVs
f. Main nozzle to an area ratio of 4:1
g. Nozzle skirt cryogenically cooled to an area ratio of 36.5:1
h. Two 8-in. turbine discharge lines
i. Turbine-exhaust-cooled nozzle skirt extension

The detailed component trade-off studies that resulted in the currently defined components are discussed in the individual component sections.

The complete results of the NERVA engine optimization program will be covered in Report RN-S-0440, which will be issued early in CY 68.

(3) System-Oriented Zero-NPSP Study

A method of analysis was established and a study was made of the effects on a three-stage Mars vehicle for a 1982 stopover mission if a change were to be made from a conventional propellant feed system requiring a positive suction head for satisfactory operation to a zero-NPSP system with a pump capable of operating with saturated propellant at the tank discharge.

A scale-of-effort limitation restricted the study to a single mission and a single vehicle configuration. The results, however, are considered to be fairly general and indicative of the order of magnitude of

the differences between the two systems, as both the mission and the vehicle represent the types of operations considered plausible in the next 20 years; moreover, both were studied and reported with a high degree of definitive details.

A reduction of 100,000 lb is estimated in the vehicle weighing approximately 1.93×10^6 lb initially if a zero-NPSP system is used instead of a positive one. The penalty for the positive pump is mostly due to the large amount of propellant (approximately 2 to 4%) being rendered unusable to the pump by the excessive increase in vapor pressure from nuclear heating. In addition, this residual penalty can increase very rapidly for the positive-NPSP system if the heating rate exceeds that for which shield weight was selected.

The study has also shown that, with either the positive- or zero-NPSP pump, the vehicle weight is sensitive to the shield weight and tank pressure and to the vent pressure selected. Generally, the positive pump system requires heavier shields, a higher tank pressure, and lower vent pressure than the zero-NPSP system.

An analytical optimization procedure that allows selection of the correct combination of the above parameters was also established. The number of the detailed report covering this study is RN-DR-0133.

(4) Shield Optimization Program

A computer program for optimizing a nuclear shield has been completed and put in production.

The program calculates the change in weight as a function of shield weight for a nuclear-power vehicle performing a specified mission. Any mission and vehicle parameters can be specified in the program, as well as operating tank pressure and vent pressure module by module.

The effect of shield weight on the temperature of the propellant as a function of firing time and nuclear heating rate is calculated in the subroutine, based on the tank heating program developed by NASA-Lewis. From this subroutine, the amount of residual propellant for a specified NPSP requirement is evaluated and used to calculate the unusable-propellant penalty. The program also computes the penalty due to boil-off and stage weight associated with a particular shield. All weight penalties for all stages, multiplied by appropriate mission desired influence coefficients, are summed up to give an estimate of total penalty in initial vehicle weight.

The program was used to define the optimum single-engine internal-shield size so the design of NR-1 could proceed on schedule.

The results of this study are shown in Figure 5. The results show that the optimum internal shield size is nearly the same for a single-module or clustered-module configuration.

It is recognized that the clustered configuration imposes large vehicle weight penalties with the present engine and tank configuration and with the present internal-shield concept used. Alternative solutions to reducing the penalties are being evaluated, such as increasing separation distance, revising tank configurations, using alternative shield arrangements, and decreasing inlet-fluid density requirements to the engine system to 30% vapor by volume.

(5) Nuclear-Stage Performance

A computer program was computed and put in production that permits the calculation of mass ratio and payload fractions as functions of engine I_{sp} and stage propellant fraction for either a single-stage or a multistage vehicle (up to three stages). Parametric plots of stage performance in terms of ideal ΔV requirements were made for both a single-stage and a three-stage vehicle with ΔV requirements approximating those for a 1982 direct-opposition Mars mission. These plots were presented in a CY 67 quarterly progress report.

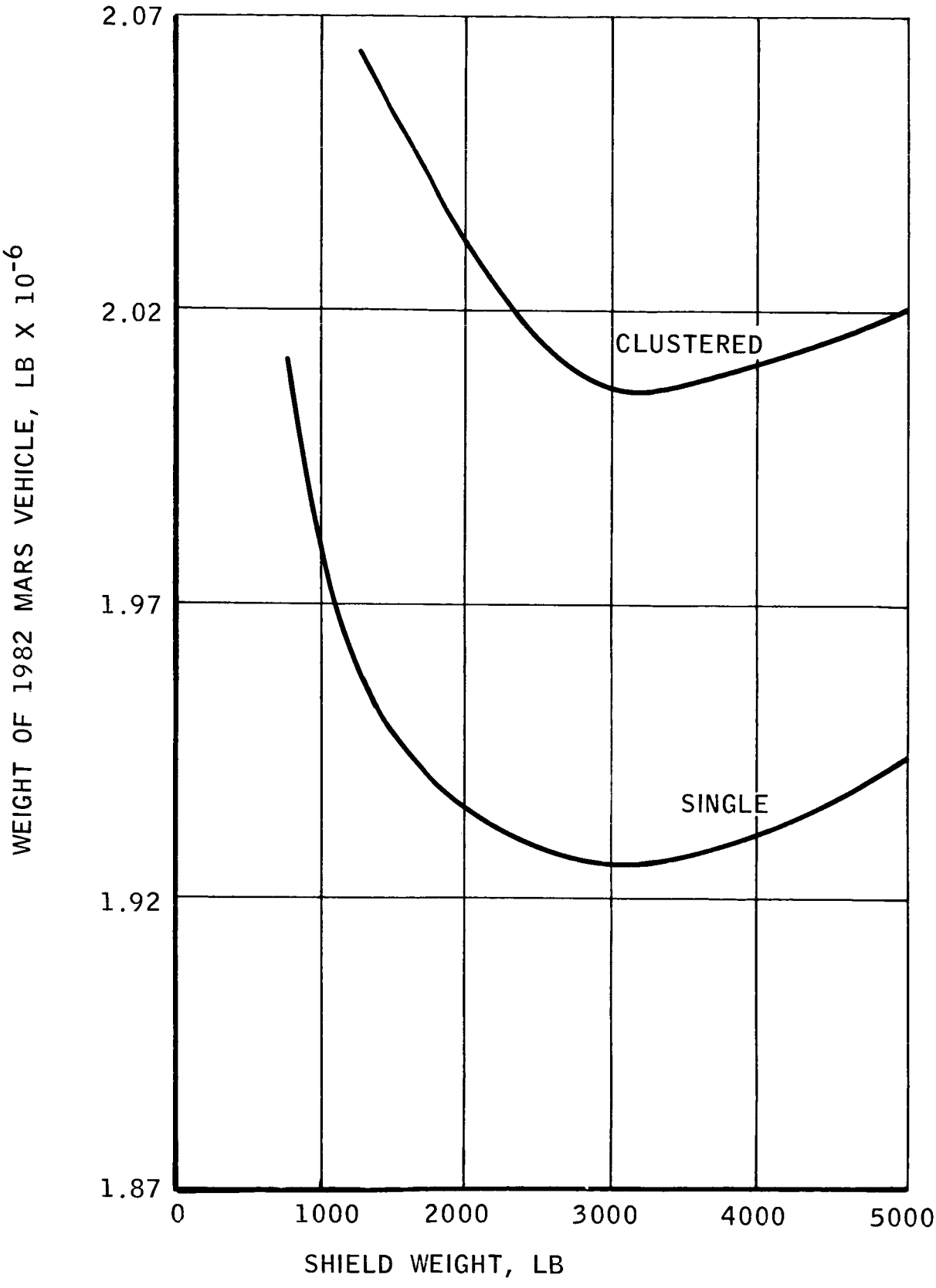


Figure 5 - Shield Optimization (Based on Propellant Tank Heating)

The performance of the vehicles with currently planned or advanced nuclear engines can readily be compared with the performance of vehicles using chemical propulsion in terms of payload or initial vehicle weight.

(6) Optimum Expansion Ratio For NE Skirt Extension

As reported in the second quarterly progress report for CY 67, a study was performed to determine the expansion ratio for the NE skirt extension that would give the minimum vehicle weight (1982 Mars vehicle) in earth orbit. In the last quarter, this study was updated to reflect the latest NERVA-engine weight and performance trade-off factors recommended by TRW. The results of this study indicate that an expansion ratio of approximately 85:1 is optimum for the 200,000-lb-thrust NERVA engine. The trade-off factors that changed from those as reported in the second quarter are as follows:

	From	To
Lb vehicle weight/sec I_{sp}	5,000	4,200
Lb vehicle weight/lb thrust	0.5	0.75
Lb engine weight/sec I_{sp}	300	240

(7) Flight Safety

The configuration of the NERVA-engine emergency coolant system and the total-system cooldown-fluid requirements for sub-orbital engine starts were integrated in support of the NERVA flight-safety studies.

Plots of thrust and specific impulse resulting from the flow of fluids during engine cooldown were prepared and forwarded to LMSC for incorporation into the overall vehicle flight-safety studies.

Contributions made to NERVA flight-safety studies included analytical studies of mission trajectories for the suborbital-start operational mode, definition of critical time periods, and cooling requirements of the engine system, as well as design studies of methods of providing the required cooldown capability. Detailed information is presented under Subtask 2.7.

(8) NERVA-Engine Design Drawings

Definition of the engine configuration by means of assembly, piping-diagram, installation, and envelope-comparison drawings has been continued throughout CY 67. The initial configuration was based on Concept A of the engine parametric study (250,000-lb thrust). A subsequent configuration of a 200,000-lb-thrust engine was prepared as a reference engine for the engine optimization study and as a basis for the NERVA engine development plan, Report RN-DR-0103. In August and September, a third configuration was prepared that reflected the results of the engine optimization study and technical redirection from SNPO-C.

The drawings prepared during CY 67 were:

Drawing Title	Drawing Number First Config.	Second Config.	Third Config.
Preliminary NERVA Ground Test Engine Piping Diagram (E/STS 2-3)	1117925	1118415	1118442
Engine Envelope Comparison	---	1118417	1118443
Preliminary NERVA Ground Test Engine Piping Diagram (ETS-1)	1118341	1118418	1118444
Preliminary NERVA Ground Test Engine Assembly (ETS-1)	1118397	1118416	1118445
Preliminary NERVA Ground Test Engine Installation (ETS-1)	1118398 & 1118399	1118419	1118446
Preliminary NERVA Ground Test Engine Assembly (E/STS 2-3)	1117896	1118414	1118448
Preliminary NERVA Ground Test Engine Installation	1117926 & 1118396	1118421	1118449
Preliminary NERVA Ground Test Engine Assembly (NE-8 & 10)	---	1118422	1118450

The drawings of the first configuration were included in RN-DR-0079, and RN-DR-0103 contained drawings of the second configuration. The drawings of the third configuration were the basis for RN-67009.

(9) NERVA-Engine Planning Parts List (PPL)

Planning parts lists for all engine configurations included in the NERVA-engine development plans were prepared and included in RN-DR-0079 and RN-DR-0103. RN-67009 did not include a PPL; however, a PPL for the current (third) engine configuration has been prepared.

(10) NERVA-Engine Measurement-Requirements Document (MRD)

The need to initiate preparation of instrumentation and control-measurement requirements for engine ground tests and for flight tests was recognized early in CY 67 and preparation was started at that time. Four iterations were accomplished during CY 67, starting with component-designer requests totaling approximately 1450 analog measurements. Current requirements include 712 analog measurements for NE-2 and -3 as defined in the current MRD for these engines issued on 6 July 1967.

This activity precedes preparation of the measurement-requirements list (MRL) for each engine test. The MRDs contain a description of the measurements required and the quantities. MRDs have been issued for NE-1, NECF, NE-2 and -3, NE-4, NE-5 and -6, NE-7 and -9, NE-8 and -10, and for the minimum measurements required for NR tests as specified by the engine-system designer. These documents provide the basis for design and program-planning activities.

(11) NERVA-Engine/Module-Propellant-Tank (MPT) Interface Definition

Definition of the engine side of the NERVA-engine/MPT interface continued throughout CY 67. Initial preliminary definition was given on Drawings 1117896 and 1118414, mentioned previously. Meetings were held with MSFC and SNPO-C to discuss definition of this interface primarily to meet the MSFC schedule for design and fabrication of the MPTs for E/STS 2-3. The major meetings were held in November, March, May, July and August.

Some unresolved differences currently exist between the MSFC and NRO design concepts for this interface. Report RN-PA-0011, issued in July 1967, presents the NRO design concept.

Final resolution of the interface design differences awaits action from a meeting to be held by SNPO-W, with SNPO-C and MSFC participation.

(12) NERVA-Engine Requirements for E/STS 2-3 Design

Revisions were provided to the existing E/STS 2-3 design criteria early in CY 67 on the basis of the engine configuration presented in Report RN-DR-0079.

During the remainder of CY 67, assistance was provided in the direction and review of E/STS 2-3 design activity as follows:

a. Participated in the 30% design review of the E/STS 2-3 preliminary design.

b. Participated in review of proposed changes to design criteria as requested by SNPO-O and the AGC E/STS 2-3 coordinator.

c. Submitted a request to change the design criteria for LH_2 pressure during fast and emergency cooldown to 1500 psia.

d. Submitted a request to increase the data-recording channel allocation for the NERVA engine from 540 to 712. This request was based on the MRD preparation activity previously discussed.

e. Prepared a current definition of engine fluid requirements for consideration of change in E/STS 2-3 design criteria.

(13) Interface-Control-Document (ICD) Planning and Preparation

The general NRO policy regarding the ICD portion of the configuration management program was prepared. Planning has been initiated for the details of ICD content and format, as well as the procedures related to interface control. Preparation of the portion of a NERVA ICD pertaining to interfaces between the nuclear subsystem and interfacing nonnuclear engine components and subsystems is progressing. Preparation of interface concepts and definition is also underway, as discussed previously.

(14) Preliminary Design of Remote Interfaces Within the Engine

Effort was directed primarily toward design of the engine remote plane at the forward surface of the thrust-structure subassembly and the structural remote joint between the thrust structure and the pressure vessel. The guidelines directing remote interface design are described in Volume II of RN-DR-0103, as amended by the deletion of some component and subsystem remote-replacement capability (described in Report RN-67009).

Current guidelines include capability to remotely remove and replace the thrust-structure subassembly from the engine in E-MAD and to remotely install and remove the engine from the test facility with the EIV-MCC by using nondestructive methods.

The description of CY 67 design activity related to remote interfaces is included in the appropriate subsubtasks for the individual components, such as thrust structure, pressure vessel, lines and valves, electrical distribution system, and pneumatic system.

(15) Assistance in Preparing NGTM Specification

SNPO-C was assisted in preparing a NGTM system specification. Initial activity in December 1966 and January 1967 involved review of the NGTM system and tank-assembly end-item specification drafts prepared by MSFC. Preparation of a NRO version of a NGTM system specification was then undertaken, and the draft was transmitted to SNPO-C on 3 April 1967. Subsequent NRO activity included review and comment on another MSFC draft of the system specification dated 22 May 1967. CY 67 work concluded with submittal to SNPO-C, in August, of NRO comments on the 22 May specification draft.

(16) Engine Loads

The vibration and shock design loads for all conditions were prepared for inclusion in the NERVA-engine environmental specification. A preliminary NERVA-engine modal analysis was prepared that included stage-tank (MSFC) and nuclear-subsystem (WANL) inputs as well as nonnuclear engine components. This analysis included both flight and ground-test engines. Both longitudinal and lateral vibrational modes were investigated. A new computer program was developed for determining response characteristics of a dynamic system.

(17) Engine Weight Studies

Complete engine weights for the nine different engine sizes considered were prepared as part of the parametric study. Once the engine size was selected, these weights were expanded into a complete weight report that was kept current to reflect the various modifications and upgrading of the engine. Weights were computed for pressure vessels fabricated of various materials, and these figures were used in selecting the material from which the pressure vessel was to be made. Weights for proposals (such as for a tank gamma-heat shield and for anticriticality poison systems) were also calculated.

A breakdown by percentage of total weight of the materials used in the engine was prepared for use in a nuclear environmental study. Engine moments of inertia about the roll, pitch, and yaw axes were calculated to be used for gimbal actuation and vehicle performance analysis. The dynamic analysis of the engine required an engine-mass-distribution model, which was established and calculated. One of the more significant achievements was the acquisition of a computer program from COSMIC for computing weights, centers of gravity, and moments of inertia. This program was modified to the IBM 360-65 computer and has increased the flexibility of weight analyses.

(18) Documentation

During this period, the following documents were generated for the NERVA program:

(a) Revision of the engine design specification into contractual format as a contract-end-item (CEI) specification, AGC-90103.

(b) Revision of the environmental-requirements specification, AGC-90107, to upgrade requirements.

(c) NERVA component-requirement documents (NCRDs):

90118 Coolant Valve
90119 Discharge Shutoff Valve
90121 Turbine Block Valve
90122 Turbine Power-Control Valve and Actuator
90124 Turbine Inlet Lines
90125 Turbine Exhaust Line
90126 Diluent Bleed Line
90127 Structural Support Line
90134 Pneumatic System

90135 Pump Discharge Line

90149 Turbopump Assembly

90151 Nozzle, Skirt, and Bleed Ports

90152 Thrust Structure

90154 Pressure Vessel

90155 Electronic Power, Instrumentation and Control

90176 Nozzle Skirt and Extension

90177 Engine Control Instrumentation

90179 Electrical Distribution

(d) The index of cleanliness documents controlling cleanliness in the NERVA program was upgraded and reissued.

(e) Engineering documents used in NERVA design were reviewed and consolidated into a series of NRO preferred standards.

(f) The NERVA program-plan specifications and component documentation were revised, resulting in RN-DR-0103, Vol. IV, Books 1 and 2.

(19) Configuration Management

During the last half of CY 67, a NERVA configuration-management plan was formulated. The plan outlined the system by which configuration control would be enforced on the NERVA program and was in general agreement with the concepts of the Apollo configuration-management manual NPC 500-1, except for differences necessitated by the uniqueness of the NERVA program.

A presentation outlining this system was made to SNPO-C, MSFC, and SNPO-W representatives and was followed up with the submittal of a report (RN-PA-0011) on the proposed NERVA configuration-management plan.

(20) Engine Requirements

Detailed analytical studies were conducted to define the angulation requirements for the thrust-vector system and to define nozzle influences on engine optimization. The results of these studies were presented in Reports RN-Q-0041 and RN-Q-0042.

(21) NERVA-Engine Development Planning

Revised NERVA-engine long-range development plans were prepared including subsubtasks 3.1.0 and 0.1.0, covering the design, development, and testing through PFRT and delivery of the NERVA engine. These development plans were included in Documents RN-DR-0103 and RN-67009.

(22) NERVA-Engine Test Planning

A detailed test program was developed for NE-1 testing in ETS-1. This test description was used to determine the minimum required modifications to ETS-1. A description of the test program and the facility modifications were forwarded to SNPO-C.

c. XE Test Engineering (1.1.2)

(1) Planning and Coordination

(a) XECF

The XECF Test Specification (RN-S-0314) was approved in February 1967. This specification provides the engineering basis for preparing detailed procedures for conducting the XECF tests at NRDS, Jackass Flats, Nevada. Included in the specification are instructions for receiving inspection of test articles; assembly and checkout; installation in ETS-1; operational testing; and disposition after testing.

The XECF Test Specification and Procedures Review Board (TS & PPB) was convened March 1967 at NTO. Participation of Aerojet personnel on the board continued until the engine was completely assembled and stored pending installation in ETS-1.

The Test Review Board was convened in September 1967 to coordinate the testing of XECF.

(b) XE-1

The XE-1 Test Specification (RN-S-0352) was conditionally approved by SNPO-C in May 1967.

The XE-1 Test Specification and Procedures Review Board (TS & PRB) was convened June 1967 at NTO. Aerojet participation will continue until installation of the engine in ETS-1. The XE-1 TS and PRB coordinated changes in the Test Specification and procedures of the XECF prior to the convening of the XECF Test Review Board.

(c) XE-2

The XE-2 Test Specification (RN-S-0400) draft was transmitted to SNPO-C/NTO/WANL for review.

(d) Documents

NTO documents with respect to test description and operating procedures were reviewed by AGC and comments transmitted.

(2) Measurement Requirements List

The Measurement Requirements Lists (MRLs) were revised to eliminate facility channels that are not needed; to ensure that MRLs, Recording Display Requirements (RDRs), and channel datalog agree; and to ensure that data and controls requirements for the engine were incorporated.

The XE-2 MRL was submitted to SNPO-C for approval in the last quarter of the CY 1967.

(3) Failure Mode Analysis

The failure-mode analysis of the XE-1 was reviewed and revisions were made as required by the current configuration of the engine.

2. Propellant Feed System (1.2)

a. Technology-Engine Propellant Feed System (1.2.0)

(1) Pump Inlet Line

Fabrication of the 1117125-9 propellant inlet line for XE-1 was completed during the first quarter of CY 1967, and a final acceptance report was released.

Fabrication of one 706957-19 propellant-inlet line for XE-2 was nearing completion at the close of CY 1967.

(2) Turbine Exhaust Line

One complete turbine exhaust line (TEL), comprising one each upper and lower line segments, was assembled for GN_2 blowdown tests to verify the adequacy of the exhaust nozzle section to provide the correct turbine exhaust back pressure under various flow rates. The test data indicated that the overall line compared to the theoretical model within $\pm 2.9\%$*. The XECF and XE-1 lower turbine exhaust lines, as received from the fabricating vendor, required rework for minor discrepancies. After verification testing, the lines were returned to the vendor for completion of the minor rework. The final EIRB was conducted on 31 May 1967, and the lines were determined to be satisfactory for XECF and XE-1 use.

Fabrication and acceptance testing of both the upper and lower TELs required for XE-2 were completed.

* RN-TD-0033, Narrative End Item Report, XE Turbine Exhaust Lines, 17 March 1967, by D. W. Berry

The XE-2 4-in. butterfly valve was assembled and acceptance-tested to the requirements of the assembly drawing. The unit is currently awaiting receipt of the actuator for final assembly.

(9) Turbine Block Valve (TBV)

The XECF, XE-1, and XE-2 TBVs were assembled and tested in accordance with acceptance-test plan RN-TP-0030. NEIRs RN-TD-0025, RN-TD-0020, and RN-TD-0031 were published; and an EIRB was conducted for each valve. The XECF and XE-1 units have been installed in the appropriate engine system.

(10) 3/8-in. Pilot Valves

Pilot valves required for XECF/XE-1 use were tested in accordance with acceptance-test plan RN-TP-0002. NEIRs RN-TD-0016 and RN-TD-0027 were published, and an EIRB was conducted for each valve. The units are presently installed on the engine systems.

The pilot valves required the XE-2 valve system were tested in accordance with acceptance-test plan RN-TP-0021. NEIR RN-TD-0040 was published and an EIRB was conducted. The valves are available for XE-2 assembly.

b. NERVA Pneumatic Supply System (1.2.1)

The current configuration of the pneumatic system is shown in Figure 6. The system shown may be subdivided into the following subsystems:

(1) Storage Tanks

Two 38-in.-dia storage tanks are required to store the gas required to power the engine actuators during the engine start

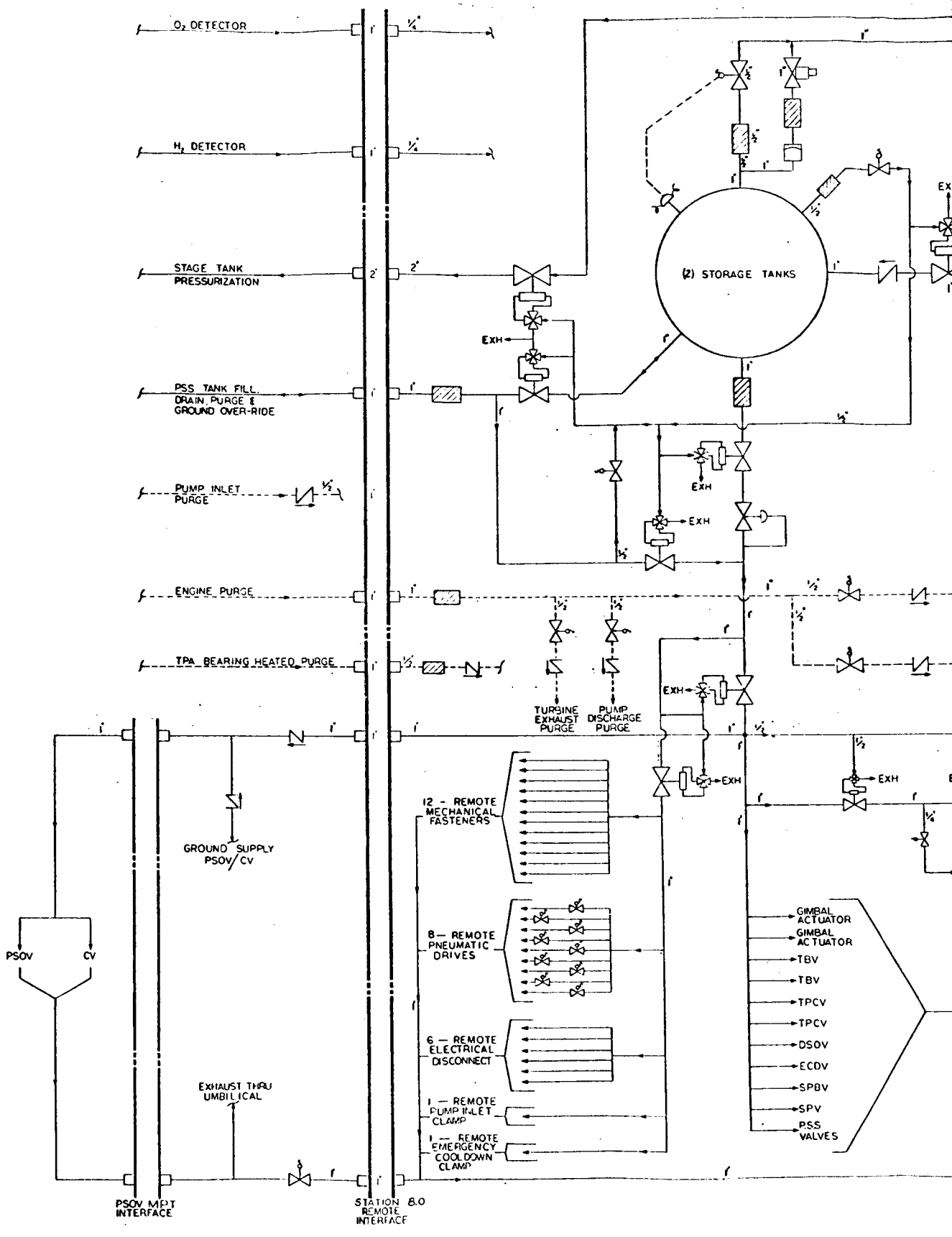
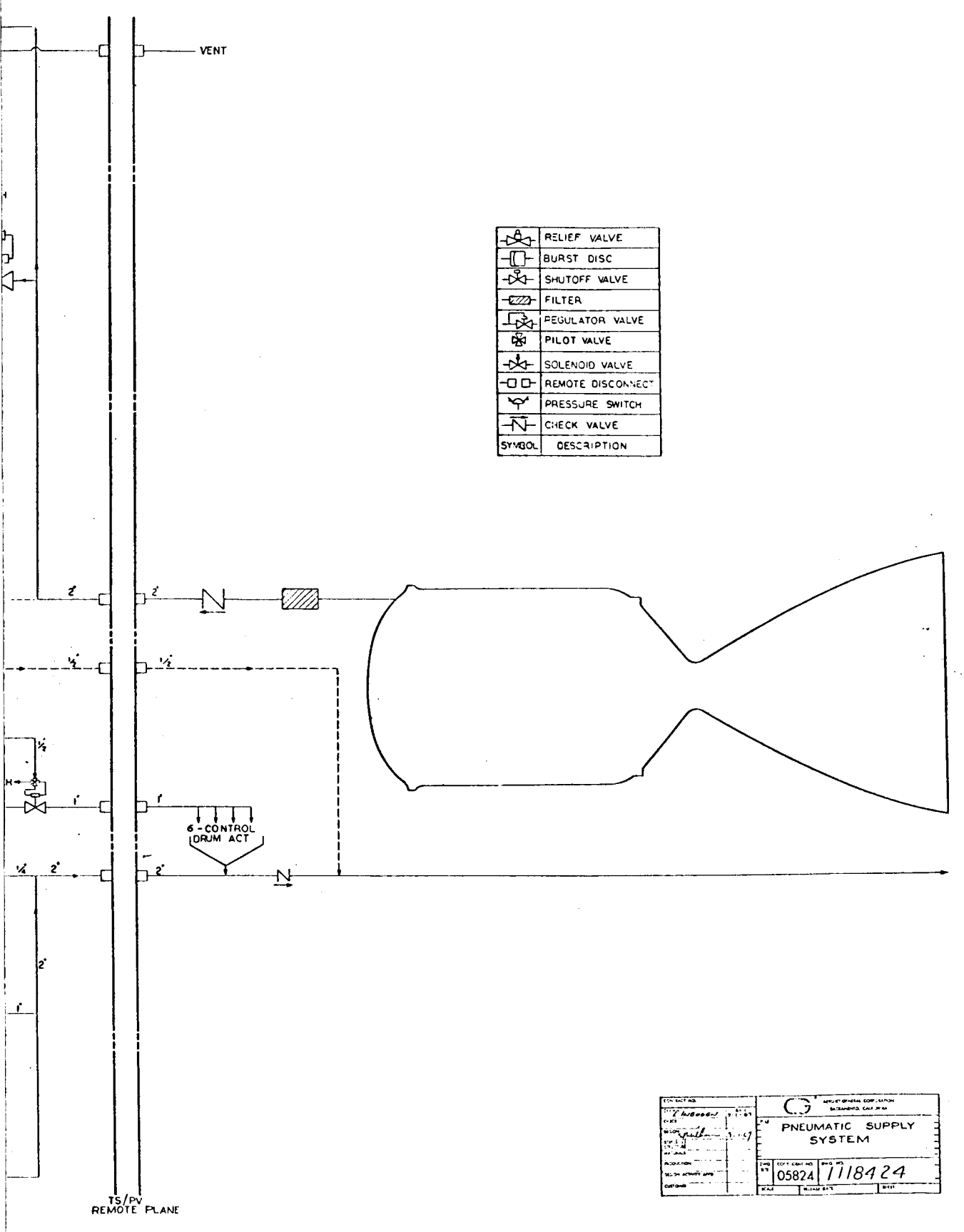


Figure 6 - Pneumatic Supply System



PNEUMATIC SUPPLY SYSTEM

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transient before drive gas is available from the engine pressure-vessel dome. Normal relief of the tank pressure is accomplished by a solenoid valve activated by a pressure switch that senses tank pressure. Emergency relief is provided by a burst disk located in a second vent line from the storage tank. A mechanical relief valve, set to the operating pressure of the storage tank, is located in the vent line downstream of the burst disk to prevent complete loss of the actuation gas if the burst disc should rupture.

(2) Actuator Supply Network

A network of supply lines carries the drive gas to each of the engine actuators. Pending further definition of actuator-supply pressure requirements, only one regulator is located in the main supply line, and it maintains the pressure to all actuators at 350 psia.

(3) Recharge Line

The recharge line, which connects the engine pressure-vessel dome with the storage tank, carries GH_2 to recharge the storage tank and drive the engine actuators during steady-state engine operation.

(4) Stage-Tank-Ullage Pressure Line

Ullage pressurization during steady-state engine operation is provided by gas from the pressure-vessel dome. The pressurization line from the dome bypasses the actuator storage tanks and connects to the stage-tank-ullage pressurant line at the Station-8 remote plane indicated on the schematic by the heavy, vertical, dashed lines.

(5) Storage-Tank Fill-and-Drain Line

The actuator storage tanks are prepressurized and drained through a line from the test facility to the tanks. A branch of

this line bypasses the storage tank and intersects the actuator supply network downstream of the supply regulator to allow operation of the engine actuators from a ground source.

(6) Purge Network

Purge gas to the engine is carried by three lines from a facility supply. The purge lines are indicated by the dashed lines on the schematic. Purge lines intersect the engine lines at the pump inlet, pump discharge, turbine exhaust, actuator exhaust, and storage-tank recharge lines. A separate line carries heated purge gas to the turbopump bearings.

(7) Station 8 Remote-Drive Supply Network

The plane at which the engine is disconnected or connected from the test stand is designated as Station-8. The mechanical fasteners that join the engine to the vehicle at the remote plane and the connectors for the pneumatic, electrical, and propellant lines that cross the remote plane are powered by remotely operated pneumatic motors. A supply-line network from the actuator storage tank provides pneumatic power to the motors.

In the current system configuration, gas storage is not provided for prepressurization of the main-propellant-tank ullage. Analysis has shown that total vehicle tankage weight can be reduced if the actuator gas and ullage pressurization gas are stored in separate tanks. It is assumed that the ullage pressurization gas, if required, would be stored on the stage side of the vehicle. A preliminary analysis has indicated that gas routed from the engine pressure-vessel dome through a 2-in. line to the ullage volume would increase the pressure in a 50% ullage volume by 10 psi within 50 sec during a normal engine start transient. Use of a turbopump capable of starting at zero-NPSP conditions would result in vehicle weight savings of up to 700 lb by eliminating requirements for an ullage pre-pressurization system.

(3) Propellant Shutoff Valve (PSV)

Three 8-in. PSVs were assembled, and one valve successfully completed demonstration testing*. The main-shutoff-seal leak rate was less than 0.8 scc/sec GHe with 55 psig LH_2 on the valve inlet after 300 LH_2-temperature open-close cycles.

The remaining two valves were satisfactorily acceptance-tested and made available for use in the X-engine system**.

(4) 5-in. Swing Check Valve

During the initial months of CY 67, four each 1115728-29 5-in. check valves were assembled and satisfactorily acceptance-tested and made available for XECF and XE-1. In the ensuing months, a new engine-system requirement necessitated a fluid bypass around the cooldown check valve (CKV); and two 1115728-29 5-in. check valves were modified to -39 configurations, one each for the XECF and XE-1 engine assemblies, respectively. A narrative end-item report was released and final EIRB was conducted.

The necessary valve components for two additional valves (one each for 1115728-29 and 1115728-39) for the XE-2 engine assembly were completed. During the final quarter of CY 67, valves, SN 000011 and 000007 were assembled.

(5) 5-in. Butterfly Valve

A demonstration test of the 5-in. butterfly valve was successfully conducted during the initial period of CY 67. This test

* RN-TP-0016, Demonstration Test Plan for X-Engine System, Eight-Inch Propellant Shutoff Valve, 21 September 1966, by A. L. Armitage

** RN-TD-0013 and 0030, Narrative End Item Report - NERVA Eight Inch Propellant Shutoff Valve, 10 November 1966 and 11 January 1967, respectively; by V. A. Smith

series included 500 open-close valve cycles at ambient conditions and over 300 open-close cycles at LH_2 temperature conditions followed by a rigorous leak check*.

Deliverable valves for XECF and XE-1 engine systems were assembled concurrently with testing of the demonstration valve. At the conclusion of the satisfactory demonstration-test series, acceptance testing of XECF valves was started in accordance with the acceptance-test plan**. All phases of the acceptance tests of the XECF-designated valves were successfully completed, and the valves were shipped for the engine system.

Cryogenic testing of the XE-1 valves was performed in accordance with the above acceptance-test plan, and a final EIRB was conducted on the valves before they were made available for use on the XE-1 engine assembly.

Fabrication of the required valve components for XE-2 was initiated and completed, and assembly of the first unit commenced during the latter portion of CY 67.

(6) 3/8-in. Check Valves

Demonstration tests were satisfactorily conducted on both the hot-gas and cryogenic 3/8-in. check valves, PN 1114730-59; and results were documented in demonstration-test reports***.

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* RN-TD-0032, Demonstration Test Report - NERVA 5 Inch Butterfly Valve, 14 February 1967, by V. A. Smith

** RN-TP-0007, Acceptance Test Plan - Five Inch Butterfly Valve, 13 September 1966, by A. L. Armitage

*** RN-TD-0019, Demonstration Test Report - 3/8 Inch Cryogenic Check Valve 13 December 1966, by J. Toboni; and RN-TP-0021, Demonstration Test Report Report - 3/8 Inch Hot Gas Check Valve, 8 December 1966, by J. Toboni.

Four each hot gas and crvogenic valves were delivered to fulfill the XECF and XE-1 engine requirements*.

Two each of the 1114730-29 and 1114730-59 check valves were assembled and satisfactorily acceptance-tested for use in XE-2.

(7) 3/4-, 1-, and 2-in. Filters

During the first quarter of CY 67, all the required filter assemblies for XECF and XE-1 were successfully assembled and acceptance-tested. Two each 3/4-in. filter assemblies (PN 1118452, SNs 880001 and 880003) were made available for use on the TPCV actuator. Six 1-in. filter units were made available for use on the TPCV actuator. Six 1-in. filter units were made available for welding into the pneumatic line assemblies, as were two, 2-in. filter units. The narrative end-item reports are RN-TD-0028, RN-TD-0014, and RN-TD-0017, respectively. Additional 1-in. filter units required for the XE-2 were acceptance-tested during the latter portion of CY 67 and were shipped.

(8) Turbine Power-Control Valve (TPCV)

The XECF TPCV was assembled and tested in accordance with acceptance-test plan RN-TP-0042 and was subsequently installed in the XECF upper-thrust-structure module (UTSM). A narrative end-item report (NEIR), RN-TD-0036, was released; and an EIRB was conducted.

The XE-1 TPCV was assembled and tested in accordance with acceptance-test plan RN-TP-0026, and NEIR RN-TD-0029 was released. An EIRB was conducted and the valve subsequently was installed in the engine system.

* RN-TD-0018, Narrative End Item Report, 3/8 Inch Cryogenic Check Valves P/N 1114730-29, S/N's 880001 through 880004, December 1966; and RN-TD-0026, Narrative End Item Report, 3/8 Inch Elevated Temperature Check Valves P/N 1114730-59, S/N's 880007, 880008, 880010, and 880011, December 1966, by J. Toboni

A complete description of all analyses pertaining to the pneumatic system is contained in RN-TM-0551, Pneumatic Supply System Design Report.

c. NERVA Valves (1.2.3)

(1) Propellant Shutoff Valve (PSOV)

Several valve concepts were analyzed and compared for use as the propellant shutoff valve (PSOV) during a preliminary valve-study program*. As a result of this study, the poppet- and ball-valve concepts were selected for further evaluation**. The poppet-valve concept proved to be the optimum configuration for the 200,000-lb-thrust NERVA-engine pump-inlet system; therefore, effort was directed toward completion of the detail design and release of drawings for this configuration. The most efficient valve flow contour for the expected inlet conditions was defined and incorporated in the detail design layout. Seal diameters were established on the basis of flow contour and actuator size requirements. Sealing concepts were evaluated, and the primary seal designs that were selected were optimized on the basis of stress, thermal, material, and leakage requirements. A seal tester was designed to evaluate the poppet and actuator seals at operating pressures and temperatures and to permit refinement of seal designs before fabrication of the first PSOV was completed. Materials for use in the PSOV were selected on the basis of technology-engine valve experience, weight, ease of fabrication, and stress and thermal considerations. Because of design simplicity and symmetry, the valve can be fabricated by using current machine-shop techniques. Provisions have been made in the design to incorporate all instrumentation necessary for the development-test and flight programs.

* Williams, S. J., Preliminary NERVA Valves Study, AGC Report No. RN-TM-0391.

** Lundback, A.V., Ball vs Poppet Valve Comparison for the NERVA PSOV Application, AGC Report No. RN-TM-0429.

Since accurate prediction of the actual valve opening and closing rates is difficult because of the inherent compressibility of the GH_2 used for the actuation fluid, a computer program has been developed to examine several cases to determine the optimum actuation system. A cross section of the PSOV design is shown in Figure 7. Additional details on the poppet-valve design can be found in the design report*.

A comparison was made between the existing SI-C LOX valve and the PSOV for the NERVA application**. The SI-C LOX valve was concluded to be unsatisfactory for use as the NERVA PSOV; extensive modifications would be necessary to improve its ability to meet requirements for leakage, radiation, remote operations, and temperature. The NERVA PSOV has been designed to meet both design and off-design operating requirements. High confidence in the ability of the PSOV to perform as stated is derived from the design techniques used, the capabilities of present technology-engine valves, and the inherent simplicity of the design.

Detail fabrication drawings for the PSOV seal tester have been completed and released. Purchase orders have been placed for component part fabrication. Detail fabrication drawings for the PSOV are complete and have been released. A design review of the PSOV was completed.

(2) Three-Way Pilot Valve

The design-criteria specification was completed for the 1/2-in.-tube-size, three-way pilot valve; and advanced quotation requests were sent to six vendors. Technical proposals were received from all but one of the vendors contacted. An evaluation of the proposals received disclosed that two vendors have designs that appear to fulfill the design-specification requirements, and both designs warrant further investigation.

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* Anton, D.; Lundback, A.V.; and others; NERVA Propellant Shutoff Valve (PSOV) Design Report, AGC Report No. RN-TM-0449.

** Lundback, A. V., Evaluation of the SI-C Lox Pre-Valve and AGC Poppet Valve for the NERVA PSOV Application, AGC Report No. RN-TM-0420.

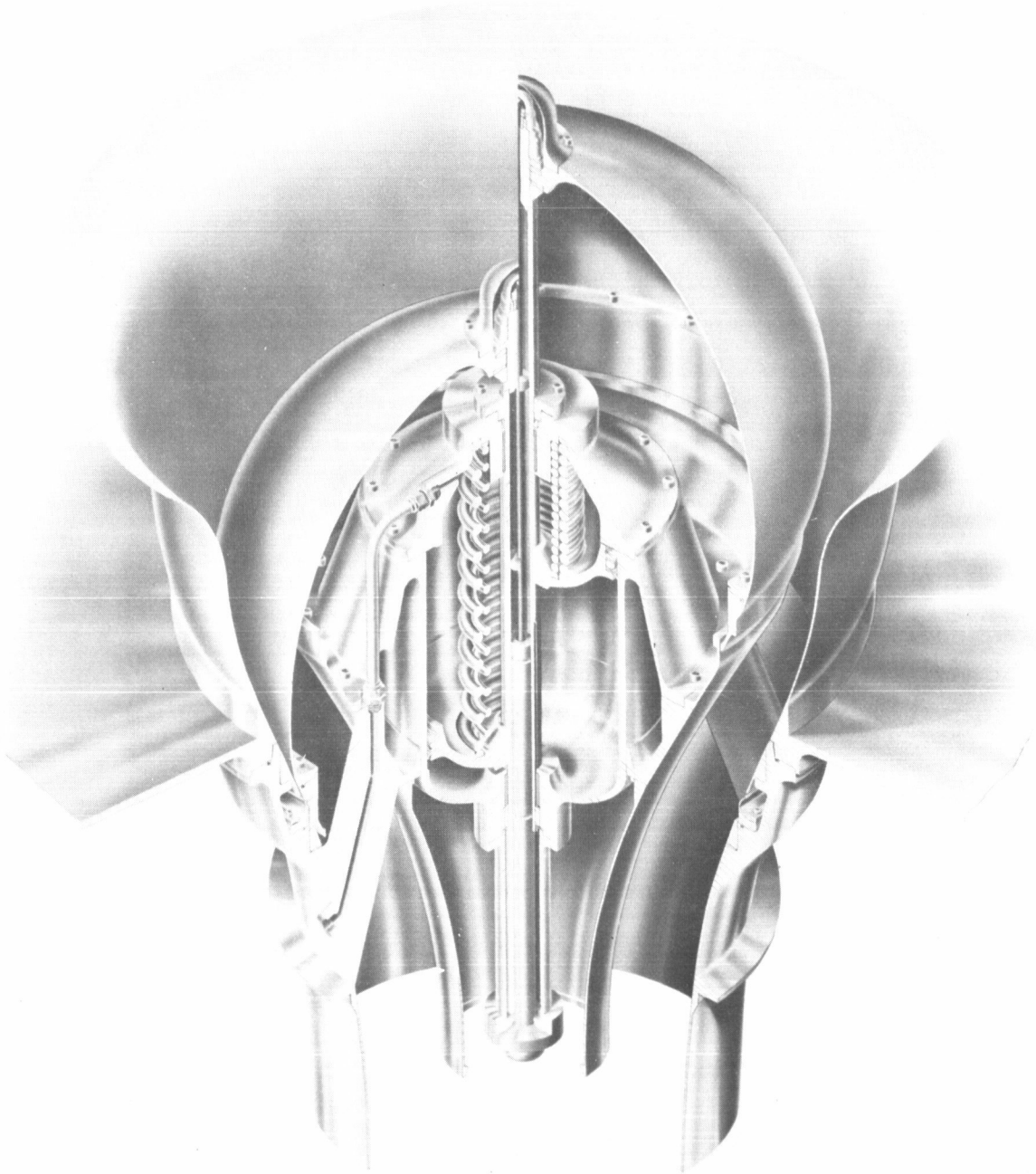


Figure 7 - Cross Section of Propellant Shutoff Valve

(3) Cooldown Valve (CV)

Seven methods of achieving the required cooldown-valve function were investigated, and the advantages and disadvantages of each method are discussed in Report RN-TM-0443, Preliminary Design Report - NERVA Engine Cooldown Valve. As a result of this analysis, actuation of the PSOV to provide pulse cooldown flow was determined to be the most desirable method because it obviates a separate cooldown valve. This method cannot be selected, however, until information on cycle-life capability is available from PSOV development tests. The method of incorporating the cooldown valve into the PSOV poppet dome was, therefore, selected as the prime interim concept until the PSOV cycle-life data are available, because the cooldown valve could be removed from the system at a later date without affecting PSOV design. On the basis of the selection of a cooldown valve located on top of the PSOV poppet dome, the design concept shown in Figure 8 was generated. The concept utilizes a single-acting, spring-closed-type poppet valve. LH_2 flows through an annular flow passage in the PSOV dome to the pump inlet when the CV is opened by applying pneumatic pressure through the flexible supply line and into the actuator. The actuator is sealed with a bellows; therefore, the main shutoff seal is the only dynamic seal that can leak hydrogen into the engine system. The main shutoff seal is shown only schematically; a metal lipseal similar in configuration to the PSOV main shutoff seal is planned.

(4) Discharge Check Valve (DCKV)

Design proposals for the 8-in.-dia check valve were received from four prospective valve vendors. The proposals will be evaluated in detail at a later date.

(5) Turbine Power-Control Valve (TPCV)

A feasibility study of an equal-percentage-weight-flow TPCV was completed. Ground rules were established for the preliminary

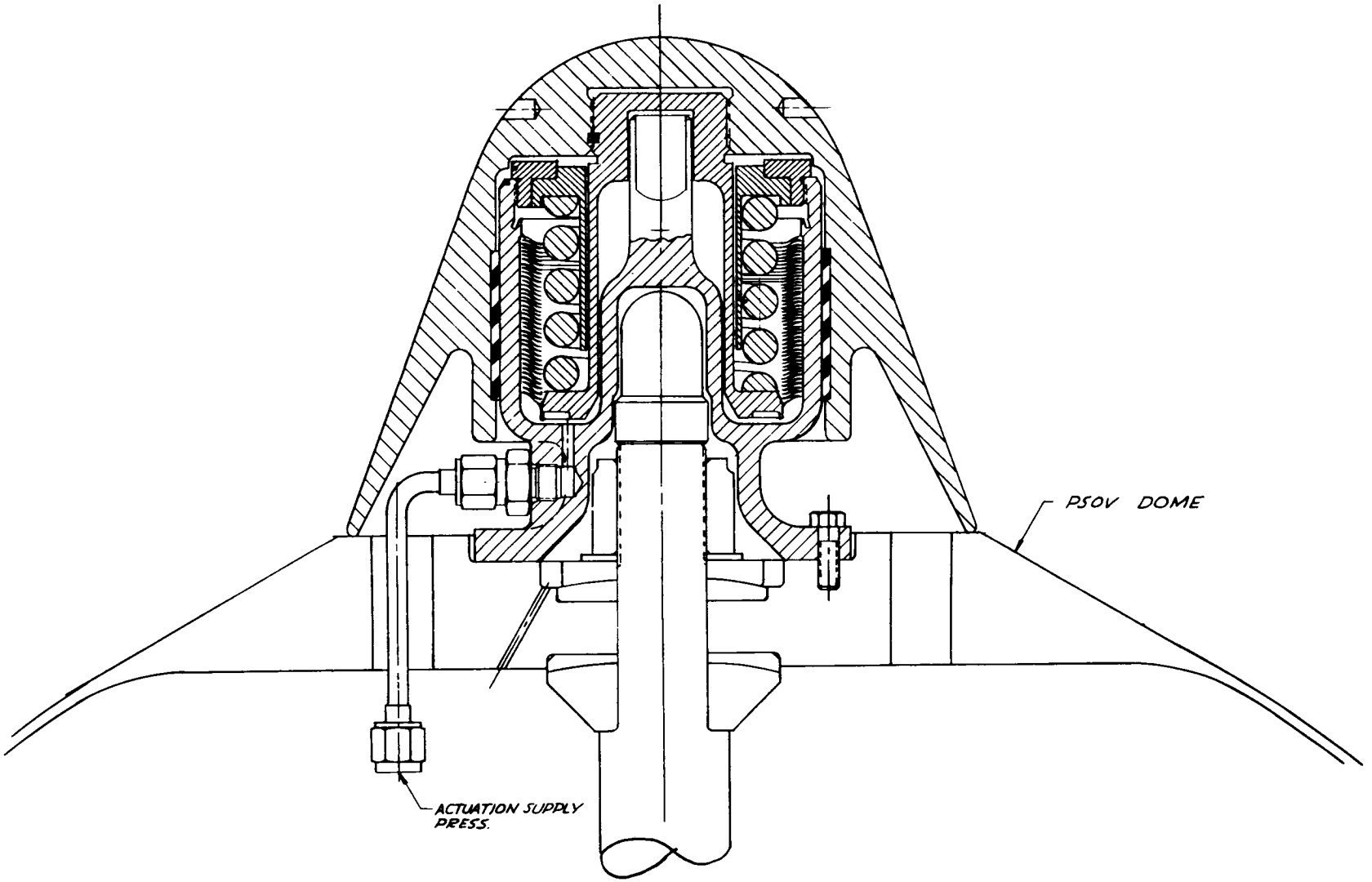


Figure 8 - NERVA Cooldown Valve Concept

design, and the relationships of flow rate and flow area to valve opening were determined and plotted. A preliminary design layout of the TPCV was then completed on the basis of results of the design study.

Two X-engine-configuration TPCVs (4-in. diameter) were found to be suitable for NERVA use with minor shaft and bearing modifications to reduce the required actuation torque to less than 400 lb-in.

(6) Structural-Support Coolant-Valve Assembly

Preliminary design and operational requirements were established for the nuclear-subsystem structural-support coolant-valve assembly (formerly known as the special-purpose valve assembly). A preliminary design report* was published in which the requirements of the structural-support flow circuit were presented. On the basis of preliminary analysis, two 4-in. butterfly valves that are driven through a gear train by a single actuator appear to satisfy the requirements of the structural-support coolant-valve assembly. The valves are presently used in the XE-engine TPCV application and have demonstrated their design capability.

A preliminary layout drawing of the gearbox and detail fabrication drawings of the 4-in. valve were initiated.

d. NERVA Turbopump (1.2.5)

Major technical effort was directed toward analytical design studies and development test programs in support of the turbopump design. The following sections describe the status and results of the studies and the programs conducted during the contract period.

* Report RN-TM-0445, "Preliminary Structural Support Coolant Valve Design Report", dated 8 August 1967, by L. D. Johnson.

(1) Analytical Design Studies

(a) Turbopump Configuration Selection

In the study conducted to select the optimum turbopump configuration the following five basic configurations were evaluated:

1 Centrifugal pump with three-stage overhung turbine.

2 Multistage straddled axial pump with three-stage overhung turbine.

3 Centrifugal pump with seven-stage straddled turbine.

4 Multistage straddled axial pump with seven-stage straddled turbine.

5 Two-stage centrifugal pump with three-stage overhung turbine.

The optimization study considered the performance, weight, size, and reliability trade-offs, for the engine, stage, vehicle, and mission, as well as those within the turbopump itself.

The quantitative trade-off study resulted in selection of the centrifugal pump with a three-stage overhung turbine, in spite of the pump and turbine efficiency advantages of the other configurations.

(b) NPSP Selection

An assessment of the total turbopump, engine, vehicle and mission-related systems provided the basis for selecting a twin-pool, zero-NPSP turbopump for the NERVA engine. The results of the assessment are presented in four categories. First, a review of demonstrated hydrogen NPSP experience provided design criteria that enabled investigation of cases ranging from pumping of boiling hydrogen from a tank (the zero-NPSP case) to NPSP values higher than practical for a flight vehicle. Second, based on the demonstrated technology, several optimum turbopumps were designed over this range of NPSP, and the operational, mechanical, weight, performance and envelope aspects of each were defined. Third, the influence of the NPSP requirements on the vehicle was examined, and indicated that nuclear heating of the propellant was of major importance because of its impact on useable propellant, tank design, pressurization requirements and reliability. In the fourth phase, overall systems and mission integration considerations were used to evaluate candidate configurations primarily to achieve the greatest assurance of mission success, and secondarily to provide a quantitative measure of mission performance.

(c) Detail Design Studies

1 Axial Thrust

A study was conducted to determine if net shaft axial thrust could be maintained within the 3- hour life capability of a tandem set of 110mm ball thrust bearings, or if a piston-type, thrust-balance device will be required. A further objective was to determine if the thrust balancer is required and, if it is, could it be incorporated into the basic power transmission package without requiring major turbopump interface design changes.

Net shaft axial thrust or bearing load was reduced from 25,000 lb based on previous estimates to zero, with the capability of biasing the tolerance on this net thrust toward either the pump or the turbine. This reduction in thrust unbalance was accomplished by extension of the pump backvanes beyond the impeller discharge diameter and by a substantially more refined analysis of total thrust. In addition, an analysis of the repeatability of thrust (the variation of net thrust from assembly to assembly or test to test due to the tolerance on several pressure and area combinations) and the adjustability of thrust (an external adjustment of backvane flow rate and turbine/transmission buffer zone back pressure) indicates that it may be possible to maintain net thrust within the 3-hour life capacity of the tandem thrust bearings.

A parallel design study has shown that a thrust balance piston system capable of supporting $\pm$30,000-lb thrust could be incorporated in the same envelope but would degrade the turbopump performance by the additional pumping losses associated with recirculation of the balance circuit flow.

2 Critical Speed

Vibration analysis of the rotor configurations shown in initial layouts indicated turbine rotor natural frequencies of axial vibration that are within the operating speed range. Increases in rotor thickness (axial stiffness) to raise the nature frequencies sufficiently above the operating range resulted in a reduction in the shaft whirl critical speed margin so that it was necessary to reduce rotor tip speed (diameter) by about 2%. The reduction in operating tip speed resulted in a turbine efficiency reduction of about one point.

3 Thermal Analysis

Extensive thermal analysis in support of rotor operating clearance selection and turbopump development planning was completed. Two significant results were evident: it will be necessary to compromise the steady-state operating clearances slightly to accommodate ambient temperature operation during the start-up transient, and test durations of 10 to 12 minutes will be required to achieve thermal equilibrium in the turbine during turbopump development testing.

(2) Development Program

(a) Pump Cavitation Performance

A series of tests was conducted with a modified NERVA technology turbopump to determine pump pressure rise as a function of hydrogen flow rate over a range of inlet conditions varying from liquid-to liquid/gas mixtures at low values of NPSP.

The pump had an integral inducer-impeller with a 7° inducer inlet tip angle and an inlet diameter of 6.95 in. The pump was operated at a constant inducer tip speed of 670 ft/sec at seven inlet flow coefficients ranging from 0.063 to 0.088 (Table 2).

The pump was fed through a conventional straight inlet line preceded by a simulated tank bottom valve and a low-velocity section that simulated stage tank bottom outflow velocities at 3 to 4 ft/sec. Performance data are referenced to the conventional suction-line location and to the simulated tank bottom location used as the NPSP reference in the NERVA engine.

TABLE 2

TEST SUMMARY

Test No.	Run No.	Type Test	Speed, rpm	Q/N	Inlet Flow Coeff, ϕ_{IT}	Percent of Q_1, Nom	Axial Inlet Velocity cm, ft/sec	i/β_{IT}
1	1	H-Q	22,000	0.117-0.333	0.0351-0.10	49.5-141	23.5-67	0.71-0.18
2	1	Cav	22,000	0.280	0.084	118.5	56	0.314
3	2	Cav	22,000	0.236	0.0708	100	47.3	0.42
4	2	Cav	22,000	0.212	0.0636	90	42.5	0.48
5	3	Cav	22,000	0.260	0.078	110	52	0.36
6	3	Cav	22,000	0.295	0.0885	125	59	0.28
7	4	Cav	22,000	0.288	0.0864	122	57.6	0.295
8	4	Cav	22,000	0.224	0.0673	95	45	0.45

The significant results of the tests are as follows:

1 A pump can be operated with significant amounts of ingested vapor (up to 30% by volume) starting with liquid-inlet conditions, at values of NPSP equal to the velocity pressure.

2 Pumping can be accomplished under zero-NPSH (total pressure equal to vapor pressure) tank conditions in a functional system, including inlet valve and line losses.

3 Excessive loss of pressure-rise capability occurred as a result of excessively high tip speed and inlet velocity; limits of 500 and 40 ft/sec, respectively, should be maintained.

4 Pump efficiency, determined by turbine power balance, varied closely with pump pressure rise.

5 Stable suction and discharge pressures were observed.

6 A high degree of speed control was possible by modulation of the turbine inlet valve to match the observed speed to the desired value.

(b) Bearing Development Program

1 Full-Scale Bearings

A development program with the ultimate objectives of developing and demonstrating hydrogen-cooled bearings adequate for the NERVA turbopump was initiated. Bearing sizes and operating conditions consistent with the results of the engine and turbopump optimization studies

were tentatively selected. Experience with the M-1 fuel turbopump, which had the same size bearing in liquid hydrogen at similar loads and speeds, and the NERVA technology turbopump experience, provide a basis for NERVA bearing development.

Because experience with the M-1 and NERVA-technology bearing programs indicates that it is less difficult to develop roller bearings than comparable ball (thrust) bearings, only an initial test examination of roller bearings was planned. Four to six bearing tests were planned for CY 67 with primary emphasis on ball-bearing development.

The initial test was completed in January 1967. Total accumulated test time for the bearings was 39 minutes at loads above 10,000 lb (17,000 lb shared on tandem set); at the target load of 13,800 lb (25,000 lb shared) total test time was slightly more than 25 minutes. Testing was discontinued when drive torque suddenly increased to about twice its normal value.

Posttest inspection of the bearings showed apparent fatigue failure in both bearings. In general, both bearings showed fatigue damage of balls and races. Both cages were in excellent condition, even though considerable heating must have accompanied the ball and race damage. Cracking of the outer race on one bearing has not yet been adequately explained, but thermal conditions may have been responsible. This is a likely cause since coolant flow delivered to this bearing was considerably lower than planned.

The second test of the planned series was completed in April 1967. Total accumulated bearing-test duration was 25 minutes at loads above 10,000 lb. Test time at or above the target load of 13,800 lb was slightly more than 16 minutes. Testing was discontinued when drive torque increased.

Posttest inspection of the bearings showed apparent fatigue failure in one of the two test bearings.

The tester was reassembled for the third test, which was completed in May 1967. Total accumulated bearing-test duration was 4.5 minutes at loads above 5000 lb. The time spent at or above the revised target load of 6000 lb (1000-lb shared) was slightly more than 3 minutes. Testing was discontinued when tester drive torque suddenly increased. The target load was revised prior to this test due to improved turbopump design, which indicated the feasibility of reducing the predicted thrust bearing load from 25,000 to 10,000 lb. This decreases the capacity required of each of the two bearings of the tendem set from 13,800 to 6000 lb based on a 60%/40% load-sharing assumption.

Posttest inspection of the bearings revealed a retainer failure of the 85-mm slave roller bearing. The test bearings were filled with debris from the slave bearing, but were in good condition otherwise.

A fourth test was successfully completed in August 1967 with 3 hours of operation at the revised load of 6000 lb. Post-test inspection of the test bearings indicated that no measurable wear or damage had occurred.

2 Subscale Bearings

Tests of subscale bearings (less than NERVA size), were initiated using the 50-mm technology bearing tester. This effort will be conducted in support of the combined materials and turbopump design activity to develop bearings capable of withstanding radiation dose levels that exceed the tolerance of Armalon, if the need for bearings of this type of bearing occurs.

Two tests were conducted in June 1967. The objective of the first test was to determine the durability of a Rolcon or cageless, all-metal roller bearing and a PBI/glass retainer thrust bearing. The test was terminated after 30 minutes when the tester drive torque increased.

Posttest inspection of the bearings showed that the upstream ends (exposed to the coolant inlet) of the guiding quills in the Rolcon bearing were chipped.

The PBI/glass retainer had one heavily damaged ball pocket with the wear on the side opposite the normal (driving) side. Wear in the remaining pockets was slightly greater than that observed with similar Armalon bearings subjected to similar conditions. The degree of wear was probably increased by the resistance to cage rotation resulting from reverse wear in the heavily damaged pocket. Interpretation of the test results was complicated by metal chips from the Rolcon bearing in the raceways and on the balls.

The second test was conducted to evaluate a PI/glass retainer in the thrust bearing. The test was terminated after 138 minutes due to an increase in tester drive torque.

The retainer was in good condition following the test. Increase in drive torque was due to excessive end wear of the rolling elements in the slave roller bearing.

A third subscale bearing test was completed in July when a second all-metal roller bearing successfully withstood 3 hours of operation at the expected NERVA low-speed shaft conditions (2000 lb at 6000 RPM) for an aft (turbine end) bearing subjected to high radiation dosage.

Posttest inspection showed no apparent wear or damage of any of the bearing components.

3. Reactor System Integration (1.3)

a. Reactor Test and Interface Control (1.3.0, 1.3.1)

(1) Major Accomplishments

Major accomplishments during this contract year were delivery of NRX-A6 components to NTO, assembly of the XE-1 and NRX-A6 reactors into pressure vessels at WANL, initiation of the NR interface control document and approval of the NRX-A6 Test Specification. Significant program redirection cancelled the NRX-A7 test and scheduled the NRX-A6 test for the first quarter of CY 68.

(2) Support Activities

During CY 67, System Engineering provided the project management and technical support for the NRX system design and system operations activities. System design activities included non-nuclear assembly design, NRO/WANL interface control, instrumentation installation design, establishment of measurement requirements, and review of ground-support equipment. Relative to system operations, activities included test planning documentation, establishment and coordination of component assembly and checkout requirements, acceptance and shipment of components to the test site, the coordination of test-site activities by other Aerojet organizations, and NRO representation on the TS&PRB Board.

(a) System Design Efforts

1 Non-Nuclear Assembly

Components for the NRX-A6 and the general requirements for accomplishing this assembly are defined on the NRO Non-Nuclear Assembly drawing 1117076. This drawing was continuously reviewed for

consistency with the systems interface requirements under the supervision of the NRX-A System Design group by conducting detailed discussions with the component designers and technical support personnel. The WANL design drawings for the NRX-A6 propellant inlet line welding and pressure test fixture were reviewed and approved. The installation and welding of the line at NTO was supported by System Design personnel. The proposal for an additional flow measurement device in the propellant feed line was coordinated with the component design and System Analysis Divisions in NRO and resulted in a decision to place the device in the test car line.

2 NRO/WANL Interface Control

Interface Control Drawings (ICD), which regulate the design, fabrication, and inspection of the interface components at NRO and WANL, were prepared by NRX-A project personnel. System Design personnel determined the NRO component design requirements, and, together with the WANL-supplied reactor requirements, created the ICD drawings that documented the mechanical interface details for the NRX-A6 test assembly, and controlled all subsequent changes to the ICD. Some specific interface control deviations approved and incorporated into ICD 1115780 were: use of nozzle S/N 88025 for NRX-A6 backup; incorporation of the WANL calorimeter support bracket; deletion of the WANL insulating cylinder from the pressure vessel cylinder-to-reactor support interface. The A6 ICD differs from previous ones because of the new aft-end support and the change in test location to Test Cell C.

3 Measurement Requirements

In conjunction with NRO analytical and component design groups and WANL engineering personnel, NRX-A System Design personnel completed the measurement requirements list (MRL) defining the measurement and instrumentation requirements for the NRX-A6 test assemblies.

A continuous review of this computer printout document is made by the System Design personnel to provide a current technical document. The MRL forms a part of the NRX-A6 Test Specification and defines each parameter to be measured, its location, general quantitative and qualitative performance requirements, part numbers, historical record of changes, and other pertinent data. Examples of the approximately 75 revisions to the MRL during CY 67 are: use of carbon-resistor measurements for the LN2 Dewar mounted on the test car; assignment of flame-spray, side-by-side channels to the Vidar system and addition of two channels for insulation resistance measurement; deletion of four pressure transducers from the single tap at the nozzle inlet and correction of the setup range of seven temperature measurements.

4 Instrumentation Installation

The NRX-A6 instrumentation installation drawings and the accompanying electrical schematic drawing were prepared and maintained throughout the year by the NRX-A System Design personnel. The NRX-A6 measurement requirements list is used as the authority for preparing and maintaining these drawings. Close coordination with the various NRO design disciplines assured selection of the proper instrumentation to achieve the desired test objectives. Overall NRX-A6 test requirements for instrumentation were integrated through scheduled test car meetings with WANL and NTO.

Details shown on the instrumentation drawings are the geometric location, type of component, installation requirements, wiring location, and system design criteria. A significant inclusion in the NRX-A6 test is the metal-sprayed instrumentation cables and thermocouples on the pressure vessel exterior wall as shown on AGC drawing 1117200. The metal-sprayed cables are part of a side-by-side experiment to qualify the metal coating as an acceptable means of protecting external instrumentation.

(b) Systems Operations

1 Test Planning

The NRX-A6 Test Specification final draft, WANL-TNR-215, was approved by NRO and was issued in March 1967 by WANL. Proposed modifications of the Test Specification are now being reviewed and will be resolved in the next contract year.

This document is derived from the overall test objectives of the NRX-A6 Test Plan, and details the component inspections, assembly/disassembly operations, operational tests, test limits, and other detailed information in order to assure safe operation of the test article. The engineering, operational, and safety requirements defined by the Test Specification are the basis for all test planning and test support documentation. The Systems Operations personnel review all preliminary documents and coordinate the NRO comments with WANL, NTO, and SNPO-C prior to the release of an approved document to ensure that the requirements of the Test Specification have been met.

2 Test Procedures

Test Operations procedures prepared by NTO are currently being reviewed for the NRX-A6 test. These procedures basically fall into two categories: (1) NRX-A-type operating procedures for the inspection, assembly, and checkout of the test article, and (2) NTO-type procedures used to support the assembly and facility operations associated with the test. Effort in this area was greatly increased because the NRX-A6 test assembly will be tested in Test Cell C instead of Test Cell A, which was used for NRX-A5. At this time the NRX-A6 receiving, assembly, and checkout procedures have been reviewed and approved for use. The NRX-A Systems engineering test planning files were made available to the XE program throughout the year.

3 Component Assembly, Acceptance, and Shipment

Shipment of the NRX-6 non-nuclear components was completed. Additional NRX-A6 seals for the forward closure and the nozzle joints were shipped to NTO to be used as spares for the XE-1 engine. Any of these seals not used on the XE-1 engine will be used as spares for the NRX-A6 assembly. A complete inventory of all NRX-A6 non-nuclear components at NTO was made by system operations personnel to ensure that the components on site were in an acceptable condition and the required records were on file.

During the week of 18 September 1967, systems operations personnel provided technical support to WANL for the assembly of the NRX-A6 reactor into the pressure vessel at the WANL plant. Assembly of the test article at NTO is now scheduled during the first quarter of CY 68.

4 Test Site Assembly Operations

Technical support is being provided for the assembly operations section in the E-MAD and for Test Cell C engineering for the assembly of the test car and the test cell modifications. System operations personnel provided assistance to NTO as required during the NRX-A6 Test Car (S/N T-7) assembly to coordinate and resolve operational and mechanical problems.

Preliminary definition of NE/NR interfaces was begun during this report period. Major accomplishments during the year were establishment of drawing format, designation of NRO and WANL coordinators and definition of 50% of the NR-1 interfaces.

b. NRX and XE Reactor and Fuel Development (1.3.4, 1.3.5, 1.3.6)

The general purpose was to review the reactor development and fuel improvement progress, and to provide information relative to reactor design and its interface with the technology and NERVA engine to the engineering groups concerned with integrating the nuclear subsystem into the engine system; and to supply data as needed for engine design and assembly, test planning, system analysis, and test review. The information needed to accomplish these tasks was acquired and kept up to date by regular monitoring of subcontractor design and testing procedures, and review of progress reports and technical memoranda. In addition, program plans, schedules, procurement packages and proposals were reviewed to improve cost effectiveness and ensure compatibility with the overall program plan.

The fuel development program was monitored to determine its effect on expected reactor performance and life, and to assist in the evaluation of process changes, process controls, and fuel element testing.

Regular attendance at monthly mechanical, fluid flow, and corrosion test review and planning meetings provided the opportunity to assist the subcontractor in facility and test planning.

Specific activities conducted in support of the purpose of the S/S/T are as listed below:

(1) Prepared, negotiated, and maintained the NERVA Policy and Interface Procedure Guide NJD-14 as a basis for the detail working interface between the engine and reactor subsystem development groups.

(2) Planned, set up, and assisted with conduct of XE-1 shield streaming experiment at Waltz Mills WANEF Test Facility.

(3) Established agreements between WANL and NRO relative to post-operational disassembly of the XE-1, in order to establish criteria for NRO ground support equipment.

(4) Made an evaluation for NRO management of the alternative courses of action that could be taken to remove the contamination from the XE-1 reactor assembly.

(5) Provided assistance to WANL in the installation plan of the 20,000 gallon LH_2 Dewar at WANHES. Assistance was given to both WANL and NRO to improve coordination of the resonance-survey test set up for XECF.

(6) Kept a current tabulation of the NRX-A6 fuel element electrical and corrosion test data for use after completion of the A6 test runs in comparing the electrical test data with the corrosion test data effectiveness.

(7) Monitoring of the nuclear-subsystem effort was maintained.

4. Thrust-Chamber Assembly (1.4)

a. NRX and XE Nozzles (1.4.0)

(1) Nozzle Analysis

Evaluation of the braze alloy deposits, on the NRX-A3, NRX/EST, and NRX-A5 Nozzles, revealed some significant differences between analytical predictions and actual run conditions for the hot-gas-side, tube wall temperature. This condition was discussed in detail in the CY 66 Report. The analytical model has been revised to bring the predictions in line with run conditions; however, no coolant channel design changes are necessary because of this revision. The original coolant channel design is capable of operating at positive margins of safety at conditions predicted by the new analytical model.

The ability of the technology nozzle to operate satisfactorily under NRX-A7 conditions was evaluated. Coolant channel wall temperatures were calculated relative to stress conditions and were shown to be acceptable. Heating rates in the nozzle jacket were released, and nozzle jacket wall temperatures were calculated. Preliminary stress analysis showed that the jacket would function with a positive margin of safety. However, prior to completion of the formal analysis, work on this item was stopped.

The NRX-A6 nozzle was evaluated relative to conditions to which it would be subjected. Positive margins of safety were shown at all points.

(2) Nozzle Development

Although fabrication of the NRX-A6 Backup Nozzle, S/N 880025, was completed in CY 66, final buyoff of the nozzle was accomplished in the current contract year. The nozzle is stored at Aerojet.

Final buyoff of the XE-1 nozzle, S/N 880030, was accomplished during the previous contract year. Most of the fabrication was completed in CY 66. The nozzle was shipped to NTO.

Fabrication of the XE-2 nozzle, S/N 880028, was completed during the current contract year. This unit was originally completed as the NRX/EST backup and was converted for use on XE-2. Some coolant channels of nozzle S/N 880028 became blocked with O-ring material; therefore, S/N 880029 nozzle, which had been damaged previously, was assigned for use on XE-2, and its damaged area was repaired.

Leakage from the coolant channels was noted at the aft end of nozzle S/N 880029, and the leakage was repaired. In the meantime, the coolant channels of S/N 880028 had been cleared. Nozzle S/N 880028 was again designated for use on XE-2, and further work on S/N 880029 was halted. Final buyoff of nozzle S/N 880028 occurred on 28 September 1967.

Major reports completed during the past contract year were RN-S-0366, the final report for the Heat-Transfer Margin Tests for the XE Nozzle, and RN-TM-0408, which documented the results of the NERVA Nozzle Hot-Bleed-Port Seal Evaluation Program.

b. NERVA Nozzles (1.4.1)

Detail design of the NERVA nozzle is continuing. The following specific tasks were accomplished during the past quarter, pursuant to the primary design task:

(1) The nozzle gas-side contour selection was completed. It was decided to use a throat discharge coefficient of 0.980 in calculating a diametrical nozzle throat size of 15.350 in. This decision was based on previous nuclear nozzle experience and on the data included in Report NAS 7-136F.

Parametric studies were also conducted to determine the effect on nozzle performance of varying the hot-gas isentropic expansion exponent (γ). The results of this study are presented in Figure 9. The weight advantage curve was developed by applying appropriate weight tradeoffs to the performance versus γ calculations. The change in γ from 1.375 to 1.320 resulted in an increase of nozzle I_{sp} of .29 sec. The contour was smoothed to avoid performance losses of approximately 3 sec due to contour imperfections.

(2) Nozzle-reactor interface dimensions were defined in negotiations with WANL. These dimensions are currently being used for design purposes, but formal signoff of the interface control drawing has not been accomplished.

(3) Preliminary nuclear, thermal, and stress analyses have been completed to determine preliminary jacket contour and thickness data from which forging drawings could be produced. A detailed set of analyses are being made to determine final jacket size.

(4) Nozzle forging drawings were released on 25 August 1967 (Figure 10). The nozzle will be fabricated from three Hastelloy-X forgings (P/N 1134523, 1134524, and 1134525). The drawings, with accompanying design backup information, have been submitted to SNPO-C for review prior to placing the purchase order. To facilitate placement of this purchase order, the drawings have been released for vendor study. If design approval is obtained from SNPO-C without major design revisions, the forging purchase order will be placed by 20 October 1967.

(5) The nozzle coolant tube design effort continued. Major emphasis was on the determination of the coolant flow split between the skirt and the nozzle to balance the bulk temperature rise and to assure uniform reflector inlet temperature. The nozzle/skirt coolant flow-temperature

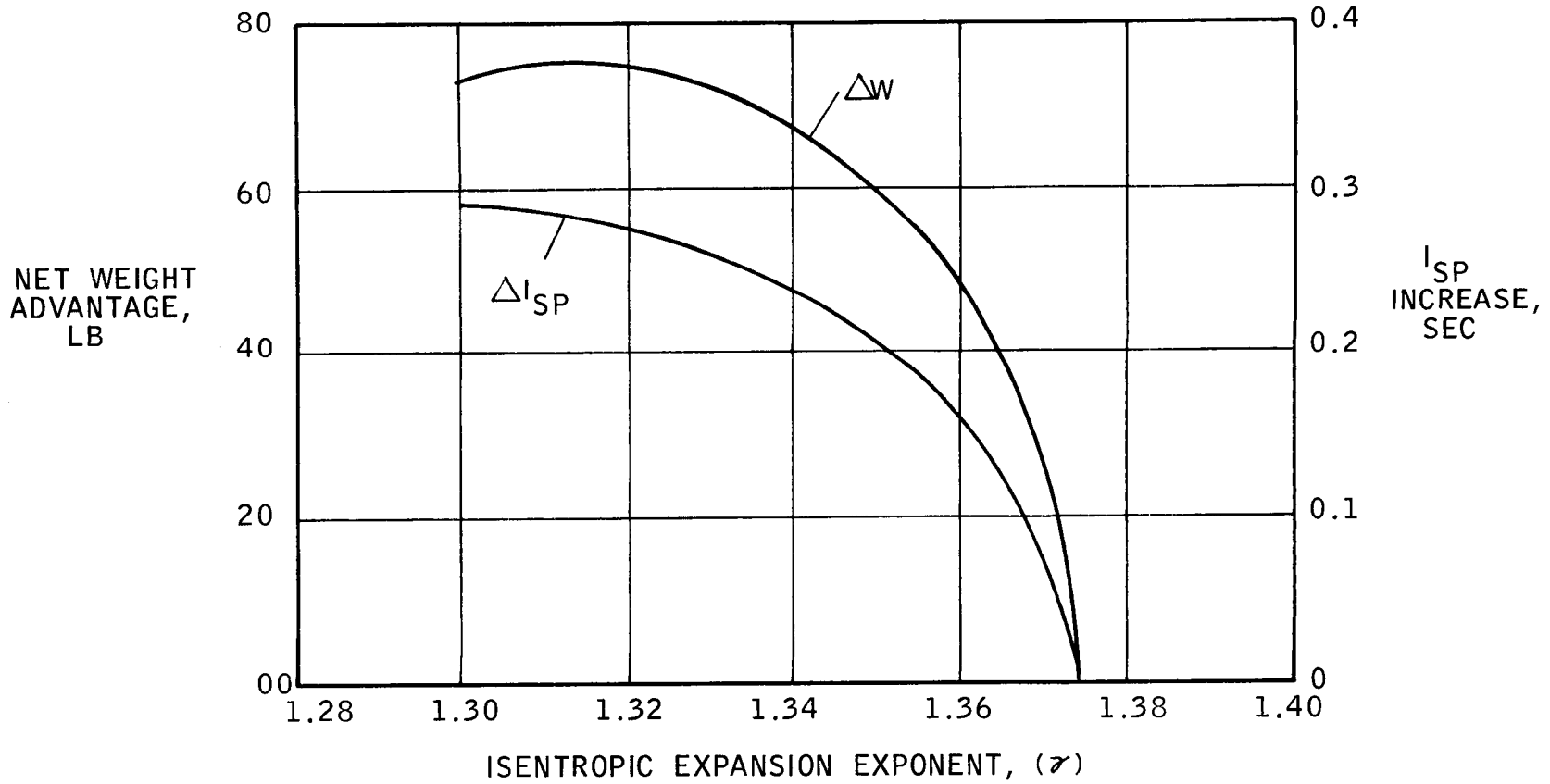


Figure 9 - Effect on Nozzle Performance of Variations in Hot-Gas Isentropic Expansion Component (γ)

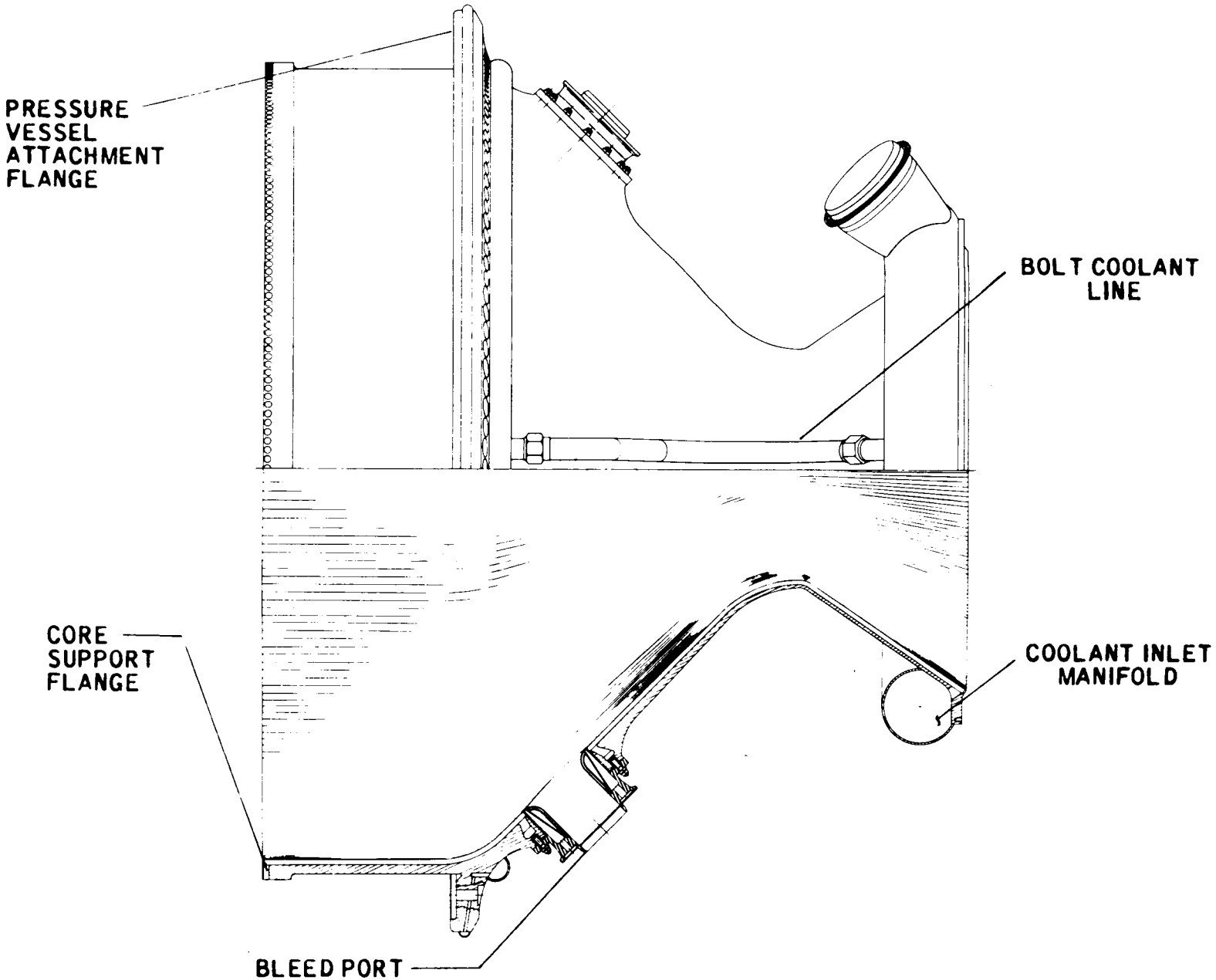


Figure 10 - NERVA Nozzle Assembly

rise relationship is shown in Figure 11. This design effort also enabled verification of nozzle ΔP/maximum gas side-wall temperature (Twg) relationship. A plot of Twg versus ΔP is shown in Figure 12.

The feasibility of using a series nozzle/skirt flow system was also investigated in a limited study. The pressure drop was found to be 560 psi, compared with a nozzle parallel flow system pressure drop of only 400 psi; therefore, the parallel flow system was selected. Table 3 shows a comparison of the flow characteristics of a series and of a parallel nozzle/skirt system.

The preliminary NERVA Nozzle Assembly Design Criteria, Report No. RN-S-0434, and the Preliminary NERVA Nozzle Development Test Plan, Report No. RN-S-0421, have been completed and submitted for publication and review prior to release.

The hot-bleed-port bypass manifold design report has been completed and approved. Publication of this document has been delayed until CY 68 due to funding limitations.

Design effort on the hot-bleed-port insert has been initiated and will continue during CY 68. The design of special coolant channel end caps, which are expected to reduce nozzle pressure drop, have also been initiated. A design concept is shown in Figure 13. The end cap designs will be subjected to hydro-flow tests, and may subsequently be incorporated into the nozzle design.

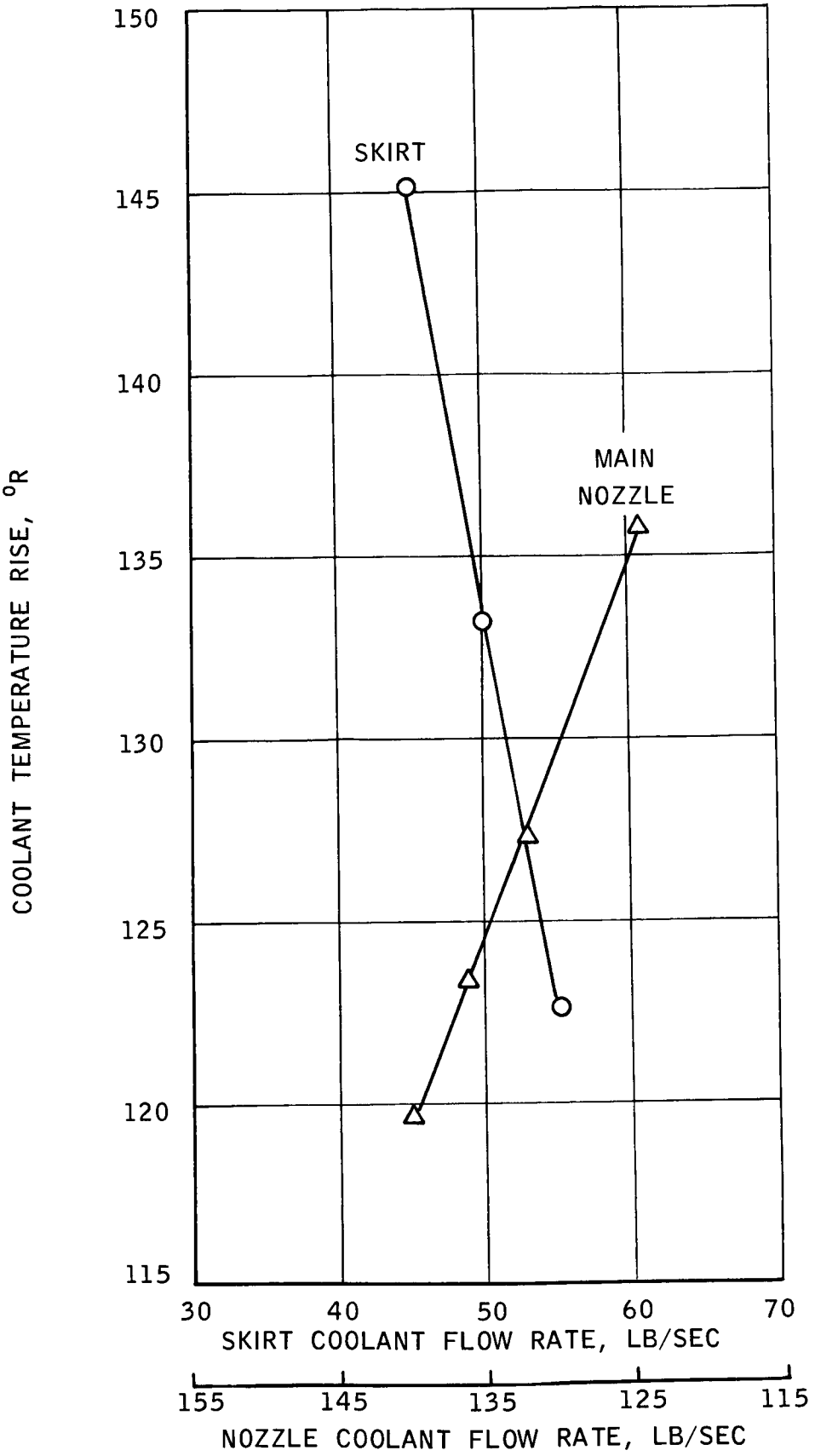


Figure 11 - Coolant Temperature Rise vs Flow Rate NERVA Main Nozzle and Skirt

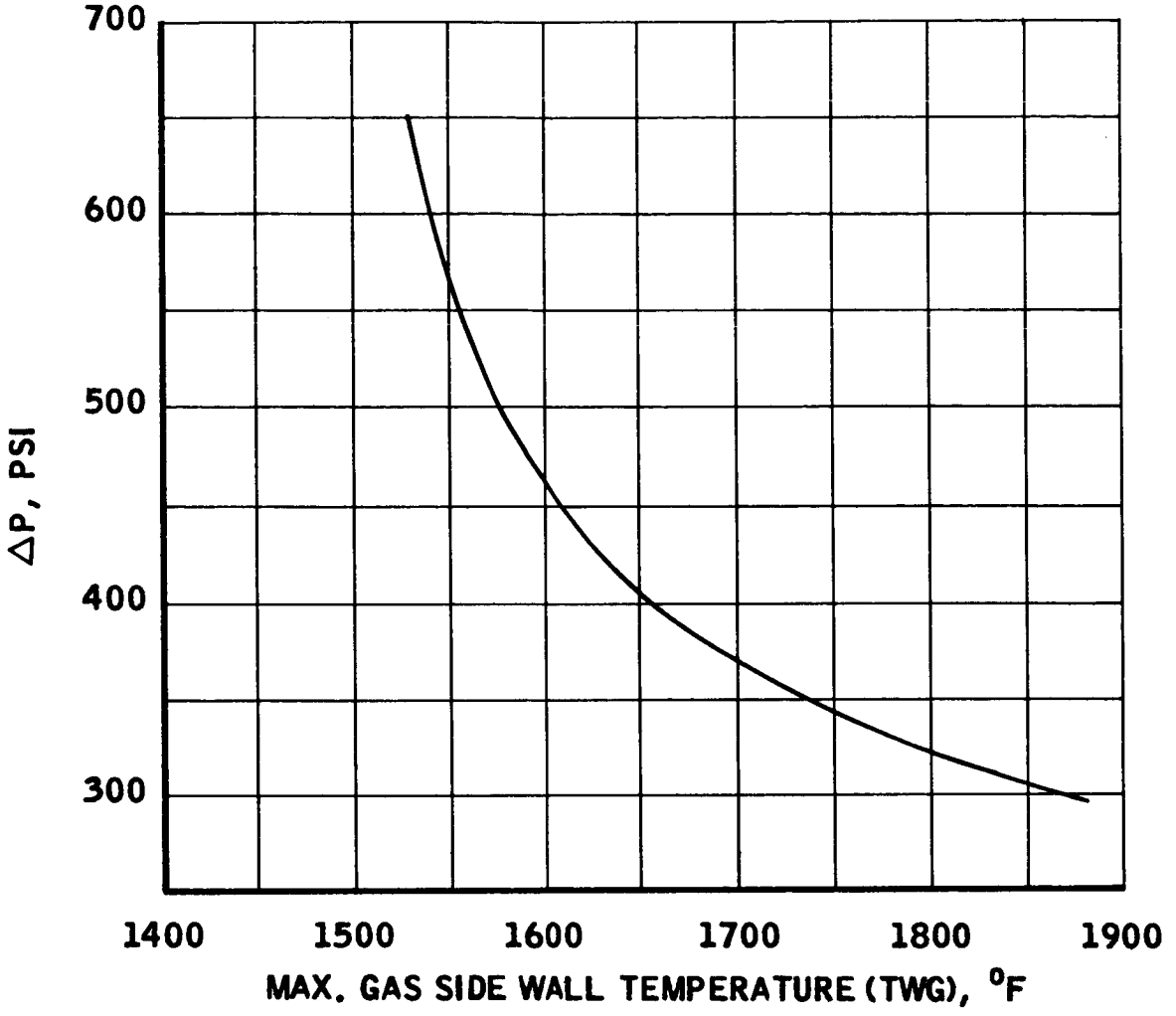


Figure 12 - NERVA Nozzle Twg Max vs Coolant Delta P

TABLE 3

NOZZLE/SKIRT FLOW COMPARISON

Skirt	Parallel Coolant Flow	Series Coolant Flow
ΔT	132°	42°
ΔP	280 psi	225 psi
$\dot{w}$	55 lb/sec	185 lb/sec
Twg max	1000°F	885°F
Nozzle		
ΔT	133°	87°
ΔP	400 psi	335 psi
$\dot{w}$	127 lb/sec	185 lb/sec
Twg max	1620°F	1590°F

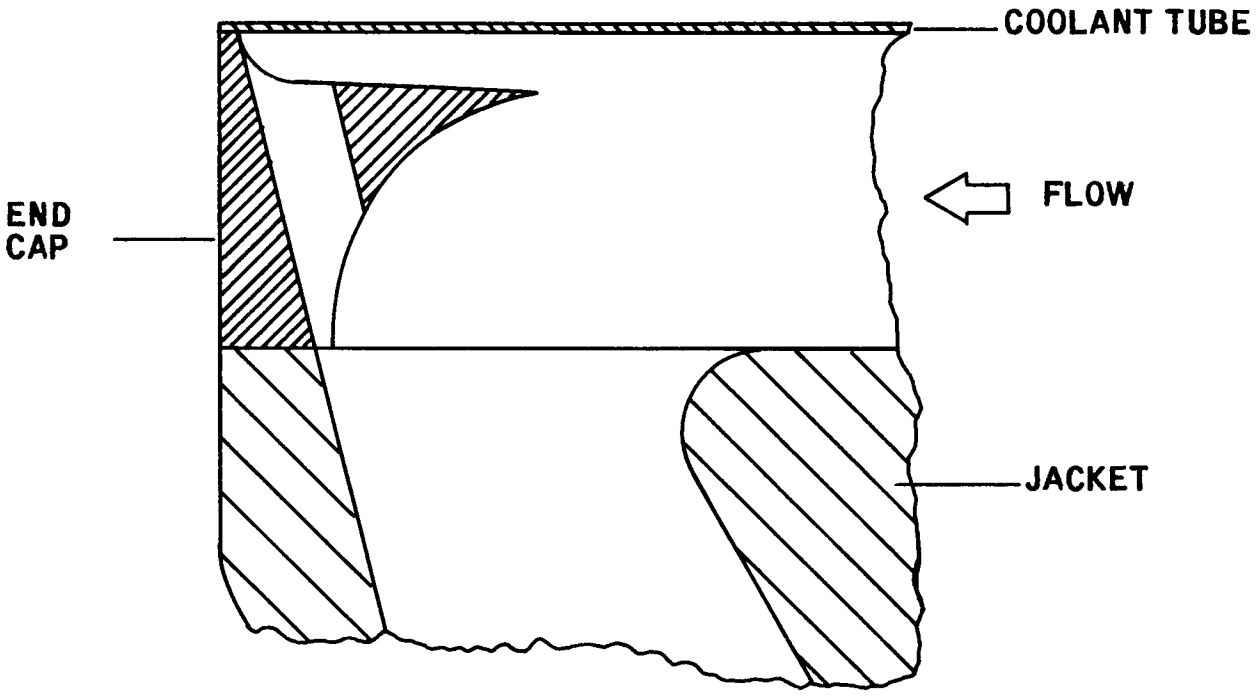


Figure 13 - Coolant Tube End-Cap Design

b. NRX and XE Thrust Structure and Lines (1.4.2)

(1) X-Engine Lines

All XECF, XE-1, and XE-2 lines (pump discharge, turbine inlet, and cooldown lines) were successfully fabricated and acceptance-tested except for the custom-fit portions of the XE-2 pump-discharge, turbine-inlet, and cooldown lines (PNs 1114239-9, 1117111-9, and 1114238-9, respectively), which are awaiting XE-2 UTS availability and the 2- and 5-in. cooldown-vent-line assemblies (PNs 1115416-9 and 1115415-9, respectively). These XE-2 line assemblies will be completed early in CY 1968.

During assembly of the XE-1 vent lines toward the end of CY 67, corrosion was detected in the interior of the line in the region of the welds. Inspection indicated that the brown-colored material resulted from oxidation, which was attributed to insufficient backup gas during welding and to weld spatter in the heat-affected zones. An inspection of other XE stainless-steel lines showed the same condition in the custom-fit pump-discharge and cooldown line assemblies. The oxidation was removed from the XE-1 PDL pump segment, XE-1 cooldown line assembly, and the XECF, XE-1 and XE-2 diluent lines. Relative to their expected end use, the oxidation level was considered acceptable in the XECF and XE-1 vent-line segments and in the XECF PDL pump segment and CDL assembly. To prevent recurrence of the oxidation problem, shop planning and inspection procedures were modified to ensure proper gas backup during welding; and any oxidation that occurred before or after welding was removed with clean stainless-steel wire brushes.

(2) XE-Engine Upper Thrust Structure

Fabrication and acceptance testing of the XE-1 upper thrust structure (UTS) was completed. Acceptance testing was conducted in accordance with the acceptance test plan*, and the part met all the

* RN-TD-0007, Acceptance Test Procedure for XE-1 Upper Thrust Structure, 15 August 1966.

acceptance criteria. This unit is identical to the XECF UTS shipped during the fourth quarter of CY 1966.

(3) XE-Engine Lower Thrust Structures

Fabrication and acceptance testing of the XE-1 and XE-2 lower thrust structures were completed. Acceptance testing was successfully conducted in accordance with the acceptance test plan*. These units are similar to the XECF lower thrust structure that was provided during the third quarter of CY 66.

d. NERVA Thrust Structure and TVS (1.4.3)

Thrust-structure and thrust-vector-system (TVS) weights were provided for the engine parametric study. The reference thrust structure and TVS for this effort consisted of a conical thrust structure and a four-point thrust-vector-alignment system with thrust-structure sections based on material properties for annealed 6Al-4V titanium alloy at a temperature of 800°F.

A conceptual design layout was completed for a TVS thrust-structure assembly using a gimbal ring for thrust-vector alignment. This concept (Figure 14) was selected for use in the reference engine in the program plan**. The assembly consists of three structural segments, an adapter to facilitate remote engine separation and assembly, an upper thrust structure, and a lower thrust structure joined by a gimbal ring. The adapter and upper thrust structure are box rings 79.00 in. in diameter, with remote connector bracketry on the OD. The upper thrust structure contains stiffened panels

* RN-TD-0008, Acceptance Test Procedure for XE Lower Thrust Structure 15 August 1966.
** AGC Report RN-DR-0103, NERVA Engine Development Program Plan, May 1967.

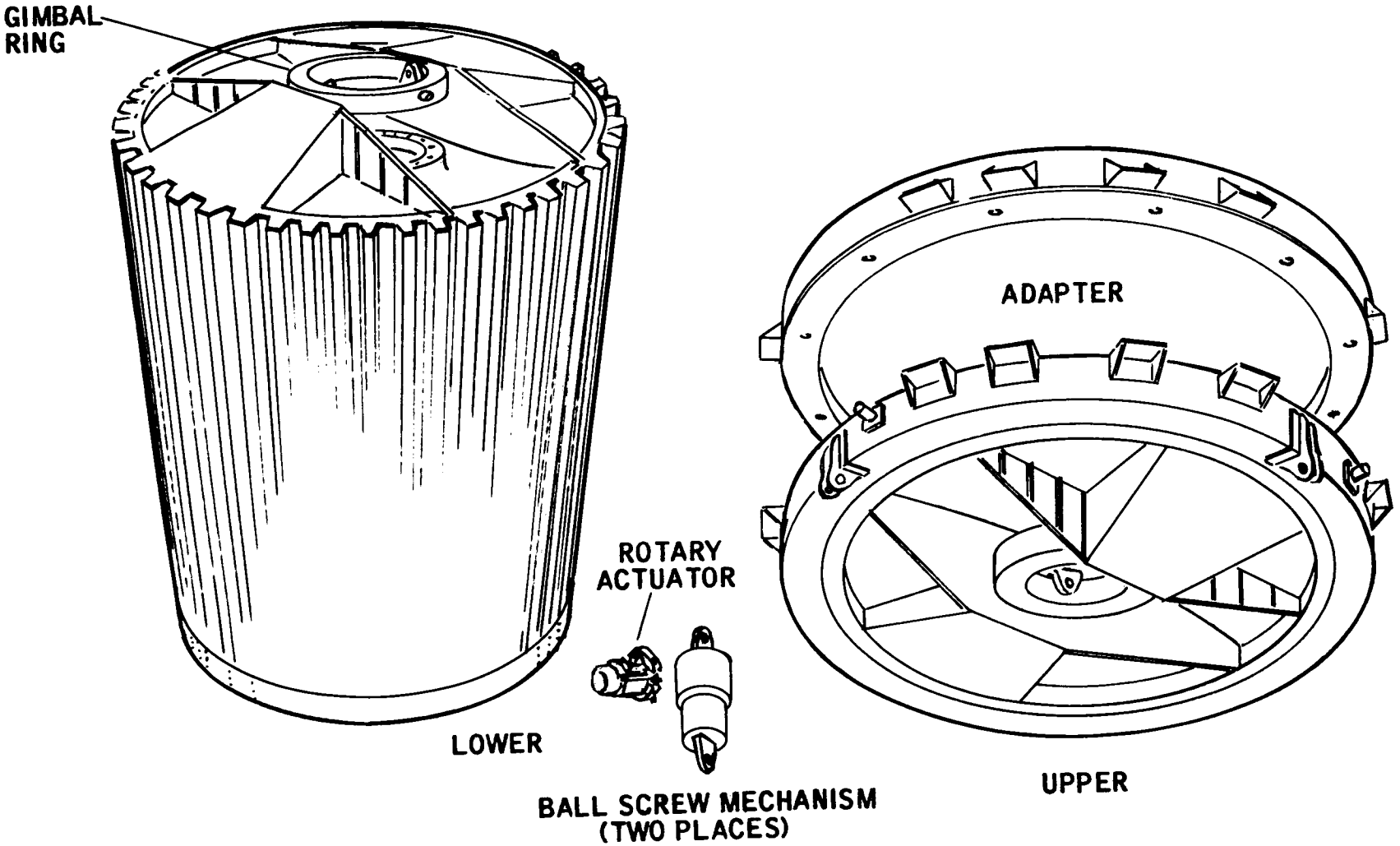


Figure 14 - Reference Engine Thrust Structure and TVS Adapter

for transmitting loads to the gimbal ring. The lower thrust structure is a semimonocoque cylinder 69.00 in. in diameter fabricated from corrugated sheet stock. Within the lower thrust structure are a sheetmetal frustrum for supporting the TPA and stiffened panels for supporting the gimbal ring. The gimbal ring is a box ring 6 by 12 in. in cross section and having a mean diameter of 35.00 in. The engine is displaced by actuating two ball screws located on the pitch and yaw axes.

When compared with the other concepts evaluated, the design has certain advantages that resulted in its selection for the reference engine. These advantages are:

(1) Compatibility with the close-coupled TPA and PSOV.

(2) A more feasible remote-plane design than that of previous concepts evaluated.

(3) Better lateral load-carrying capability and a well defined gimbal center for the ring gimbal system (compared with that for the four-point concept indicated in the program plan, RN-DR-0079*).

Conceptual design continued on thrust-structure and TVS configurations that provided better load-transfer and stiffness potential than the RN-DR-0103 reference configuration. Investigation of conical thrust structures continues for both the four-point and gimbal-ring TVS schemes.

A conceptual design study** was completed to determine the best location for the TVS. The two locations being considered were between

* AGC Report RN-DR-0079, NERVA Engine Development Program Plan, September 1966.
** RN-TM-0436, NERVA Thrust Vector System Study Location, 30 June 1967, by L. S. Lutton and R. W. Thomas.

the engine plane and the turbopump assembly (TPA) and between the TPA and the pressure-vessel closure. On the basis of the summary presented in Table 4, the forward position was selected. Analytical support was provided during the study by dynamics and actuator-loads analyses.

Studies were completed in which the locations of the gimbal center, the remote plane, and the interface between the module propellant tank (MPT) and engine were evaluated. On the basis of the TVS being positioned forward of the TPA, the selected location of the gimbal center, as shown in Figure 15 is at the center of the flexible bellows (between the PSOV and TPA). In evaluating the remote-plane and interface locations, separation of the two items was suggested, as indicated in Figure 16. The reason was that the MPT thrust structure and the adapter would form a flight-designed and easily defined structural interface between engine and MPT, and the adapter would isolate the interface from development changes in the remote plane; the separation would also permit easy and simple deletion of the remote plane without disturbing the interface definition, if such a deletion should become a requirement.

In establishing the optimum location of the interface with respect to the gimbal center, consideration was given to the effect of the relative location on:

(1) Interface design and load definition

(2) The number of pneumatic connectors at the remote plane

(3) On-stand maintenance of functional components

(4) Engine length

(5) Nuclear-radiation heating

TABLE 4

TVS LOCATION SUMMARY

Advantages - Forward of TPA	Advantages - Aft of TPA
Lower angulation requirements for line bellows	Better pump inlet conditions
Less loading of TPA and nozzle flanges	Lower TVS actuator loads
Lower radiation field	
Less complex PV and electrical wiring design	
Better thrust structure/PV remote capability	
Less space restriction at PV dome	

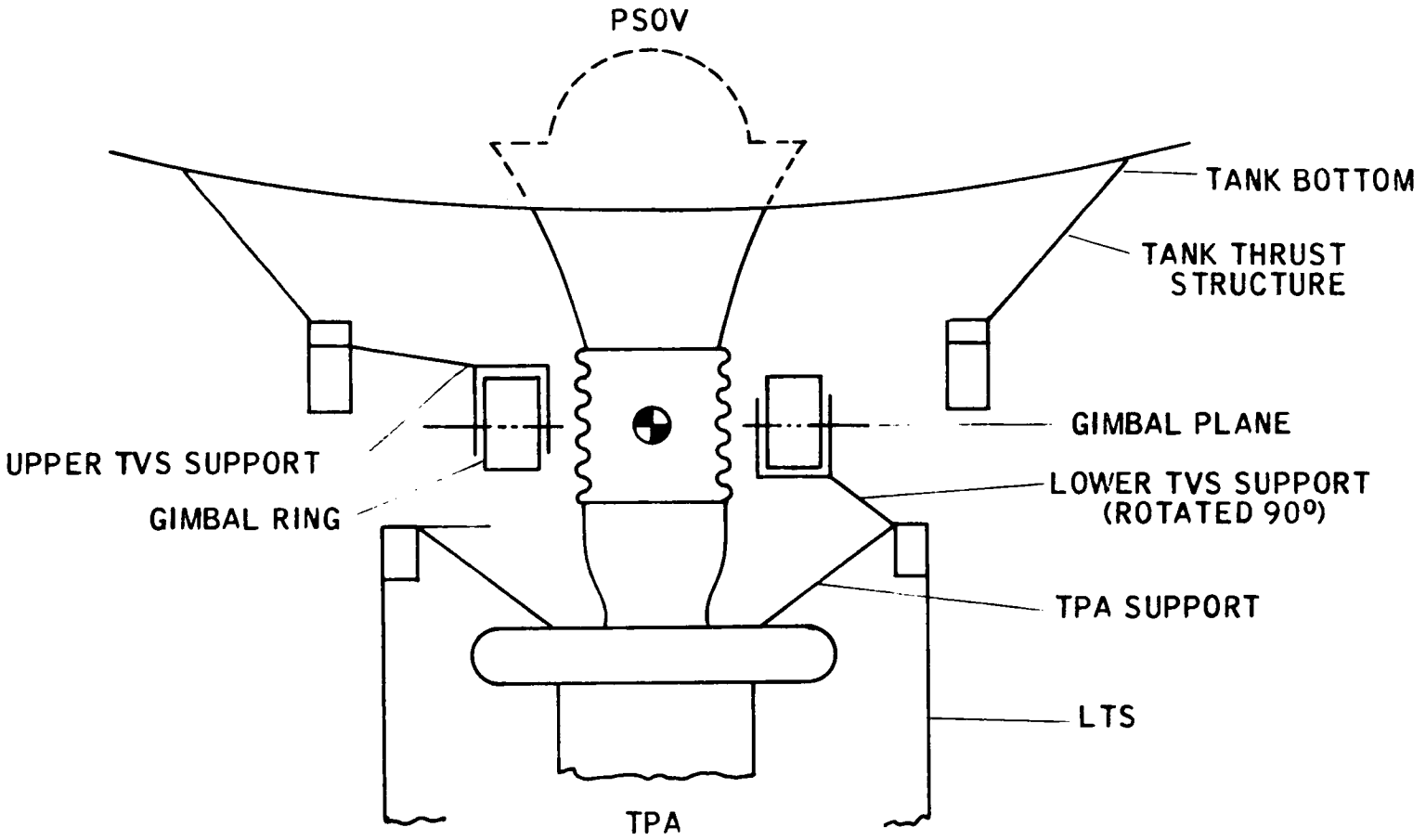


Figure 15 - Gimbal Center Location

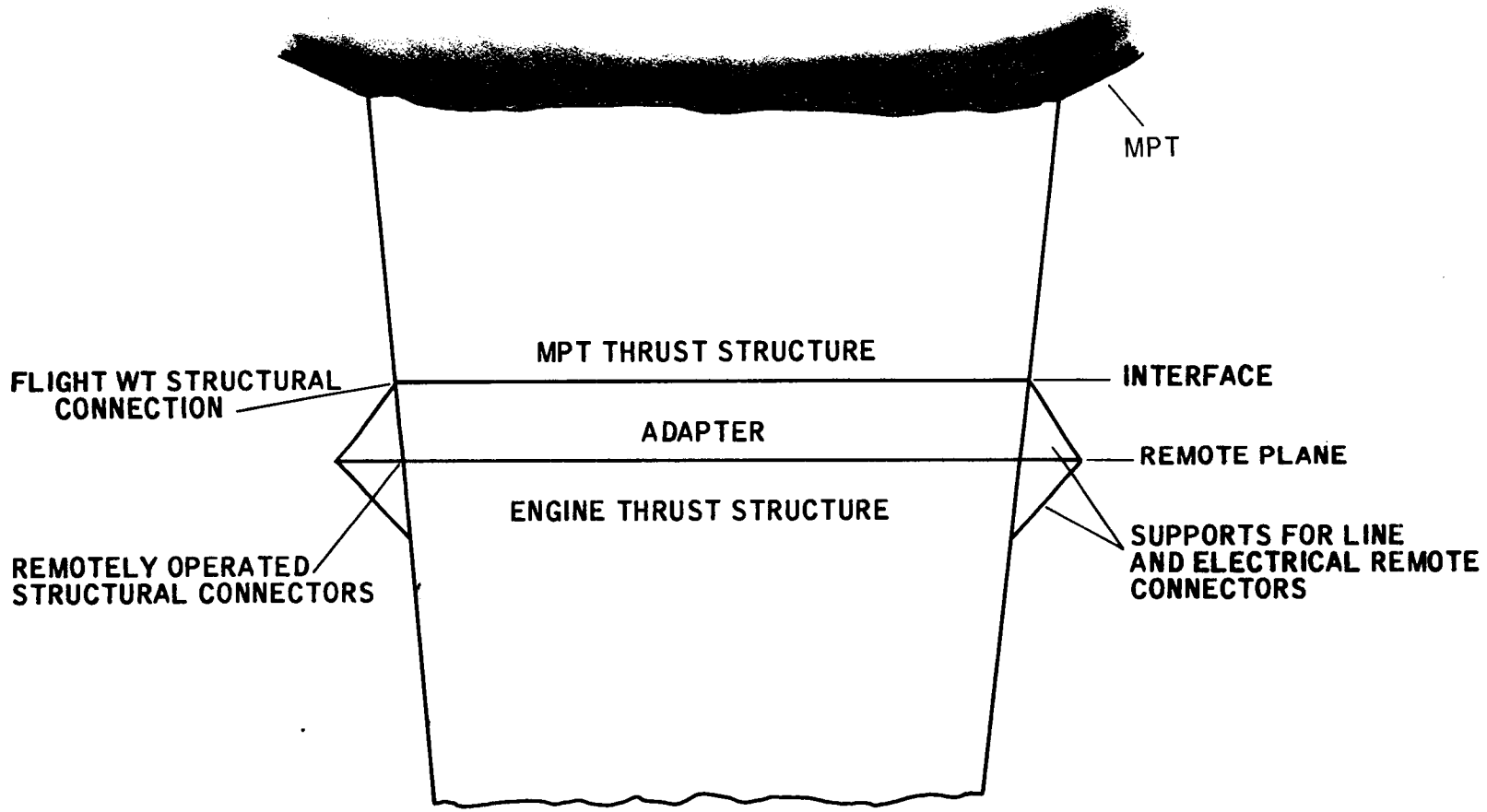


Figure 16 - Interface and Remote Plane Concept

(6) Common TVS, TPCV, and SSCV actuator requirements

(7) Effect on engine and TVS structure

The study resulted in a recommendation that the interface be located between the MPT and the gimbal center, as shown in Figure 17.

Detailed layouts showing various MPT-engine structural-interface configurations were prepared. Figure 18 shows one concept that utilizes a short box-ring adapter section located forward of the remote plane. The adapter is manually attached to the stage with threaded fasteners. The structural connection at the remote plane, also shown in Figure 18, consists of a threaded fastener powered by a pneumatic motor with a worm drive. A spring contained within the bolt ensures that the bolt will engage with the nut when the bolt is driven. In case of failure of the pneumatic motor, remote disassembly can be accomplished by removing the nut with the use of the manipulator on the EIV.

Mechanical and thermal design properties were assembled for the following prospective thrust-structure materials: annealed 6Al-4V titanium alloy, 2024 and 7039 aluminum alloys, Inconel 718, beryllium, and Lockaloy, which is a beryllium-aluminum alloy. The latter two materials will be considered only if thermal and stiffness problems are encountered with the other materials.

Preliminary development plans were completed for the thrust structure and TVS and were published as Reports RN-S-0413 and RN-S-0412, respectively.

Report RN-S-0415, Preliminary NERVA Thrust Structure and Thrust Vector System Design Criteria, was also completed and published.

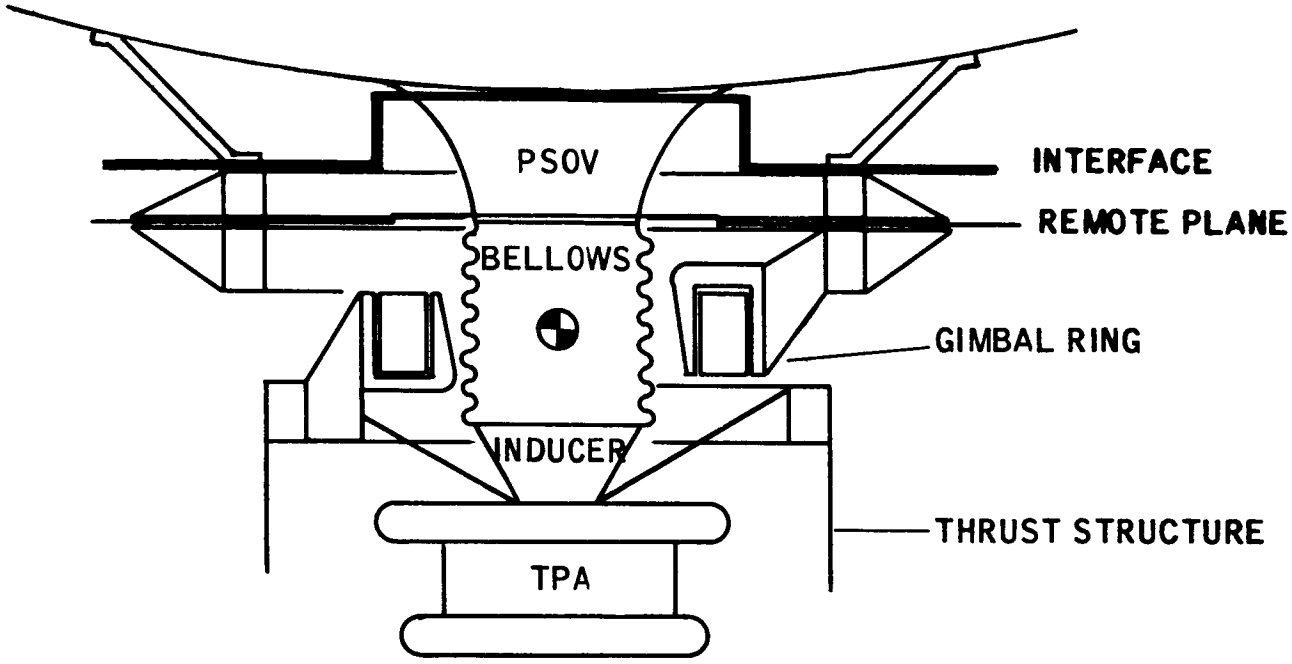


Figure 17 - Interface Concept-TVS on Engine

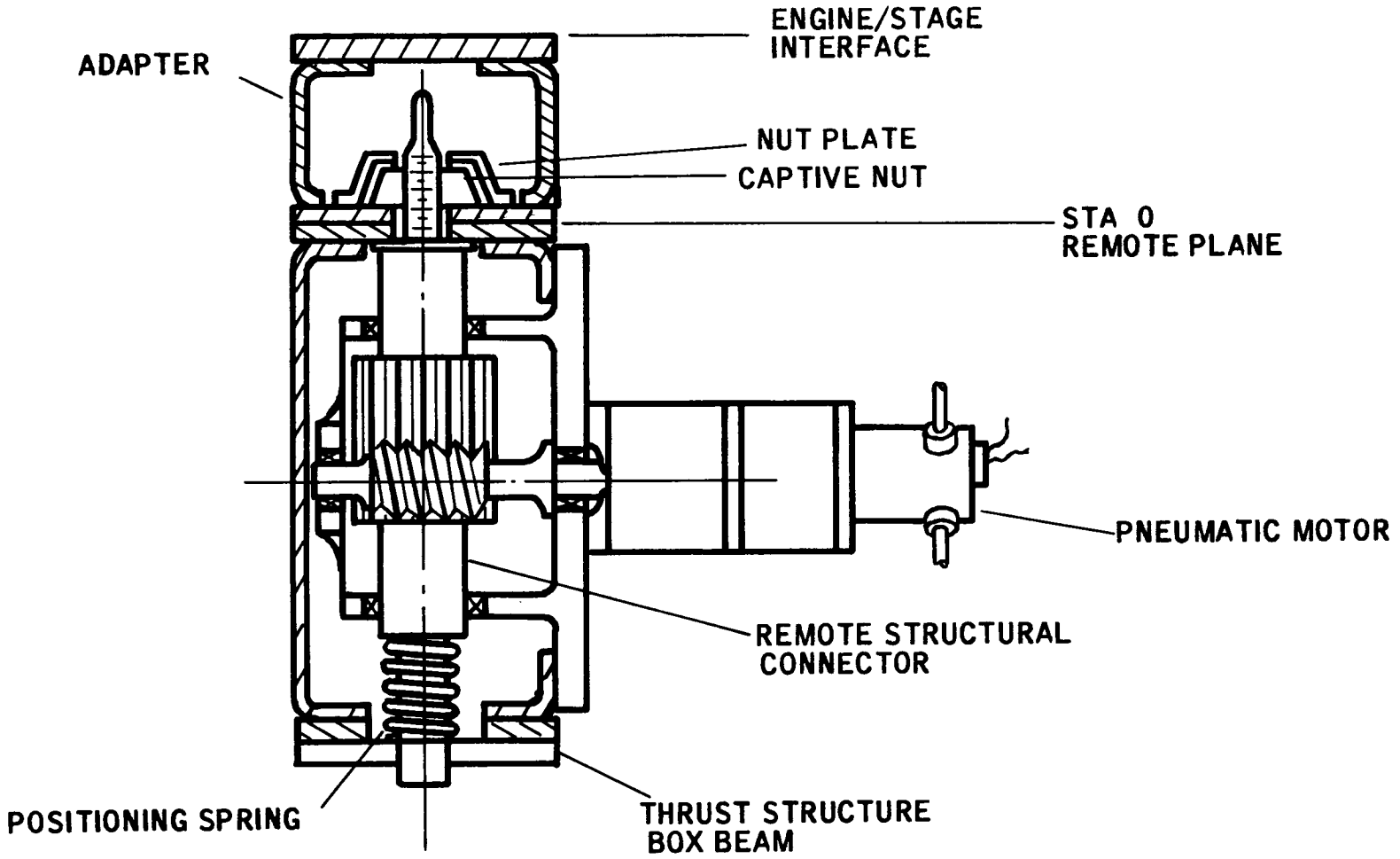


Figure 18 - Remote Structural Joint Concept

e. Technology Pressure Vessel (1.4.4)

(1) NRX/EST Pressure Vessel

A report analyzing the pressure-vessel behavior and performance during the NRX/EST test program was completed*. The structural integrity of the pressure vessel was demonstrated under the full-power NRX/EST nuclear conditions.

(2) NRX-A5 Pressure Vessel

A report analyzing pressure-vessel performance during the NRX-A5 test program was completed**. The structural integrity of the pressure-vessel assembly was demonstrated in a full-power nuclear environment. The report presents test data, data evaluation, and pressure-vessel performance.

(3) NRX-A6 Pressure Vessel

A heat-transfer report analyzing the pressure-vessel thermal performance under a full-power nuclear environment (Test Cell C conditions) was published***. The temperatures obtained during this analysis were used in a detailed stress analysis**** of the NRX-A6 pressure vessel. This analysis indicated positive margins of safety for the ambient proof-pressure test conditions and the NRX-A6 operational conditions for a fully shielded Test Cell C environment.

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* RN-TM-0372, Evaluation of NRX/EST Pressure Vessel, December 1966, by D. W. Tracy

** RN-TM-0410, Evaluation of NRX-A5 Pressure Vessel, February 1966, by D. W. Tracy

*** RN-S-0335, Steady State Thermal Analysis of NRX-A6 Pressure Vessel, November 1966, by O. Vick and W. Westmore

**** RN-S-0336, Structural Analysis of the NRX-A6 Pressure Vessel Components and Assemblies, March 1967, by W. de la Garza and J. Nevenzel

(4) NRX-A7 Pressure Vessel

Preliminary heat-transfer and stress analyses were completed for the NRX-A7 pressure-vessel design-feasibility studies. The NRX-A6 pressure-vessel design was analyzed for an expected NRX-A7 operating pressure of 860 psia, and an upgraded NRX-A6 design with a thicker-wall vessel was analyzed for compatibility with a 1000-psia operating-pressure environment. Both conditions analyzed showed positive margins of safety except for the closure bolts, which would require cooling to prevent an excessive loss of bolt preload during full-power operation.

(5) XE-1 Pressure Vessel

Structural and thermal analyses* of the XE-1 pressure vessel were conducted. The analyses indicated positive margins of safety for the ambient temperature proof-pressure test conditions and XE-1 operational test conditions.

(6) XE-2 Pressure Vessel

Pressure-vessel SN 880013, comprising the PN 1113855 cylinder and PN 1113856 closure, which was originally designated as an XE spare unit, was fabricated for end use on XE-2. The vessel was successfully acceptance-tested in accordance with AGC Report RN-TD-0002, Acceptance Procedure XE-1 Aluminum Pressure Vessel, dated August 1966, and was accepted for XE-2.

* RN-S-0337, Steady State Thermal Analysis of XE-1 Pressure Vessel, November 1966, by O. Vick and W. Westmore; and RN-S-0338, XE-1 Pressure Vessel Structural Analysis, February 1967, by J. Jellison and J. Nevenzel

(7) Pressure-Vessel Development

A report analyzing the hydrostatic proof and burst test of the hot-bleed-port nozzle and pressure vessel was completed*. The test successfully demonstrated the compatibility of a stainless-steel, hot-bleed-port nozzle with an NRX/XE aluminum pressure vessel.

f. NERVA Pressure Vessel (1.4.5)

(1) Design

Pressure-vessel supporting data were provided for the NERVA-engine parametric study, including pressure-vessel design and weight information for the numerous engine configurations.

Independent of the parametric study and engine selection, pressure-vessel design, stress and heat-transfer analyses, and material-engineering efforts were conducted to assess five prospective pressure-vessel materials: (1) Inconel 718, (2) 5Al-2.5Sn (ELI) titanium, (3) 6Al-4V titanium, (4) 7039 aluminum, and (5) 2219 aluminum. The materials investigation considered such factors as strength-to-weight ratios, fabricability, ductility, and fracture toughness in an attempt to make a technical evaluation that would lead to selection of a pressure-vessel material. Preliminary evaluations of the five materials eliminated 5Al-2.5SN (ELI) titanium and 2219 aluminum from further consideration.

Pressure-vessel layouts for the three remaining prospective materials were prepared, and a detailed weight comparison of these materials was conducted. Results of the study indicated that 7039 aluminum was the most promising material. A report** was published that presents the

* RN-TM-0412, Hot-Bleed Port Nozzle/Pressure Vessel Structural Test, May 1967, by D. E. White

** RN-TM-0428, NERVA Pressure Vessel Preliminary Weight Study, April 1967.

results of the weight study and the technical justification for recommending this material.

A detailed stress analysis was performed to substantiate selection of 7039 aluminum as the NERVA pressure-vessel material. An aluminum-pressure-vessel design layout for the 200,000-lb-thrust engine was made. Pressure-vessel nuclear and thermodynamic analyses were performed, and the results supported a stress analysis* that indicated positive margins of safety for all components of the vessel assembly. Preliminary design dimensions for the aluminum-pressure-vessel design layout were based on pressure-vessel physical requirements and reactor interface requirements obtained at the first NERVA interface meeting. This design has been continuously upgraded to maintain consistency with the latest reactor, and improvement of interface logic remains a continuing process.

Preliminary concepts for return of the nozzle-bypass/skirt-coolant flow to the aft end of the pressure-vessel cylinder (reflector inlet plenum) were prepared, and a preliminary flow study was conducted. Conceptual design and analysis are in progress.

Several preliminary conceptual designs of the thrust-structure-to-pressure-vessel remote joint were prepared. The current concept is shown in Figure 19 and is presently being analyzed for the NERVA nuclear, thermal, and load environments.

Forging and rough-machine drawings for the pressure-vessel cylinder and closure were completed for procurement of pressure-vessel forging tooling. The cylinder and closure rough-machine designs are shown on AGC Drawings 1118804 and 1118803, respectively.

* RN-TM-0439, NERVA Pressure Vessel Design Report, July 1967.

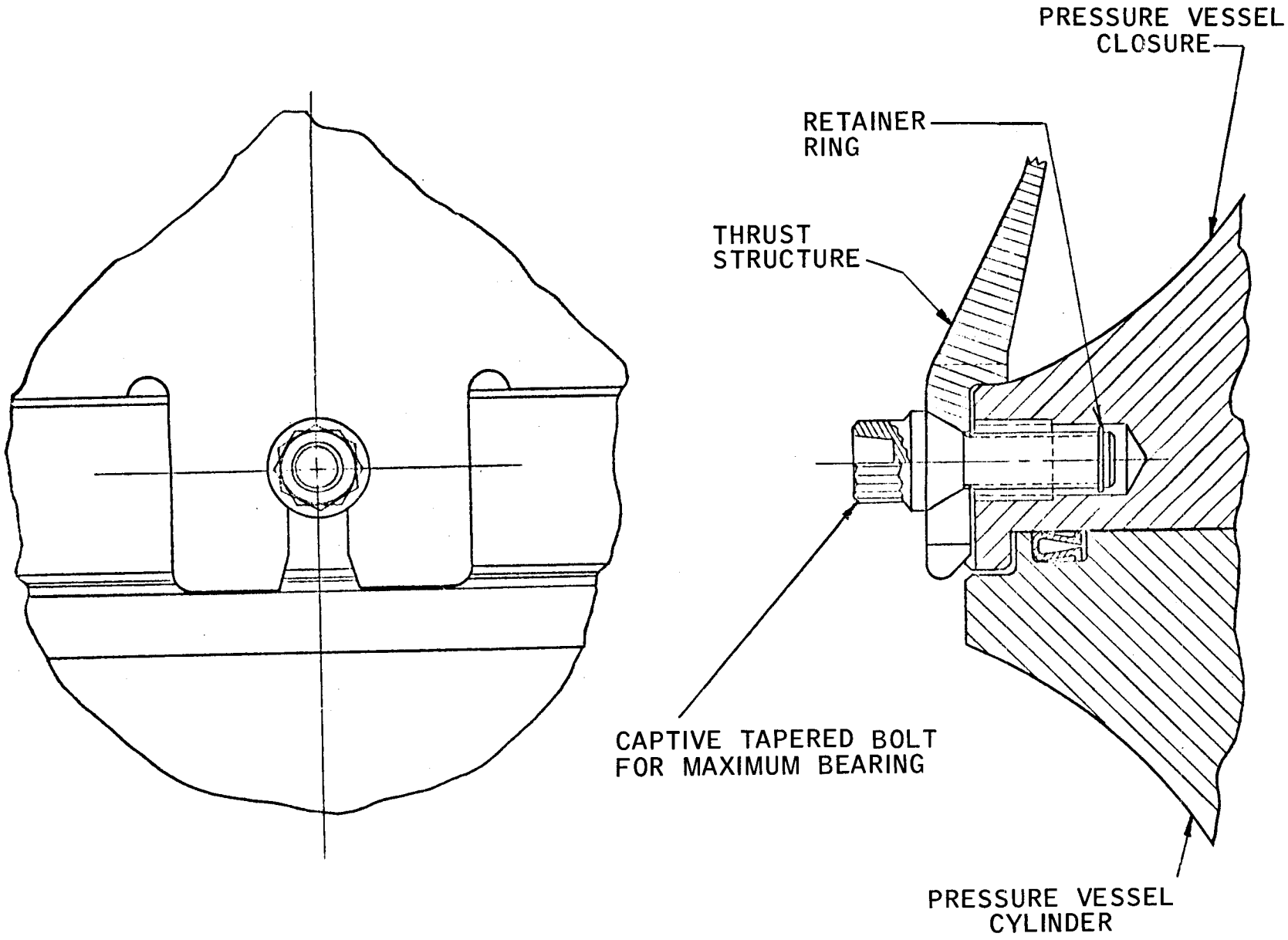


Figure 19 - Thrust Structure/Pressure Vessel Joint Concept

A NERVA-pressure-vessel design-criteria document and a development plan were prepared and published as Reports RN-S-0416 and RN-S-0414, respectively.

(2) Material Development

Parallel to, and in support of, the pressure-vessel material-selection study, a material-evaluation program was conducted in accordance with Phase I of the NERVA Pressure Vessel Material Program Plan, RN-66020, Revision 1, dated April 1967. Specific pressure-vessel materials used in the preliminary tests include the following:

(a) Aluminum-alloy 7039 forging, solution-annealed and aged to T-61 condition by ACFI, Albuquerque Division, in accordance with Kaiser proprietary cycles.

(b) Aluminum-alloy 7039 welded plate, solution-annealed and aged after welding by ACFI, Albuquerque Division, in accordance with Kaiser proprietary cycles.

(c) Inconel 718 rolled ring, solution-annealed at 1950°F for 1 hr, air-cooled, and aged at 1200 to 1350°F for 20 hr in accordance with AGC 46604.

(d) Inconel 718 welded rolled ring, solution-annealed prior to welding and aged after welding in accordance with AGC 46604.

(e) Inconel 718 welded rolled ring, solution-annealed after welding and aged in accordance with AGC 46604.

(f) Inconel 718 roll-formed cylinder section in the as-roll-formed condition, provided by the Ladish Company, Cudahy, Wisconsin.

(g) Titanium 6Al-4V (ELI) plate, pickled and vacuum-annealed 2 hr at 1400°F in accordance with MIL-H-81200.

The program included tensile, fracture-toughness, and hardness tests. The tensile tests were performed by using ASTM-R-3-type unnotched and notched (K_t = 6 to 8) specimens. Fracture toughness was determined with precracked V-notched Charpy-impact specimens. Rockwell-hardness tests were made for record purposes only.

A complete summary of test results was published in Report RN-S-0407, the NERVA materials development third quarter report for Contract Year 1967, dated August 1967.

Test specimens of 7039-aluminum parent material and weldments were fabricated for testing in the GTR-21 radiation-effects program. The radiation test data will serve to satisfy a portion of the work scope stipulated in Phase II of the RN-66020 materials program plan.

A properties literature search was conducted for high-yield-strength (220 to 240 psi) materials for pressure-vessel closure bolts. This search reduced the number of prospective materials to four: Inconel 718, Udimet 630, Waspaloy, and heat-treated 18%-nickel maraging steel.

Procurement of six subscale 7039-aluminum cylinder forgings was initiated. Three different heats of 7039 aluminum will be employed, and two cylinders will be forged from each heat of the material. The forging process will be performed by the same vendor and will duplicate the process planned for producing the full-scale NERVA pressure vessel. The subscale units will be used to establish statistical design-properties data for the material and to provide material in support of a welding-evaluation program. The subscale program is designed to satisfy the objectives of Phase II of the RN-66020 materials program plan.

(3) Fabrication

Procurement support was provided for the pressure-vessel fabrication study. Quotations were obtained for a one-piece pressure-vessel cylinder and for a multiple-piece welded cylinder for three prospective vessel materials. Although the initial forging tooling cost for a one-piece cylinder is significant, the study indicates that the composite unit price (with tooling amortized over 20 units) of a one-piece cylinder is equal to or slightly less than that of the multiple-piece welded unit. On the basis of reliability and cost, the one-piece unit was selected as the fabrication approach for the NERVA pressure-vessel cylinder. The one-piece cylinder forging will be extruded. The process starts with a rolled or forged ring and is followed by preforging to form the aft end of the vessel; the material is then extruded to form the main cylindrical section. The vessel is produced close to the required size and is worked in both the circumferential and axial directions. It is planned that the forging will be heat-treated and rough-machined to within 1/8 in. of final dimensions prior to delivery.

Machining to final dimensions from a one-piece closed-die forging was selected as the manufacturing technique for the pressure-vessel closure.

g. NERVA Lines (1.4.6)

Parametric line studies were made of the lines for various engine configurations to determine line weight and pressure drop vs line diameter. Engine configurations included engines A through H and D-5. These and other studies changed the gimballed bellows requirement from an 8- to a 7.00 in. size.

Detailed program development plans and cost schedules were made for the various engines and engine configurations.

A tentative masterline layout drawing, 1134319, was completed. This was a tentative layout because of continuing changes in NERVA engine requirements. A new tentative masterline layout drawing is in process based on the latest engine configuration.

The envelope drawing (1118695) of the 8-, 6-, and 4-in. internal gimbal restrained bellows assemblies was released. These assemblies were intended for use in the 8-in. pump discharge line, and in the 6- and 4-in. portions of the turbine inlet line. Vendors were asked to submit proposals on the 8-in. bellows assembly.

Several vendor proposals were received, but each proposal had either unacceptable features or design deficiencies. In addition, the price quotations were considered excessive.

Therefore, Aerojet designs were made for an 8.00-in. bellows assembly. Design layouts of several concepts were completed.

When the bellows requirement changed from 8 to 7 in., additional layouts were made for the 7.00-in. unit. Assembly and detail drawings were made and are expected to be released in the first quarter of CY 68.

Specification AGC-90170, which established the requirements for a single- or multiple-ply, internally gimballed bellows assembly, was produced for inclusion into the gimballed bellows drawing, 1118695. However, the specification was not included because the bellows requirement changed from an 8- to a 7-in. size.

An envelope drawing for the 7.00-in. and 4.00-in. gimballed bellows assemblies is being prepared, with the inclusion of specification AGC-90170. The drawing will be sent to vendors to obtain cost quotations. This will provide (1) a basis for cost comparison between vendor-designed and Aerojet-designed assemblies; and (2) preliminary backup vendor designs for these bellows assemblies.

An envelope drawing, 1118964, of the 8-, 4-, and 2-in. external-wire-braid restrained bellows assemblies has been started. Specification AGC-90173, which establishes the requirements for a single or multiple ply external-wire-braid bellows assembly, is nearing completion for inclusion on this envelope drawing.

Several design concepts of line joints (including flanges, seals and clamps) were made and analyzed relative to expected nuclear radiation environments.

The threaded-collar joint is the only concept, other than welding, which can withstand the conditions of radiation heating. A Marman V-band clamp design was determined to reach a temperature in excess of 2000°F.

The Aeromega-type and infundibular-type seals appear to be promising. Drawings of these seals are in process but are awaiting final joint configuration definition before being completed.

Preliminary seal tester concepts were established and a design configuration is being finalized.

The preferred material in the turbine inlet line assembly has been changed from Inconel 718 to Hastelloy C because Inconel 718 is subject to radiation embrittlement at temperatures above 900°F, and has unstable properties at 1500°F. Tests of Inconel 718 are being made to determine the effect of boron content on its irradiated properties.

Dry-film lubricants for use in the turbine inlet line have been investigated and selection has been made.

The preliminary design criteria for NERVA lines have been completed and are being published.

Vendors capable of supplying the tubing required for the NERVA lines are being sought. To date, none have been found.

h. NERVA Skirts (1.4.7)

(1) NE Skirt Assembly

Accomplishments for CY 67 on the NERVA engine skirt assembly involved the following three areas of investigation:

(a) Identification of the limits of operation for the skirt extension coordinated with system requirements and limiting conditions imposed by the coolant.

(b) Optimization of the skirt for weight and coolant conditioning for compatibility with the nozzle.

(c) Design studies to identify potential problem areas and to develop tentative solutions in preparation for the start of the design activity on the skirt assembly.

The initial work for CY 67 was support of the parametric study for optimization of the NERVA Engine System. Six sets of operating conditions were applied to the NERVA skirt assembly and designs were developed for each. Weights, pressure drop, coolant temperature rise were established and a stress analysis was made to verify the feasibility of the design concepts selected for the skirt assembly.

During the course of this investigation, basic design considerations were established and design limits were identified and compiled as design criteria. The contractual work statement for CY 67 required the preparation and submittal to the SNPO-C of preliminary skirt assembly design criteria. After completion of the engine optimization study and identification of the size of the engine system, the operating parameters pertinent to the skirt were identified and component optimization studies were initiated.

A plan for the development of the skirt assembly was established and expanded as analytical studies and design investigations progressed. In addition to preparing the NERVA skirt assembly design criteria, there was a contractual obligation to present a preliminary draft of the skirt assembly development plan to the SNPO-C Task Manager. This document was prepared to cover the design and development of the NERVA reactor skirt, NERVA engine skirt assembly, and a NERVA engine skirt for system evaluation on Test Stand ETS-1 at NTO, Jackass Flats, Nevada. The plan included design criteria, component descriptions, and test procedures for chemical-simulation testing as well as details related to the development approach.

The plan emphasized extensive analyses that were made prior to the selection of a conservative design, which will provide capability within a broad band of operation without exceeding the prescribed margins of safety. Testing has a necessary function in that it provides data to aid in verification of analyses and identifies further design characteristics that may be desired. The limits of operation are not expected to be identified by test data, but the tests will verify that the normal band of operation is well within the limits described by the analyses.

Preliminary design studies and design work accomplished in support of the engine optimization studies provided certain design margins and criteria for design of the skirt assembly were developed.

The nozzle/skirt coolant flow scheme selected for NERVA provides split flow from the pump discharge, with about one-third through the skirt and two-thirds through the nozzle. The skirt coolant exit is piped to the reflector inlet plenum to mix with nozzle coolant effluent. The flow split must be adjustable to provide identical temperature rise of the coolant for the two components consistent with reactor design requirements. Series flow for the nozzle/skirt was rejected because of increased component weight and reduced flexibility of operation for the nozzle. The nozzle could not be used independently of the skirt without subjecting it to excessive wall temperatures. The skirt contour was based on a Rao nozzle optimized for an area ratio of 100 to 1 and terminated at about 35 to 1. The termination point was selected so that when a turbine exhaust cooled extension of minimum length is installed, the assembly will provide an area ratio of 40 to 1, which is the maximum allowed by the NERVA ground test facility.

After a general assessment of the structural and thermal loads expected, it was apparent that the skirt can be constructed of materials commonly used for rocket engine components at Aerojet.

The design limits for the skirt are:

(a) Gas-side wall temperature not to exceed 1000°F at design operating conditions.

(b) Coolant pressure drop for the skirt and flow circuitry to the reflector inlet plenum must not exceed the nozzle design pressure drop.

(c) Adjustment in coolant flow rate of as much as 20% from the design coolant flow rate must be possible before the structural limits of the components are exceeded, with the engine operating at the design point.

Skirt optimization studies are being made to establish the minimum number of acceptable coolant tubes and the coolant tube cross section as a function of skirt pressure drop. On the basis of these data, detailed design of the skirt as well as definitization of the NR skirt can proceed.

The plan for skirt optimization started with establishing the minimum number of tubes allowable for a wall thickness of 0.012 in., the minimum acceptable thickness relative to fabrication and handling characteristics. A total of 490 tubes was used with a split to 980 at the midpoint of the tube bundle. A wall-temperature profile was established after adjustments were made to produce a reasonable pressure drop. The weight of the skirt was calculated, then a design with a reduced number of tubes was established. The basis for the design was as follows:

(a) Match the number of tubes in the skirt with the optimum number used for the nozzle to simplify the mating of the two components. If it is practicable to have the same number of tubes in the skirt and nozzle relative to heat transfer, the tube end closures can be a simple extension of the round tube shape. No special provision other than indexing the two parts is required to eliminate the high thermal loads produced by high-velocity hot gas impinging on the skirt tube end surfaces.

(b) Establish the cross section of the new tube bundle by duplicating local coolant velocities of the 490/980 tube arrangement. Overall pressure drops of the two configurations are then comparable except for minor differences caused by frictional losses where the wetted perimeter of the two varies significantly. The gas-side wall temperature profiles will vary mainly because of additional wall thickness required for larger diameter tubes of the latter design.

An additional design requirement affected the number of tubes for the skirt and for the nozzle. The two-pass, skirt-coolant-flow-path geometry requires the number of tubes to be divisible by five, but nozzle fabrication characteristics are improved by having the number of tubes divisible by four. The tube bundle thus established contained 280 tubes split to 560. Tube wall thickness required in the 280-tube section is 0.020 in.; this value is reduced to 0.012 in. aft of the split. A comparison of weight indicated a reduction of about 120 lb by using 280 tubes, so this tube bundle was selected for further optimization. An evaluation is being made of the effect on pressure drop and performance of increased heat rejection to the skirt coolant that results from reducing the weight by selective reductions in tube aspect ratio. Aspect ratio is defined as a ratio of the long-to-short axes in an oblong tube.

Two approaches to skirt extension design were considered: a radiation-cooled unit, which requires the use of refractory construction materials, and a fluid-cooled tube bundle design using the turbine exhaust for coolant. The latter was chosen because of its better performance potential and more conventional construction. Conventional materials, such as CRES 347, can be used throughout, except for the nozzles at the tube outlets at the aft end of the skirt extension.

Design limits on the skirt extension are as follows:

(a) Gas-side wall temperature will not exceed 1400°F at engine design-point conditions, and should be maintained near that value throughout the length of the coolant tube bundle to minimize the heat rejected from the engine exhaust stream.

(b) Coolant gas velocity in the system, except in the nozzles at the aft end of the skirt extension, will not exceed 0.4 Mach to preclude uncertainties associated with prediction of pressure drop and heat transfer for compressible fluids at higher velocities.

The program requirements for skirt extension design information during CY 67 initially emphasized evaluation of the component operating requirements, minimum inlet pressure and coolant flow-rate conditions at a specific turbine outlet temperature, and the component weight for various engine systems under consideration. Data were presented in the first two quarterly progress reports for the NERVA Program, CY 67, describing the coolant requirements when the area ratio of the point of attachment of the skirt extension to the skirt was a significant factor. During this period modifications of the skirt extension design were instituted that improved coolant inlet pressure limits. This provided the turbopump design an additional pressure-ratio margin so that turbine efficiency could be increased.

After the engine system had been selected, analysis of the skirt extension was resumed using coolant parameters derived from turbine performance curves at the maximum pressure ratio considered for turbine inlet temperatures up to 1800°R. It was demonstrated analytically that the skirt extension is capable of operating under these conditions. Any other operating point on the curves represents, for the skirt extension, a more conservative set of conditions; therefore, the immediate need for additional skirt extension design information was satisfied. Further CY 67 efforts were limited to investigation of detail design problems such as the individual thrust-augmentation nozzles at the aft end of the skirt extension tube bundle. A layout drawing was prepared for heat-transfer analysis to establish a typical distribution of wall temperatures as a basis for materials analysis.

(2) NERVA Reactor Skirt

The primary function of the NR skirt is to act as a propellant conditioner, and to duplicate the coolant bulk-temperature rise and pressure drop effects of the NE skirt. The NR skirt is required to exhaust to an atmosphere approximating sea-level conditions and must flow full to consistently reproduce the heating characteristics of the NE skirt. An expansion

ratio of 12 to 1 was selected, and a gas-side contour was designed to blend the NERVA nozzle profile into the required area ratio. Local adjustments in the contour and overall length of the skirt were made to eliminate peaks in wall pressure and heat flux, and to match the coolant bulk temperature rise to that of the nozzle.

Mechanical design characteristics of the NR skirt are required to closely duplicate the NE skirt to provide design information for the latter skirt during the reactor development test phase. For this reason, the design of the NR skirt is totally dependent on the results of the optimization processes for the NE system. As coolant tube geometry, manifolding, and flange design features are established for the NE skirt, they are being incorporated into the design of the skirt for NERVA reactor development.

5. Engine Controls (1.5)

a. XE Control Systems Design and Analysis (1.5.0)

(1) XE-1 Engine Control System

The XE-1 engine control system successfully completed acceptance testing at Aerojet-Sacramento, 19 October 1966, and was shipped to NRDS on 26 October 1966 for installation in ETS-1. The system included: The ECS Programmer/controller chassis, TPCV/valve control chassis, chamber temperature/pressure average-reject chassis, power supplies, and racks 49 and 50. The system was installed at ETS-1 and a comprehensive checkout was completed by 21 March 1967. The satisfactory performance of the ECS was confirmed by Aerojet and WANL. A SNPO-C representative was briefed at a technical meeting conducted at NTO on 22 March 1967. The SNPO-C representative confirmed the desirability of waiving formal buyoff and of proceeding with modifications for both the XE cold flow and XE-1 power test immediately. Modifications of the XE-1 engine control system were then completed and checked out. Acceptance test procedures were completed, and the equipment operation was confirmed to these procedures by NTO quality-control personnel with a SNPO-C representative in attendance.

(2) The following modifications were made:

(a) Engine Programmer Chassis

1. Improved normal shutdown mechanization
2. Improved SCRAM shutdown mechanization
3. Improved bootstrap and chilldown delay
4. Implementation of momentary operating mode switching
5. Improved pressure compensation
6. Common-time programming of pressure and temperature demand in compliance with the modified operating line.
7. Improved pressure error override

(b) TPCV and Valve Control Chassis

1 A TPCV position override and redundant subloop position control were added.

2 Position-feedback potentiometer circuitry was modified to be compatible with NT-D1 TPCV actuator.

3 Binary valve-control circuitry was improved to reduce power dissipation in the pilot solenoids, after normal power application operates the solenoids.

(c) Temperature/Pressure Average and Reject Chassis

1 Chamber temperature signal was linearized

2 Reflector inlet temperature average circuit was added

(3) Modification kits not completed included:

(a) Pressure mode inhibit
(b) Redundant chamber temperature averager
(c) Auto start to temperature

The functional and detail designs for the 32-channel automatic zero suppression and rangeable amplifier chassis were completed. Capabilities of this equipment were reviewed by NTO and WANL, and a brief summary of equipment operation and flexibility was presented for SNPO-C. The units were fabricated and shipped to the NTO ETS-1 facility after functional tests were conducted to verify the design objectives. The equipment was installed and checked out at NTO (Figures 20 and 21).

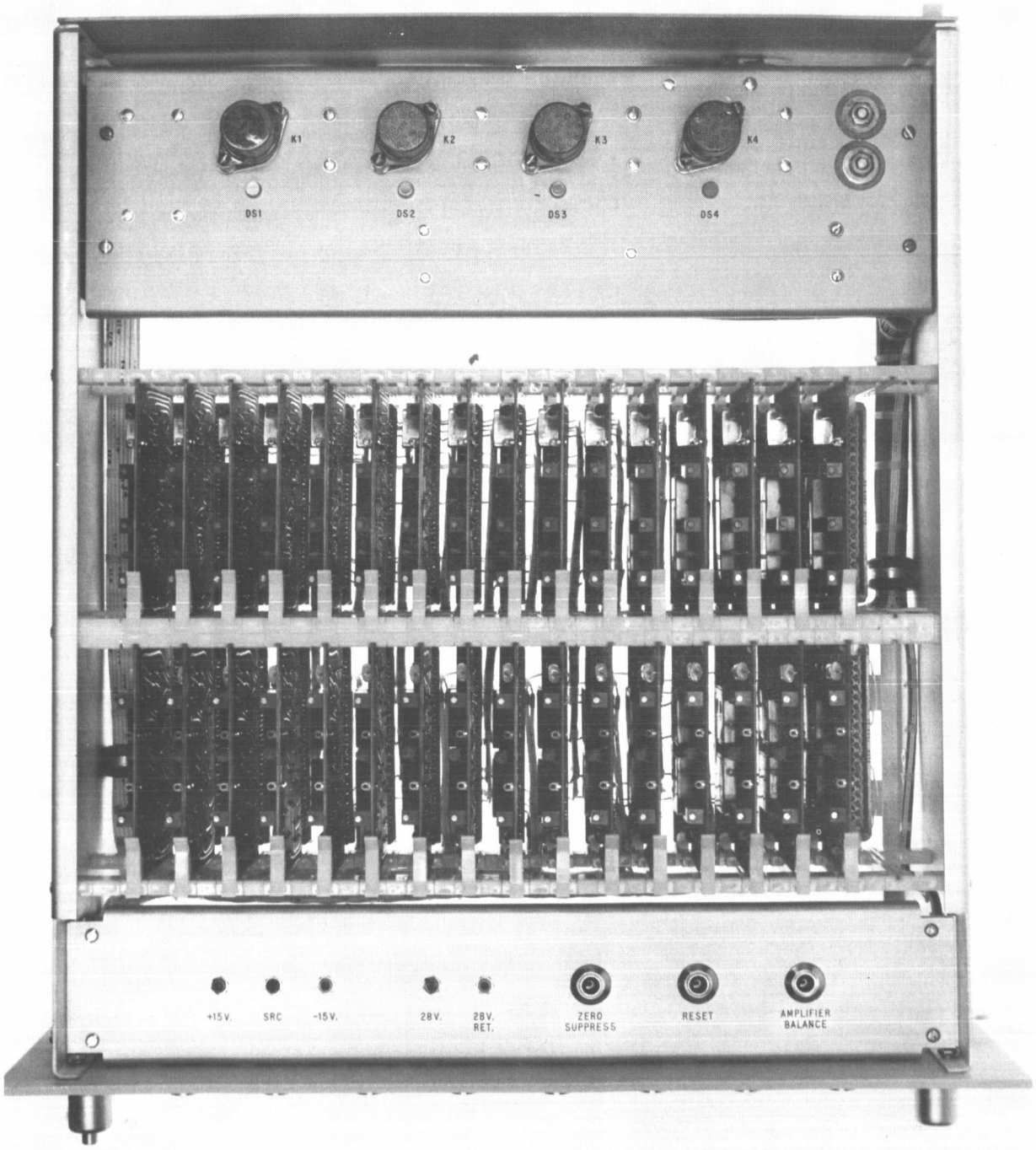


Figure 20 - Zero Suppression Chassis, Top View

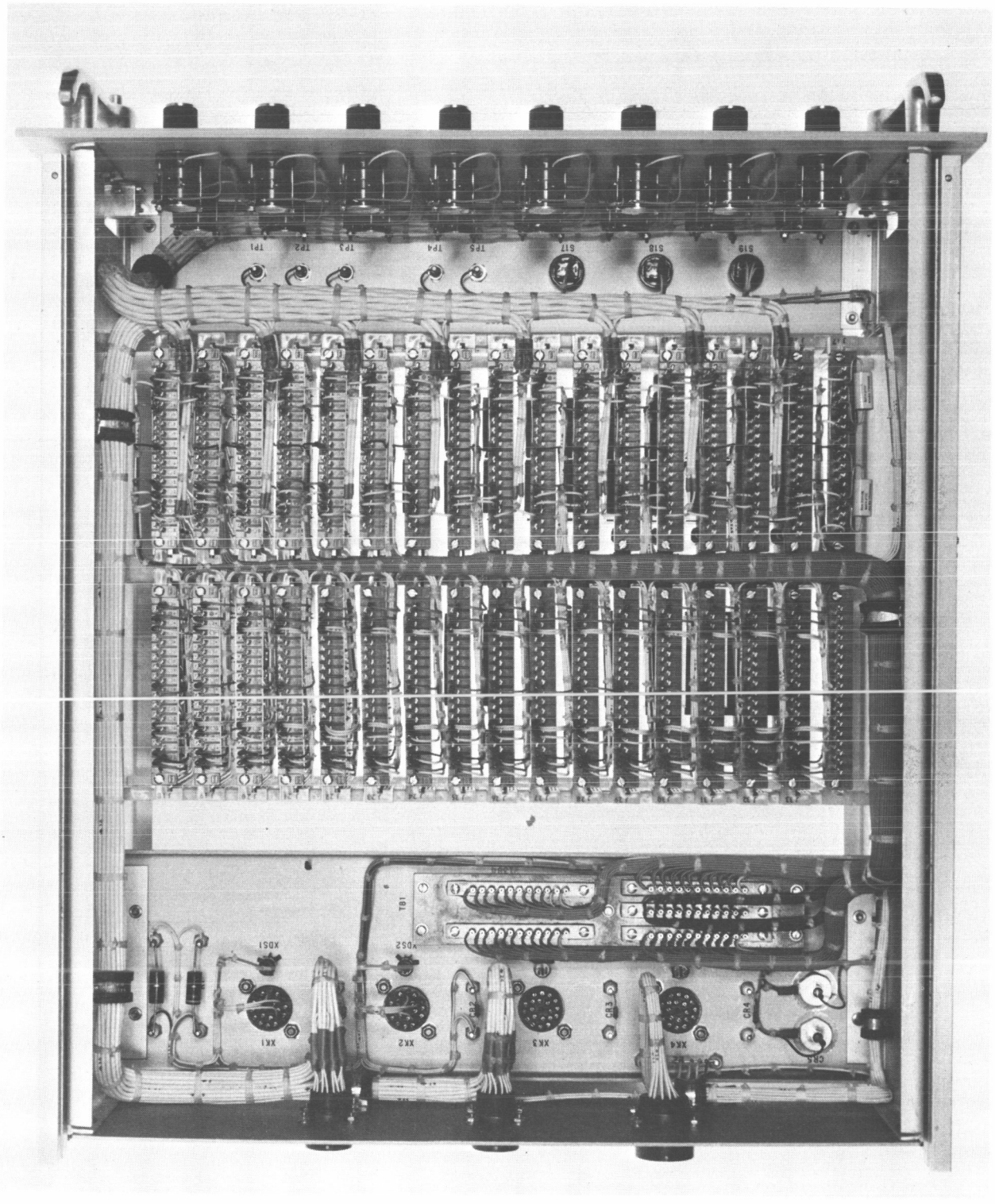


Figure 21 - Zero Suppression Chassis, Bottom View

Review of WANL functional requirements, functional designs, detail designs, and of modification instructions for changes to the XE-1 nuclear subsystem were conducted throughout this report period. These modifications included:

(a) No-flux-loop temperature controller

(b) Revised power controller

(c) Improved automatic switching logic for power mode inhibit circuits.

(d) Addition of temperature mode inhibit and logic similar to (c) above.

(e) Modified power and temperature overrides

(f) Addition of drum overrides

(g) State program temperature controller

(h) On/off temperature controller

(i) Wet and dry auto start to temperature

A 5-day operator training course summarizing ECS/TSCS operation, particularly those areas subject to modification, was presented to NTO ETS-1 operating personnel.

A comprehensive XE-engine controls review was held on 9 and 10 August 1967 for SNPO-C, LERC, MSFC, and LASL personnel. Subjects covered were: engine operating sequence, major engine controls, pressure control and engine programming, inhibits and overrides, safety system (emergency and SCRAM shutdowns), experimental controls, control test objectives and summary.

XE-1 ECS operating and maintenance instructions were completed and forwarded for publication.

The XE ECS failure-mode analysis inputs covering all subloop malfunctions were completed and forwarded for publication.

Report No. RN-S-0322, NRX/EST Engine and Control System Dynamic Testing, was published.

NDC-121, Control System X-Engine, was updated and forwarded for publication.

NDC-124, Reactor Control System, was updated and forwarded for publication.

(4) XE-1 Common Analog Model

On 2 December 1966, the common analog model for the XE-1 engine was agreed to have been correctly implemented by Aerojet and WANL. This model has since been used to design and evaluate control system, normal, SCRAM, and emergency shutdown, malfunction analysis, engine startup studies and run profiles.

A report is being prepared on the derivation of all XE-1 analog equations. WANL will provide the derivations of the equations in the nuclear subsystem, and Aerojet will provide the derivations for the facility and feedsystem equations.

(5) XE Engine Control Design

A pressure compensator was designed to provide adequate stability margins for the pressure-control loop throughout the operating regime. The transfer function expression for this compensator is given by

$$\frac{\theta_{vd}}{P_{8_e}} = \frac{0.112\left(\frac{S}{0.63}+1\right)\left(\frac{S}{5}+1\right)}{S\left(\frac{S}{3}+1\right)\left(\frac{S}{70}+1\right)}$$

Stability characteristics of this compensator at various operating points are summarized in the chart below (temperature loop closed).

Pressure, lb/sq in.	Phase Margin, degrees	Gain Margin, db	Bandwidth, cps
563	75°	18	1.0
250	55°	9	1.6
110	60°	19	0.5

The shutdown controller and pump tailoff circuits were designed and evaluated on the analog computer. An exponentially decaying step in valve position is required to prevent excessive cooling of the core and excessive heating in the nozzle. The compensation and controller gain were designed to achieve a stable control that would enable cooldown with the run tank. The transfer function of the compensation is

$$\frac{\theta_{vd}}{T_{8_e}} = 3.18 \times 10^{-3} \; \frac{\left(\frac{S}{0.63} + 1\right)\left(\frac{S}{0.16} + 1\right)}{S\left(\frac{S}{3} + 1\right)\left(\frac{S}{10} + 1\right)} \quad \frac{\text{Deg}}{^\circ\text{R}}$$

The required exponentially decaying step is described by the equation

$$e_o = (0.50\ \theta_V - 15.1)\ e^{-t/1.5} \text{ volt, } \theta_V \text{ (deg)}$$

Malfunctions resulting in controlled drum roll-in were studied. These malfunctions produce temperatures in excess of the test parameter limits because propellant flow does not decrease fast enough to compensate for the significant reduction in power. A drum roll-in detector circuit was designed to sense a failure in the temperature-control loop that would result in an uncontrolled drum roll-in and initiate a SCRAM shutdown. The detector was designed to be insensitive to any normal operating

drum roll-ins as required by a normal shutdown. The circuit was set to track the drum position at a maximum rate of 1.5 deg/sec with an error signal of 3 degrees, and to trip when the difference between the measured drum position and the detector output reached 12 degrees. The values are necessary to prevent core overcooling and excessive tie-rod temperature excursions. When the engine is shutdown at 100°/sec, the roll-in detector will initiate a SCRAM as the drums reach approximately 40°.

A pressure-error override controller was designed to reduce pressure and temperature/power demands when the unit is operating in the temperature/power control mode. The requirement for this override was based on analyses of temperature excursions beyond test parameter limits relative to malfunctions, when pressures fell below demand. The override acts to reduce temperature log nuclear-power demand and chamber-pressure demand if measured chamber pressure is less than demand. The power and pressure demands continue to decrease until the system is capable of attaining a measured pressure within 60 psia of demand, at which time the override cuts out and the system is returned to normal control with power and pressure demands set at the existing measured values.

A TPCV position-override circuit was designed to prevent rapid outward excursions of the valve caused by malfunctions in either pressure or valve position controllers. The circuit consists of three parts: a rate limited tracking circuit, a level detector and an alternate valve position controller. Input to the tracking circuit is measured valve position. Output of the tracking circuit is compared against measured valve position by the level detector. A rapid increase in measured valve position causes the level detector to switch valve control to the alternate position controller. Position demand input to the alternate controller is the tracker output at the instant of switching. The tracking circuit is limited to rates less than 1.5 deg/sec; the level detector will cause a trip when an error of 10 deg is sensed.

To detect a loss of flow in the engine, a detector was designed that responds to an extraordinarily large change in pump discharge pressure. Pump discharge pressure is followed by a pressure tracker, which cannot follow pressure changes greater than 110 psia/sec. This rate is more than the expected rate of change of pressure in normal operation. When the tracked pressure exceeds the measured pressure by the quantity (48 + 0.15 x pump discharge pressure) psi, the detector will signal an emergency shutdown.

(6) XE Dynamic Analysis

A linear dynamic model of the X-engine has been constructed for the full-power operating point. Frequency response of the model (obtained by the TAF program) is similar to that of the corresponding nonlinear TAF model. Agreement is within 1.0 to 2.0 db of gain and 5.0 degrees of phase.

A digital computer program was modified to determine the poles and zeros of selected transfer functions of a dynamic system. This program was used to obtain the characteristic denominator for the system and to obtain the individual gains and numerator polynomials for the P_8/θ_V, T_8/θ_V, P_8/θ_d and T_8/θ_d transfer functions. The resulting high-order polynomials (40th to 43rd order) were simplified to obtain more manageable expressions. Frequency plots obtained from these transfer functions showed excellent agreement with the frequency-response plots obtained by the TAF program.

A sensitivity analysis of the XE dynamic model has been started. The objective of the analysis is to provide a tool to resolve potential differences between test and analytically derived transfer functions. To determine how a change in a system parameter affects the overall transfer function, the engine was subdivided into six major sections. Transfer matrices for the five sections have been obtained. These transfer matrices will enable evaluation of the effect of parametric changes by inspection.

A method for straightforward design of control-loop compensation has been developed. The procedure is based on application of the minimum Integral-Time-Absolute-Error (ITAE) measure. A pressure-loop compensator designed by this method is currently being compared to the present XE pressure compensator based on the respective transient responses to step and ramp-forcing function inputs.

(7) XE-1 Malfunctions

A series of runs were made on the analog computer model of XE to investigate automatic countermeasures to malfunctions.

The model used in the studies is the XE CAM model and the ETS-1 facilities model. The safety circuits that were modeled consisted of the loss-of-flow detector, the drum roll-in detector, the drum roll-out detector, the pressure error override, the programmed power SCRAM, the T-26 override, and the overspeed trip. In addition the floating power SCRAM was available but was not used. The controllers that were available were the normal temperature, pressure, and power control, the state program temperature control, the T-26 override control, the SCRAM shutdown TPCV control and demand generator, the flow shutdown PCV472 control and demand generators, and the chamber conditions demand generator and tracking circuits.

The runs made are shown in tabular form in Table 5. All of the steady-state runs were completed.

The emergency system studied consisted of PCV472 when an emergency is signalled. V-5002 pressure was held at 500 psia when chamber pressure was less than 250 psia and otherwise at 1250 psia.

Preliminary evaluation of the data indicates that problems exist in those cases where the PCV472 opens inadvertently, the TPCV

TABLE 5

ANALOG COMPUTER MODEL RUNS TO CHECK AUTOMATIC COUNTERMEASURES TO MALFUNCTIONS

STEADY-STATE	Manual Emergency Shutdown	Manual Scram Shutdown	TPCV Closure (Max Rate)	TPCV Opening (Max Rate)	Drum Roll-in (100°/sec)	Drum Roll-in (45°/sec) Loss of Temp Override Set Point	Drum Roll-in (25°/sec)	Drum Roll-in (1.5°/sec)	Drum Roll-out (100°/sec) w/wo Drum Override	Drum Roll-out (25°/sec)	Drum Roll-out (3°/sec)	Drum Roll-out (1.5°/sec)	Temp Demand Zero (500)/ Thermocouple Feedback Max	Temp Demand Max (4200)/ Thermocouple Zero	Pressure Demand Zero/ Transducer Feedback Max	Pressure Demand Max/ Transducer Zero	Temp Loop Fails to Close During Startup	Pump Explosion	PDVV Fails Open (Max Rate)	PDSV Closure (Max Rate)	FSV Closure (Max Rate)	PCV-579 Fails Open (Max Rate)	Temp Ramps Up at 50°/sec	Pressure Ramps Down at 5 psia/sec	TBV Max Rate Closure	PCV-472 Max Rate Open	PCV-471/PCV-251 Max Rate Open	Scram Shutdown, Emergency Disconnected, Open TPCV
T_c = 4090°R P_c + T_{sp} Control P_c + T_c Control	X	X	X		X			X		X	X	X		X/X	X	X		X	X	X	X	X	X	X	X	X	X	
P_c = 563 psia TPCV + Drum Control				X					X	X	X																	
T_c = 4090°R P_c + T_{sp} Control	X	X	X		X	X	X											X	X					X		X	X	
P_c = 250 psia TPCV + Drum Control			X	X					X	X	X			X					X	X								
T_c = 3500°R TPCV + T_{sp} Control									X	X	X	X						X										
P_c = 573 psia P_c + T_{sp} Control	X	X																			X	X						
T_c = 3000°R P_c + T_{sp} Control	X	X																X						X		X	X	
P_c = 490 psia T_c = 2200°R P_c + T_{sp} Control	X	X											X					X	X					X		X	X	
P_c = 300 psia TPCV + Drum Control T_c = 2200°R P_c + T_{sp} Control		X						X				X		X/X					X	X								
P_c = 170 psia TPCV + Drum Control P_c + T_c Control											X								X	X						X	X	
T_c = 2200°R P_c + T_{sp} Control	X	X	X		X	X	X											X	X					X		X	X	
P_c = 90 psia TPCV + Drum Control			X	X							X																	
T_c = 1000°R P_c + T_{sp} Control P_c = 60 psia	X	X									X							X						X		X	X	
T_c = 3500°R P_c + T_{sp} Control P_c = 170 psia	X	X	X						X	X	X							X					X	X		X	X	
T_c = 1600°R P_c + T_{sp} Control P_c = 60 psia																												X

opens uncontrollably, or the drums roll out at 1 1/2 or 3 degrees/sec. The extent of these problems and possible resolutions are being investigated.

(8) XE-1 Run Profiles

The analog run profiles were made in accordance with the XE-1 Test Specification, dated May 1967 (RN-S-0352).

The analog model was set up to describe the XE-1 engine and the ETS-1 facility flow. The controls were as described in the section devoted to XE-1 Malfunctions.

A series of experimental runs were made on the analog using the recommended (test specification) 2-sec period. The resulting power overshoot and subsequent cutback produced inputs to the controller that were sufficiently severe to activate several of the safety circuits at points during the transient. A revised startup procedure was developed from this study and used for the run profiles. The recommended normal startup utilizes a 2 megawatt hold and starts the power ramp on a 4-sec period when the reflector inlet temperature reaches 100°R. The temperature loop is closed when chamber temperature reaches 1100°R, and the temperature and pressure demands start ramping when chamber temperature and pressure equal or exceed 1100°R and 60 psia.

The runs were made based on the information in the XE-1 Test Specification. This information has since been corrected (relative to discrepancies shown by the analog runs), and the profiles will be rerun.

(9) Temperature Autostart (Wet)

Analog analysis has been completed for temperature autostart (wet) tests to be performed on XE-1. The results of this analysis are subject to confirmation using digital models but are considered satisfactory for design purposes.

The temperature autostart (wet) for XE-1 consists of a system that starts a predetermined control drum profile (exponential to a preset level) and at the same time starts flow through the turbopump and engine from Dewar pressure. As power increases, the nozzle coolant tube exit temperature (TNE) is monitored as a measure of the degree of chilldown of the turbopump and nozzle (the chilldown is necessary to ensure suitable conditions for bootstrap). When the TNE reaches 300°R, a ramp of 0.1 degree/sec is added to the exponential drum demand. When the measured chamber temperature rises 300°R above the minimum temperature reached during the rise to power and chilldown, the temperature loop is closed, and temperature demand is ramped to 1100°R. When the measured TNE reaches 100°R any time after the temperature loop is closed, the pressure loop is closed, starting the bootstrap. If the measured TNE reaches 100°R before temperature loop closure, the pressure loop is closed when the temperature loop closes. When chamber temperature demand reaches 1100°R and measured chamber pressure equals demand, the normal program control of chamber temperature and pressure are initiated.

The following comments are pertinent to the preceding system:

(a) The temperature control used for the autostart is the state programmed temperature controller.

(b) Short-term restart (less than 1 day) with a non-ambient engine was not included as a requirement for the analysis since XE-1 is the first test of this experimental controller and no restart tests are planned.

(c) The preceding description of operation was for a nominal case (with the exception of the mention of conditions for start of bootstrap). Knowledge of critical position, chilldown time, reactivity coefficients, thermal time constants, initial power, etc., are variables that affect startup. Analysis showed that the programming provided tended to adapt the system to the variables mentioned.

(d) System variations analyzed were:

1 ±5 degree tolerance on knowledge of critical position

2 Chilldown (to 100°R TNE) time variations from 20 to 40 sec

3 Feedback reactivity coefficients varied ± 50%

4 Initial power varied by a factor of 100.

Combinations of the above variations were also studied.

Analysis showed satisfactory results with the autostart system even though the variations studied were well in excess of any variations that are expected during XE-1 testing.

(10) Emergency Cooldown System

(a) Summary

The initial phase of an emergency cooldown involves the replacement of LH_2 flow from the pump by that from high pressure Dewar V-5002. The flow is from the Dewar, through control valve PCV472 and into the junction with the pump discharge line, and finally into the nozzle torus and coolant tubes.

The critical load on the emergency cooldown system is imposed by a pump explosion with rapid loss of pump discharge pressure and flow rate.

The requirements to be met by the emergency cooldown system are: (1) to prevent tube burnout, the ratio of flow through the tubes to flow through the nozzle must exceed a constant that depends on the engine operating point. (This constant is 0.44 when shutdown is from design point.) (2) The chamber temperature must not decay by more than 900°F in a 3-sec period; and (3) the tie rod temperature must not exceed its limit. The first of these constraints is the most difficult since it requires a high cooldown flow to be established in a fraction of a second after the malfunction. The other two constraints are significant later in the cooldown and are met by proper sequencing and closed-loop control of PCV 472.

The work performed during the past year consisted of: (1) analysis of measured dynamic response of the LH_2 line with fixed impedance to represent the engine; (2) verification of the lumped-parameter modeling technique by correlation with test data; (3) development of the model of the complete LH_2 supply and cooldown line; (4) parametric performance studies of various system configurations; and (5) determination of PCV472 sequencing and compensation.

(b) Analyses of Test Data and Correlation with Lumped-Parameter Model

The dynamic response of the LH_2 cooldown line was measured during FEP-III. The LH_2 line from the facility test area to the engine and the engine itself were replaced by a simulator line and analog valve PCV750. The Dewar was maintained at 500 psi, and system forcing was provided by sine and square wave inputs to PCV472. Data analysis and reporting for the Facility Data Evaluation team was provided by Controls Analysis personnel.

An analog computer model of the FEP-III LH_2 line configuration was developed using the lumped-parameter method, in which the line properties were concentrated at specific points. In general, the data obtained were in good agreement with measured dynamic response data, within the limitation that the test flow rates were so low that they could not be accurately measured.

Dynamic response of the PCV472 actuator was not determined from FEP-III data because of an apparent error in the data system. A subsequent dry run was analyzed to provide a third-order transfer function, velocity limits, and time lag between demand and beginning of motion.

(c) Engine Cooldown Line Model Development

The model of the FEP-III configuration was modified and extended to represent the complete LH_2 cooldown line up to its junction with the pump discharge line, together with the pump discharge line.

The representation of the LH_2 compressibility factor was extended from a constant to a linear variation with pressure approximating an isentropic process.

In any of the following cooldown schemes that are discussed, a valve isolates the Dewar from the cooldown-pump discharge function. The downstream portion of the line is pressurized and chilled by a reverse flow from the junction, which is vented near the isolating valve. Bypasses are installed to carry the reverse flow around intermediate check valves. The cooldown line dynamics are substantially different during backflow because of the characteristics of the check-valve bypasses. The backflow model was used to determine engine transfer functions under normal operation and transient operation during startup. A study of the time lag involved in

pressurizing the cooldown line during startup as the pump discharge pressure builds up, revealed that the vent should be closed during a fast startup to prevent excessive pressure drops across the bypass.

(d) GH_2 Cooldown Model

Except for a limited study of small accumulators incorporated on the LH_2 line, cooldown performance has only been studied relative to liquid cooldown systems.

Investigation of a GH_2 cooldown scheme has progressed to the point of developing an analog model. The computer model has the following system components: high-pressure GH_2 bottles, GH_2 supply line, control valve PCV251, GH_2 line downstream of PCV251 to CHV1721, the LH_2 emergency downline to the torus, and a downstream vent, RSV457.

The GH_2 model has not as yet been incorporated with the XE analog model.

(e) Initial Flow Ratio Minimums

All of the cooldown schemes investigated show a rapid drop in flow ratio to a minimum in the first millisec after the malfunction. This is due to the requirement that the fluid at rest in the cooldown line must be accelerated before a flow of the required magnitude can be re-established in the nozzle tubes.

After investigation of a number of models the arrangement that has the more nearly equal lump sizes was selected as the one that best approximates the inertial effect.

The value of the initial flow ratio minimum apparently depends only on the severity of the malfunction, i.e., the rapidity of the pump discharge pressure decay. Emergency cooldown performance has been computed for a range of decay-time constants with initial flow-ratio minimums above 0.44 corresponding to values greater than 20 millisec.

Runs made with instantaneous loss of pump-discharge pressure were used as inputs to a transient heat-transfer analysis and indicated that transient flow ratios below 0.44 did not result in a nozzle wall temperature as high as that with a steady-state flow ratio of 0.44.

(f) Cooldown System Evaluation

Subsequent flow-ratio behavior was investigated for a number of variations of the two basic cooldown schemes:

1 PCV472 initially closed; high Dewar pressure
2 PCV472 initially open; low Dewar pressure

In the former, PCV472 is opened as quickly as possible after sensing the malfunction; in the latter, the opening of a check valve is automatic once downstream pressure has decayed below Dewar pressure. Performance was determined as a function of the following schedule of cooldown-system parameters.

Parameter	System Influenced	
	PSV472 Closed	PCV472 Open
Dewar Pressure	X	X
Downstream Temperature	X	X
Loss of Flow Detector	X	
Sensing Time Lag	X	
Check (Isolation) Valve Location		X

(g) PCV472 Control System

A parametric study was made, using the analog model to determine the open-loop sequencing and the closed-loop compensation required to satisfy overcooling and tie-rod-temperature constraints.

A step demand of 30% open on valve position was followed 200 millisec later by a step demand to 10% open and was initiated by the loss of flow detector.

The closed-loop temperature-control system was enabled after an additional 60 millisec delay (to minimize switching transients), and the chamber temperature was exponentially reduced to 1000°R. The closed-loop compensation network was designed to ensure system stability, transient response, and zero steady-state error.

(11) GHe Purge System

An analog model of the gaseous helium line from the gas supply bottles to PCV449 and the line downstream to the engine compartment was developed to investigate the possibility of establishing a demanded helium flow into the engine compartment within 300 millisec after an SGS malfunction to prevent air intrusion in the duct.

The analysis showed that a demanded flow of 30 lb/sec can be established in approximately 155 millisec after a position command to PCV449, allowing 145 millisec for detection of the SGS malfunction and command signal to the valve.

(12) NRX-A6 Analog Model

A comparison of WANL analog steady-states and frequency responses with Aerojet RAF runs for the facility and reactor showed close agreement. Agreement on the NRX-A6 CAM has been reached.

b. Sub-Subtask 1.5.1 - NERVA Engine Control System Design and Analysis

(1) Control Studies

Control dynamic studies for the engine power range of operation were continued. Two methods of reactivity control using the support structure valve and drums were investigated. The first method used chamber temperature error to control the support structure valve and a support structure temperature error to control the drums. The second method used the chamber temperature error to control the support structure valve, and when the support structure valve position was above or below some preset limit, a fixed drum rate was injected into an open-loop drum demand. The third system used the support structure valve and a pump discharge flow-diverter valve to increase the support structure valve's range of control; this method did not use any drum control. All three methods provided satisfactory dynamic response.

Nonlinear gain compensation in chamber temperature error to support structure valve position demand reduces the velocity error coefficient to a negligible amount for a step change in thrust between 100% and 60%.

An analog computer model for the two-spool NERVA TPA inducer-pump system was programmed. The model consisted of a detailed inducer-pump TPA model and a simplified engine model to study dynamic stability of the two-spool TPA. Studies consisted of operating the system model from 20% to 120% power; 20% power was the lower limit of the engine, and 120% was TPCV full-open at design temperature. Further studies consisted of ramping the chamber pressure from design point to 100 psia. Based on these preliminary studies good dynamic stability was obtained.

Equations for the engine feed system and the two-spool TPA were prepared for the complete engine model to investigate bootstrap and engine control system.

Also, a new set of heat-transfer equations have been written for the split-flow-path nozzle. The first set followed the XE method of one nozzle average wall temperature per flow path used for the hot- and cold-side heat transfer, with nozzle-wall heat storage per flow path lumped in the one wall temperature equation. The new set of equations has three wall temperatures in the radial direction per flow path representing the hot-side, cold-side, and an average wall temperature. The nozzle-wall heat storage is divided into three equal sections.

The EST data indicates that the engine has a slower chamber-pressure response than the engine model. These changes are intended to improve the nozzle pressure response and in turn make the chamber-pressure response more realistic.

Studies were made with the NERVA engine TAF digital program to determine the proper turbine power margin, which is directly related to the available TPCV pressure drop at engine design operating conditions. As the available TPCV pressure drop at design conditions is increased, the ability of the engine to operate successfully in a power-saturated condition is diminished. The engine power-saturated condition is defined as equivalent to a wide open TPCV with the engine design chamber temperature held constant. Engine operation with a low power margin at design (small TPCV pressure drop) penalizes its ability to bootstrap during the starting transient. A study is required of compromises between these extremes. Preliminary TAF runs indicate that if the design power margin necessary to bootstrap is significantly higher than 10%, a programmed orifice in series with the TPCV may be necessary to protect against excessive TPA speed and turbine temperature if the TPCV moves to a wide-open position. The turbine inlet temperature is adjusted to achieve design-point conditions by sizing the diluent bleed line, thereby providing the proper mixture of hydrogen from the hot bleed and diluent bleed lines. A continuing study is being made of the effects of turbine power margin on turbine inlet temperature at off-design conditions and on engine system controls.

(2) Evaluation of Integrated Circuits for Application in the NERVA Engine Flight-Engine Control System

Controls personnel attended several technical presentations by manufacturers of integrated circuit modules. These sessions indicated that the integrated circuit industry is mainly oriented toward solution of digital problems, although the possibility of hybrid incorporation of integrated microcircuits with discrete components appears feasible. The evaluation is continuing.

The Microcircuit Division, Von Karman Center, was consulted to determine the division's potential for development of components suitable for the flight-engine control system. Microcircuit techniques can readily provide all functions currently in use for active controls, signal conditioning, power distribution and regulation, and the operator-electronics interface. The use of microcircuit techniques enables direct initiation of the detail design based on the discrete component schematic. In addition, the volume and weight reduction that is possible by the use of microcircuits is expected to exceed 1000 to 1 relative to discrete component circuits. Extensive use of microcircuits for the flight-engine control system appears to be feasible and desirable.

c. XE Control Actuators (1.5.2)

(1) Actuators - Model C

Turbine power control valve actuator, Model NT-C2, S/N 13 was successfully source accepted at Bendix Corp. Research Laboratory, Southfield, Mighigan, 8 December 1966, and shipped to Aerojet-Sacramento.

Refurbishment of TPCV actuator, S/N 11, by Bendix Corp. continued until TPCV actuator, Model NT-D1, S/N 18, which was used in the NRX/EST Program, was sufficiently decontaminated so that it could be returned to the NRO Controls Laboratory. The residual level of radioactivity

was between 40 and 50 mr/hr on the surface. External surface swipes read 3500 dpm per 100 cm^2 of surface area. Determination of the level of internal contamination was based on the level of activity of the contaminants in the exhaust gas. Four filters were placed in parallel in the exhaust line, and readings from the elements in these filters ranged from nondetectable to 129 dpm. The preceding tests completed the post NRX/EST evaluation of TPCV actuator, Model NT-D1, S/N 18. Actuator performance in these tests met specifications and verified the assignment of this unit to back up the life-endurance portion of the qualification test program in place of S/N 15. It was decided to use TPCV actuator S/N 15 for the XECF test in place of the Model NT-C2, S/N 13, actuator. This decision was made after review of the costs and schedules relative to the refurbishment of TPCV actuator Model NT-C2, S/N 11 and 13, since it was determined during additional Aerojet performance evaluation testing of S/N 13 actuator that the transmission had design deficiencies associated with gears and bearings and the method of supporting them, and that the availability of S/N 18, as backup in the Qualification Test Program, was questionable. The refurbishment program for S/N 11 and 13 was cancelled, and the actuators were used for development work only. The following is the actuator usage schedule:

Model	S/N	End Use	Availability
NT-D1	15	XECF	Provided to Components Department for Mating to Valve
NT-D1	16	XE-1	Provided to Components Department for Mating to Valve
NT-D1	17	Qualification Test Program	On Hand
NT-D1	18	Qualification Test Program Backup	On Hand

(2) Actuators - Model NT-D1

(a) Qualification Test Program

The design and fabrication of the TPCV Model NT-D1 actuator life-test fixture for the actuator life tests was completed and

testing started in the NRO Actuator Laboratory. (Figures 22 and 23) The tests consisted of vibration, proof, humidity, shock and endurance tests on the actuator alone; high-temperature hydrogen flow testing of the complete actuator, valve assembly; and finally the actuator-valve assembly utilization for turbine power control during an actual hot-firing test of the complete reactor/engine system. The preceding tests qualified the NT-D1 actuator for use in the Technology Engine Program.

In addition to qualifying the actuator, information obtained during the program resulted in recommendations to (1) improve the follow-on hardware, (2) provide additional testing, and (3) update actuator performance criteria.

Hardware improvements included (1) the possible addition of a mechanical feedback between first and second stages of the servovalve for improvement of performance under vibration conditions; (2) the possible increase in actuator output torque by means of additional gearing; (3) the improvement of current transmission gear-tooth geometry; (4) improvement of servovalve discharge line bellows installation; and (5) the possible reduction of ullage between the actuator servovalve and gear motor, resulting in a stiffer system.

The recommended additional effort generally will consist of breadboard tests of the indicated improved hardware.

Updating of the performance criteria will consist mainly of (1) basing the actuator performance criteria on loaded dynamic conditions, and (2) specifying the actuator performance requirements in terms of open-loop characteristics.

The following reports that were completed during this contract year support in detail the qualification of the Bendix Model NT-D1 TPCV actuator for use in the Technology Engine Program:

1 RN-DR-0082 - Post NRX/EST Turbine Power Control Valve Actuator (S/N 18) Evaluation

2 RN-DR-0127 - Proof-Pressure Test

3 RN-DR-0128 - Vibration Test

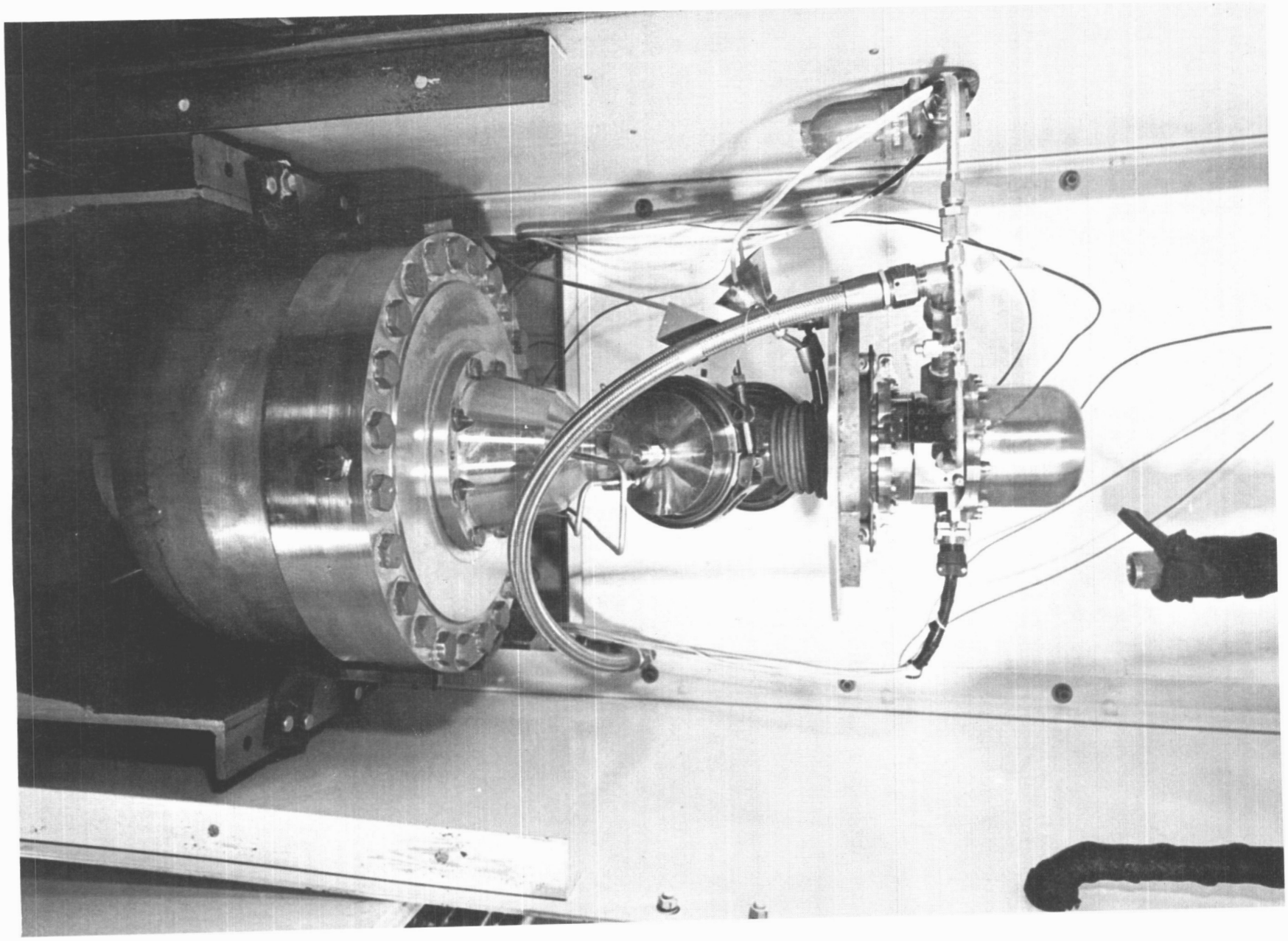


Figure 22 - TPCV Actuator Life Test Fixture

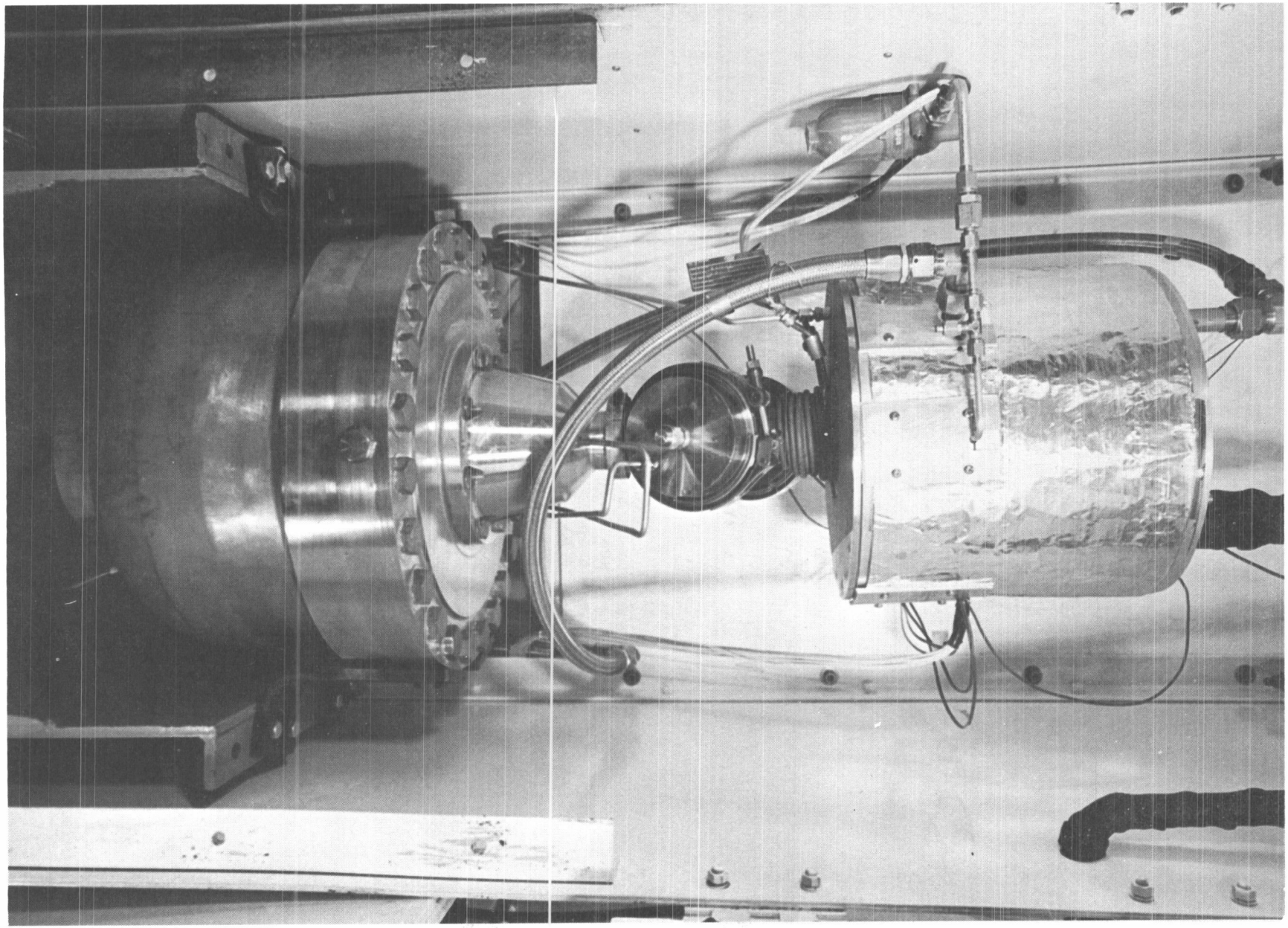


Figure 23 - TPCV Actuator Life Test Fixture with Pressure Chamber

4 RN-DR-0129 - Shock Test

5 RN-DR-0130 - Humidity Test

6 RN-DR-0131 - Endurance Test

7 RN-S-0430 - Summary Report

8 RN-S-0425 - Qualification Test Plan

9 Report No. RN-DR-0084, Electro-Pneumatic Servo-Actuator Evaluation Procedure, has been published. This report was written to facilitate engineering evaluations of the TPCV actuators, Models NT-D1 and NT-D2.

10 Report No. RN-S-0348, Operating and Maintenance Instructions, TPCV Actuation Subsystem, Models NT-D1 and NT-D2, has been published and distributed.

(b) Common Analog Model Runs

A series of XE-engine simulated (CAM) runs was made with an actual TPCV actuator inserted in the analog system. These runs were made to determine the engine pressure loop performance with the non-linearities of the loaded actuator in the loop. Pressure loop response $(P_8/P_{8D})^*$ with fixed drums was measured for:

1 CAM XE-1 with standard analog simulated actuator.

2 CAM XE-1 with S/N 17 actuator unloaded.

3 CAM XE-1 with S/N 17 actuator at 70% of estimated torque load (100 in. lb friction and 180 in. lb spring torque).

a For P_{8D} of ± 5 psi.

b For P_{8D} of ± 10 psi.

*P_8 - Chamber Pressure
P_{8D} - Demanded Chamber Pressure

The simulated actuator and the unloaded real actuator were in excellent agreement, but the loaded actuator was not accurately represented by the simulated actuator. The 3-db roll-off frequencies (bandwidth) were:

1. 0.7 cps for simulated actuator.
2. 0.7 cps for unloaded actuator.
3. 0.2 cps for 70% loaded actuator and P_{8D} of $\pm$10 psi.
4. 0.1 cps for 70% loaded actuator and P_{8D} of $\pm$5 psi.

These analog runs were repeated, providing the same results as already indicated, except that bandwidth was measured at 0.3 cps compared with 0.2 cps in the first test. Additional tests at three power levels, at different P_{8D} levels, with and without the temperature loop closed (fixed drum) and at 100% actuator load were run. The pressure loop indicates adequate stability under all tests conducted.

(3) Actuators - Model NT-D2

Negotiation of Subcontract NP-000141 was completed with Bendix Research Laboratory Division for five Model NT-D2 TPCV actuators, a seal development program, and required spare parts. Bendix Research Laboratory obtained long-lead items required for the actuators. This authorization to proceed with the long-lead procurement was granted immediately prior to the end of the previous contract year.

Aerojet has reviewed the Bendix drawings and has suggested some revisions. One suggested change was the redesign of the NT-D2 model output shaft dynamic seal to make it interchangeable with the current NT-D1 actuator seal. Aerojet reviewed and approved the seal and potentiometer

specifications, thereby enabling Bendix to procure critical long-lead-time items. Aerojet surveillance of Bendix designs and drawings was continuous throughout the contract year.

Procurement of the Model NT-D2 actuators progressed although some problems have been encountered. Two vendors (Gits Brothers and Koppers) delivered seals that failed to meet performance requirements. The Koppers' seals failed at the start of life cycling when the bellows assembly developed fractures. Koppers is working to correct the deficiency in their design. The Gits' seals did not fail structurally; running torque loads in excess of the specification requirements occurred. Although these torque values are in excess of the present Bendix specification requirement, they are the same as that of the Gits' seals that were used successfully on the Bendix Model NT-D1 TPCV actuator during NRX/EST Program.

During the last week of the contract year, potential problems were detected in the gear, bearing, and bearing-support design of the transmission for the NT-D2 actuator, and these problems are being investigated.

d. Electronics Development (1.5.3)

New circuits were developed and components associated with the circuits for use in the XE-1 engine control system modification program were evaluated. The modifications and associated circuits are discussed in Sections 1.5.0 and 1.5.1. The following circuits were developed.

(1) Development of Rate-Limited Tracker Concept for Override Application

(a) XE-1 Drum Override

The concept of monitoring a given parameter in the system by comparing the delayed output of a rate-limited tracker with the

input parameter resulted in the development of the drum override circuitry for the XE-1 nuclear subsystem. This application provides a redundant position-control loop, which is automatically selected if the drum velocity/displacement combination exceeds normal system limits. The tracked parameter in this application is the ganged-drum-demand analog signal.

(b) XE-1 TPCV Override

The concept developed for the XE-1 drum override was similarly applied to the monitoring of the TPCV measured position analog signal to enable selection of a completely redundant TPCV position controller. The TPCV and pressure control subloops were made immune from system-damaging electronic failure by the addition of this override.

(2) Improvement of Fail-Safe Zener Clamping Circuitry for Differential Input Operational Amplifiers

It was determined during system breadboard testing, that the Nexus operational amplifiers used for control application in the XE-1 ECS would not limit current at equal magnitudes for current-saturated positive and negative outputs. Since conventional design practices require zener diode-limiting in shunt with the amplifier output, a circuit modification was developed to provide equal voltage limited outputs for both polarities by augmenting the amplifier output impedance at the connection point of the shunt Zener diode. This modification was incorporated into the XE-1 demand generation subsystem.

e. NERVA Engine Control Actuators (1.5.5)

A search for vendors of applicable electropneumatic servoactuators was completed. Only two companies have adequate experience: the Bendix Corp. and the General Electric Co. The Cadillac Gage Co., Conductron Corp., and Curtiss-Wright Corp. reported experience with

electromechanical devices of relative short duty cycle. Companies contacted were:

Aeronutronic Division of Philco-Ford Corp.
AiResearch Manufacturing Corp.
Allison Division of General Motors Corp.
Bendix Corp.
Cadillac Gage Co.
Conductron Corp.
General Electric Co.
Harmonic Drive Division, United Shoe Machinery Corp.
Kearfott Division, General Precision Inc.
Walter Kidde & Co.
Moog, Inc.
National Water Lift Division, Pneumodynamics Corp.
Stratos Division, Fairchild Engine & Airplace Corp.
Vickers, Inc.
Weston Hydraulics Ltd.

During the search, The Bendix Corp. revealed its recent development of the Dynavector servoactuator, which could be readily adapted to the NERVA program. This actuator is similar to the U.S. Shoe Machinery Corp. Harmonic Drive but does not have the flexible member. Instead of a flexible member it has captured vanes between the stationary gear and the orbiting ring gear. The Dynavector actuator has a simpler design than the TPCV actuator currently in use. It has a shaft assembly in rotation requiring only two bearings, while the present unit has an air motor, a gear train, and requires eight bearings.

Although Bendix has fabricated and tested Dynavector actuators for various applications, such as hydraulic units for aircraft rudder linkages, pneumatic units for flight-stabilization systems and electric units

for tank gun elevation, additional development will be required to meet the NERVA environmental and interface requirements. Bendix has further indicated that Dynavector actuators could be developed to meet NERVA requirements within 12 months.

The present actuator requirements relative to characteristics and quantity are as follows:

	Quantity	Operating Torque, in.-lb	Angular Velocity, degrees/sec
SPV Actuator (two valves per actuator)	23	500	75
TPCV Actuator	31	600	360
TVS Actuator	39	400	920

This information indicates that on an output torque basis, the requirements are basically similar for the three units and that a single development program should be justified.

Formal quotations for the delivery of six servoactuators (three each) for TPCV and SPV that will be required by August and September of 1968, have been requested from Bendix and General Electric. These quotations are due by the end of September and the hardware procurement can start during the early part of October 1967.

The preliminary NERVA thrust vector system development plan was completed as reported in RN-S-0412, which has been submitted to AEC-NASA Space Nuclear Propulsion Office, and is covered under Subtask 1.4.3.

(f) Rack 37 Patch

(g) Additional Isolation Amplifier Cards for Rack 40R069

(h) Modification of Test Simulation Panel

(i) CTE Console Modification (Figures 25 and 26)

(j) ATE Console Modification (Figures 27 and 28)

(k) Engine Safety System Improvements (Figure 29)

(l) Cooldown Control (Figure 30)

(m) Pump Discharge Pressure Average and Reject

(n) TSS Modifications

(o) TSE Modification (Figures 30 and 31)

(p) ASE Modification (Figures 32 and 33)

(2) Modification Kits Awaiting Long-Lead Procurement:

(a) Rack 48 Door Modification

(3) Modification Kits Not Completed:

(a) Add Manifold Pressure Average and Reject

(b) Purge and Actuation Gas Panel

A design review meeting was conducted with NTO, NRO, and SNPO-C personnel to review all TSCS/ECS modifications.

Updating of inputs was accomplished in preparing the TSCS/TSS operating and maintenance instructions for publication.

The TSCS failure mode analysis covering all equipment malfunctions was completed and submitted for publication.

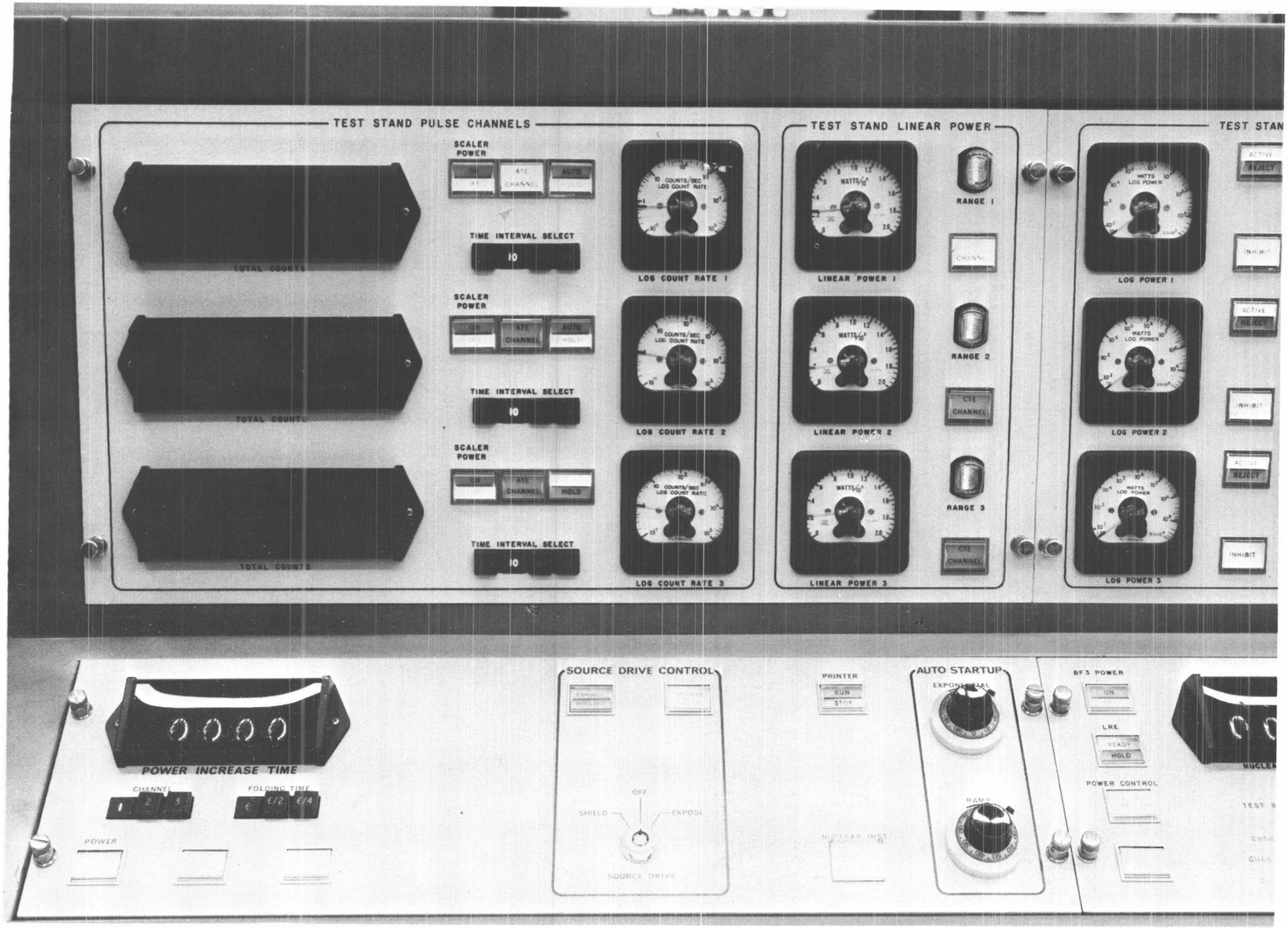


Figure 24 - Source Drive Control Panel

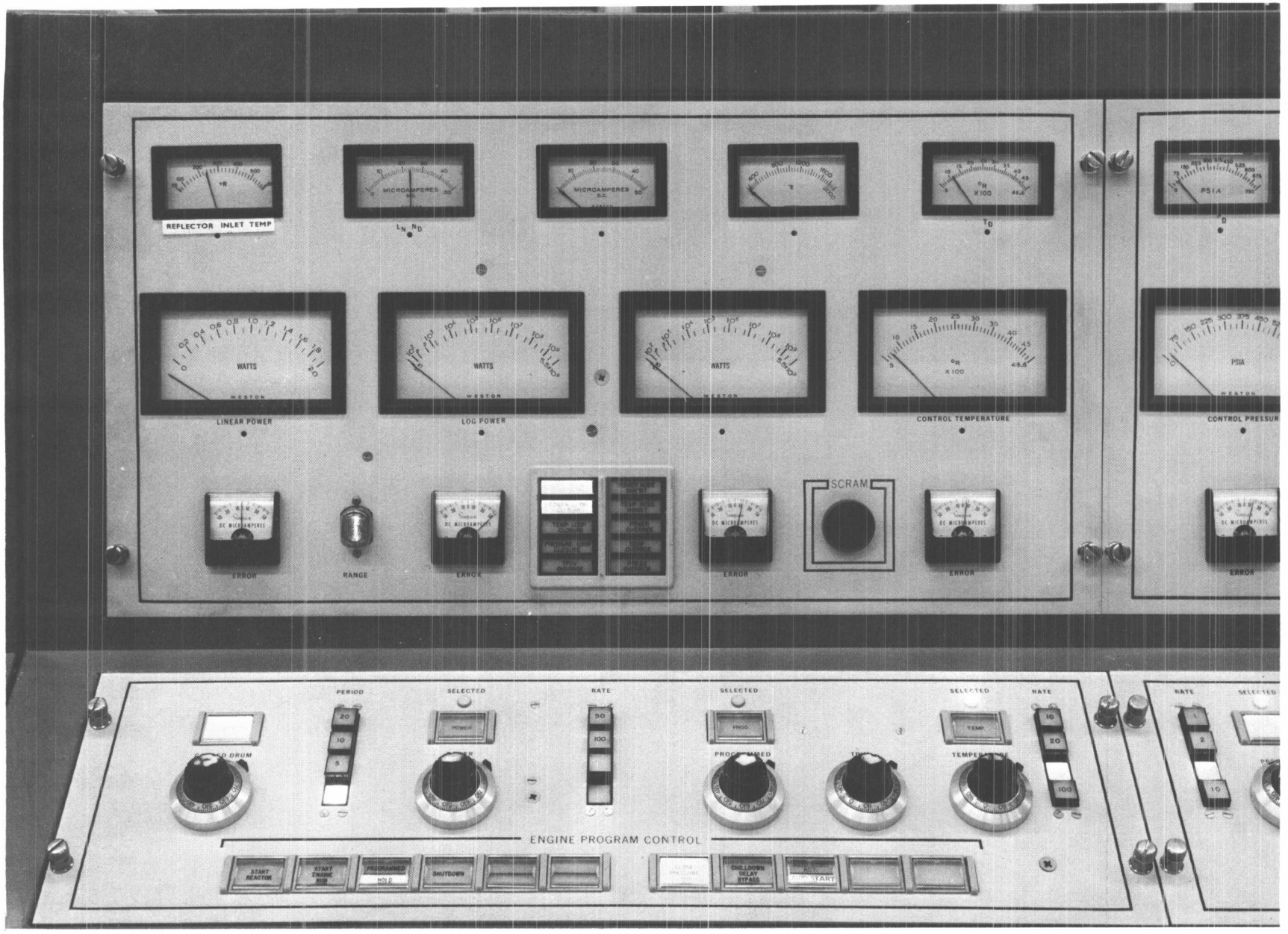


Figure 25 - CTE Console, Left Half

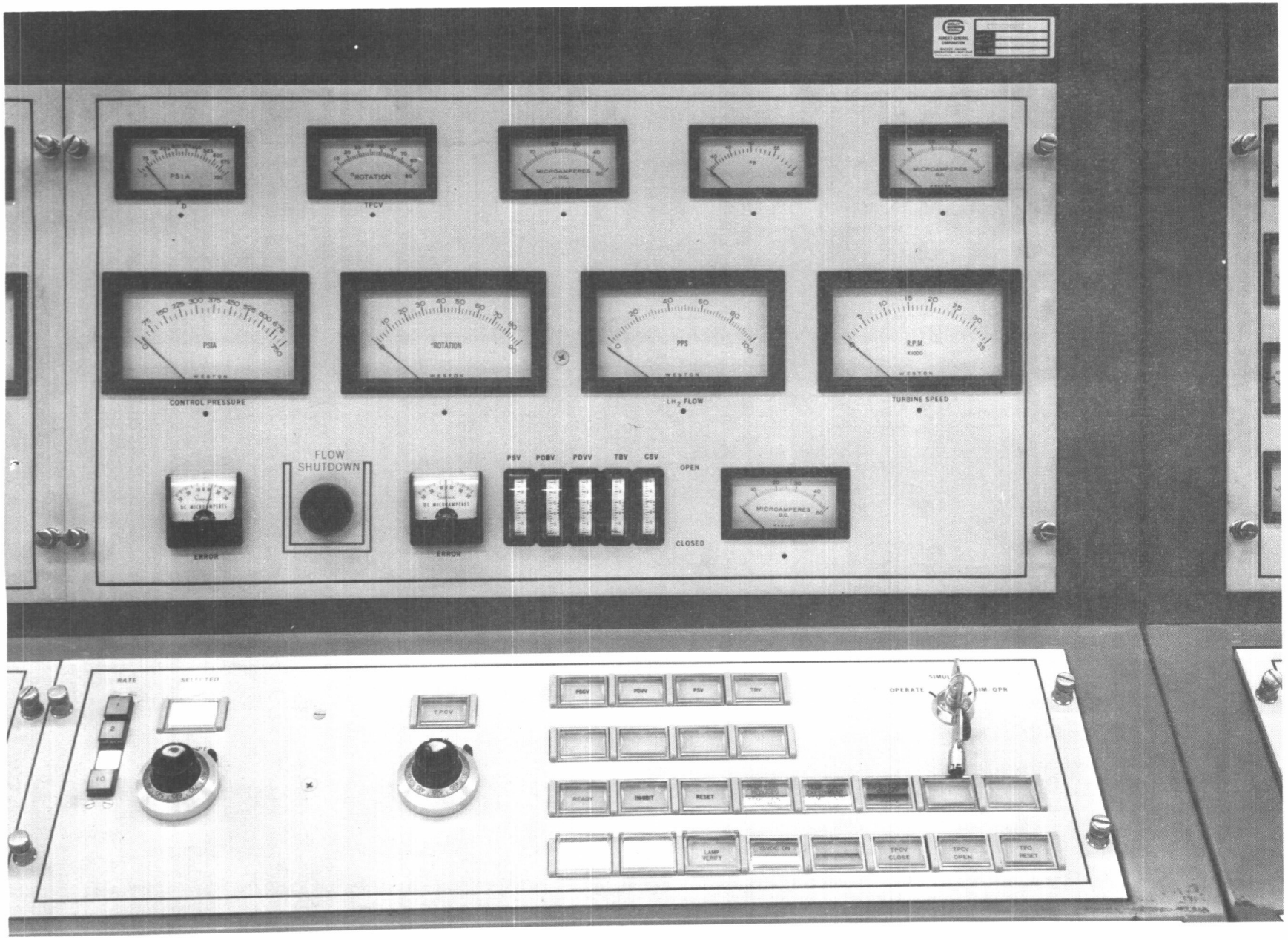


Figure 26 - CTE Console, Right Half

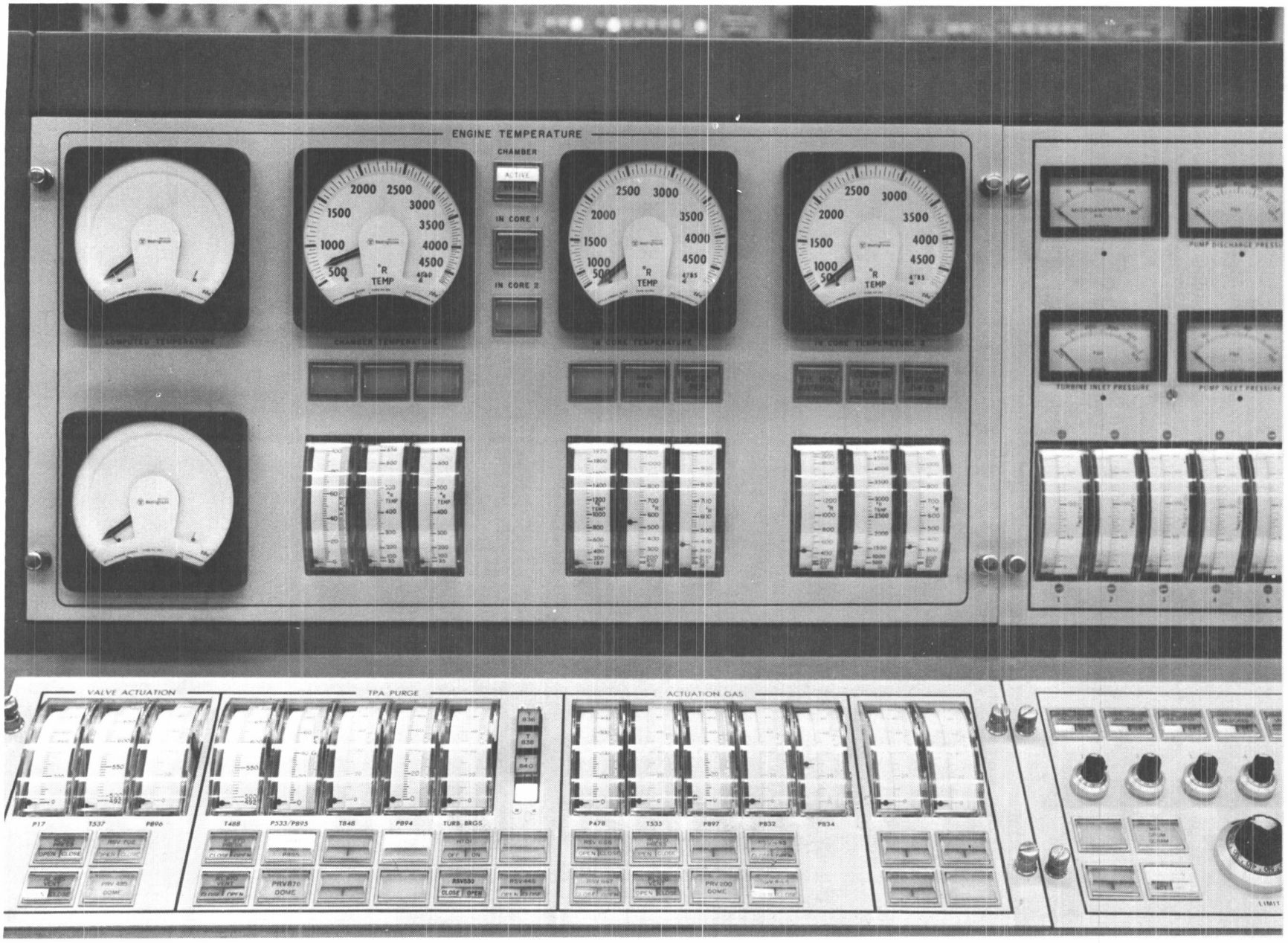


Figure 27 - ATE Console, Left Half

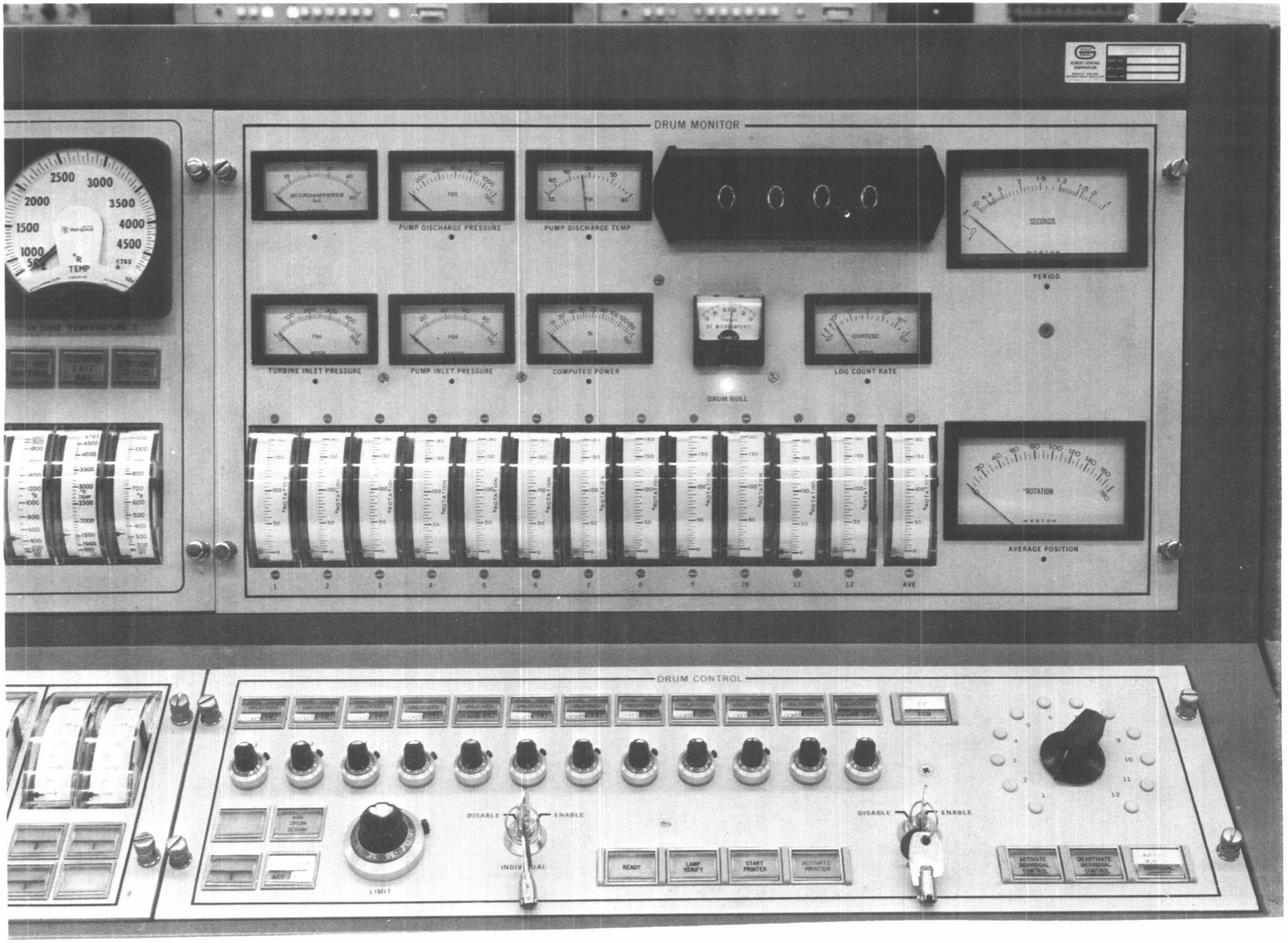


Figure 28 - ATE Console, Right Half

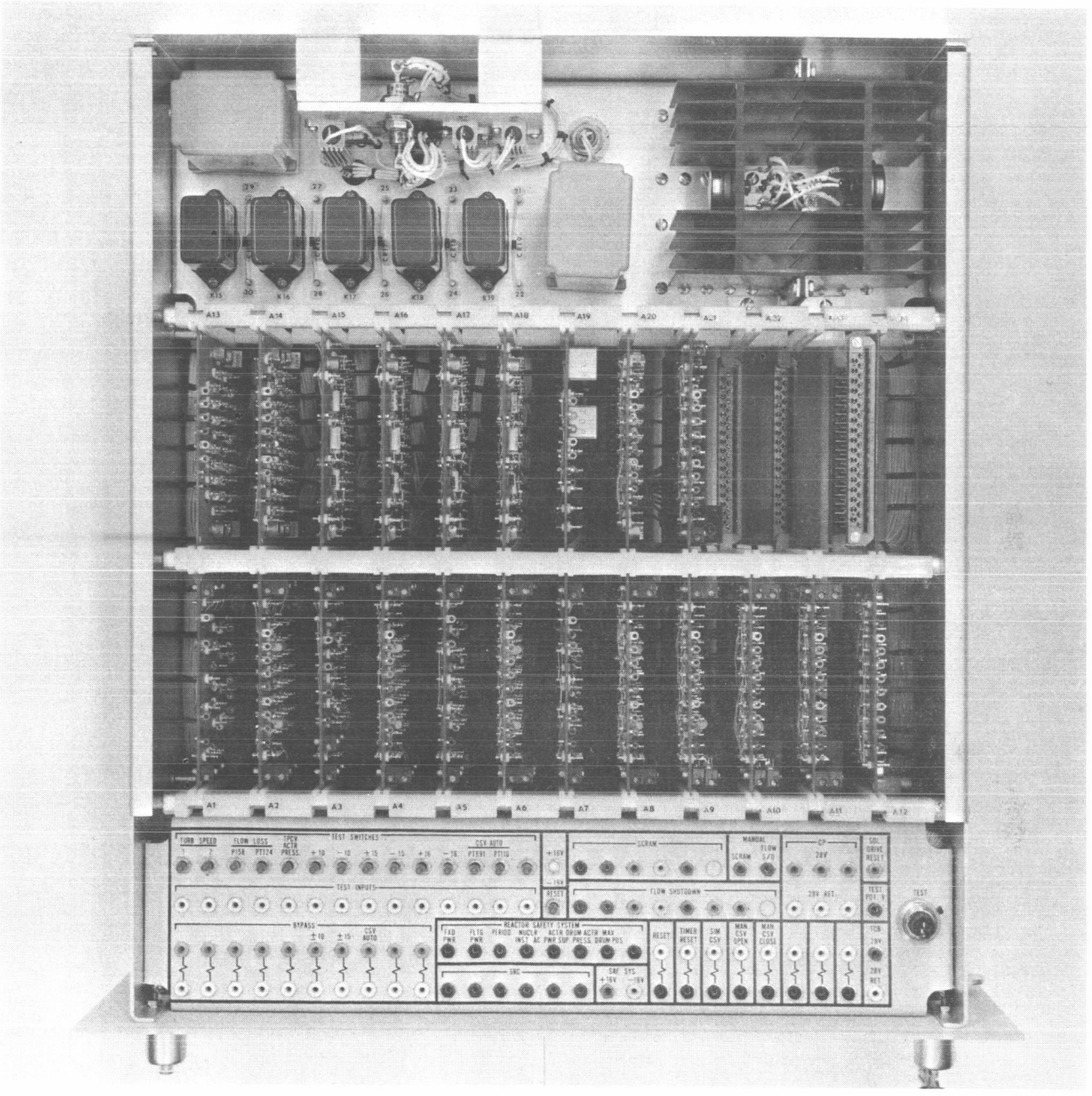


Figure 29 - Engine Safety System Chassis Showing Top View

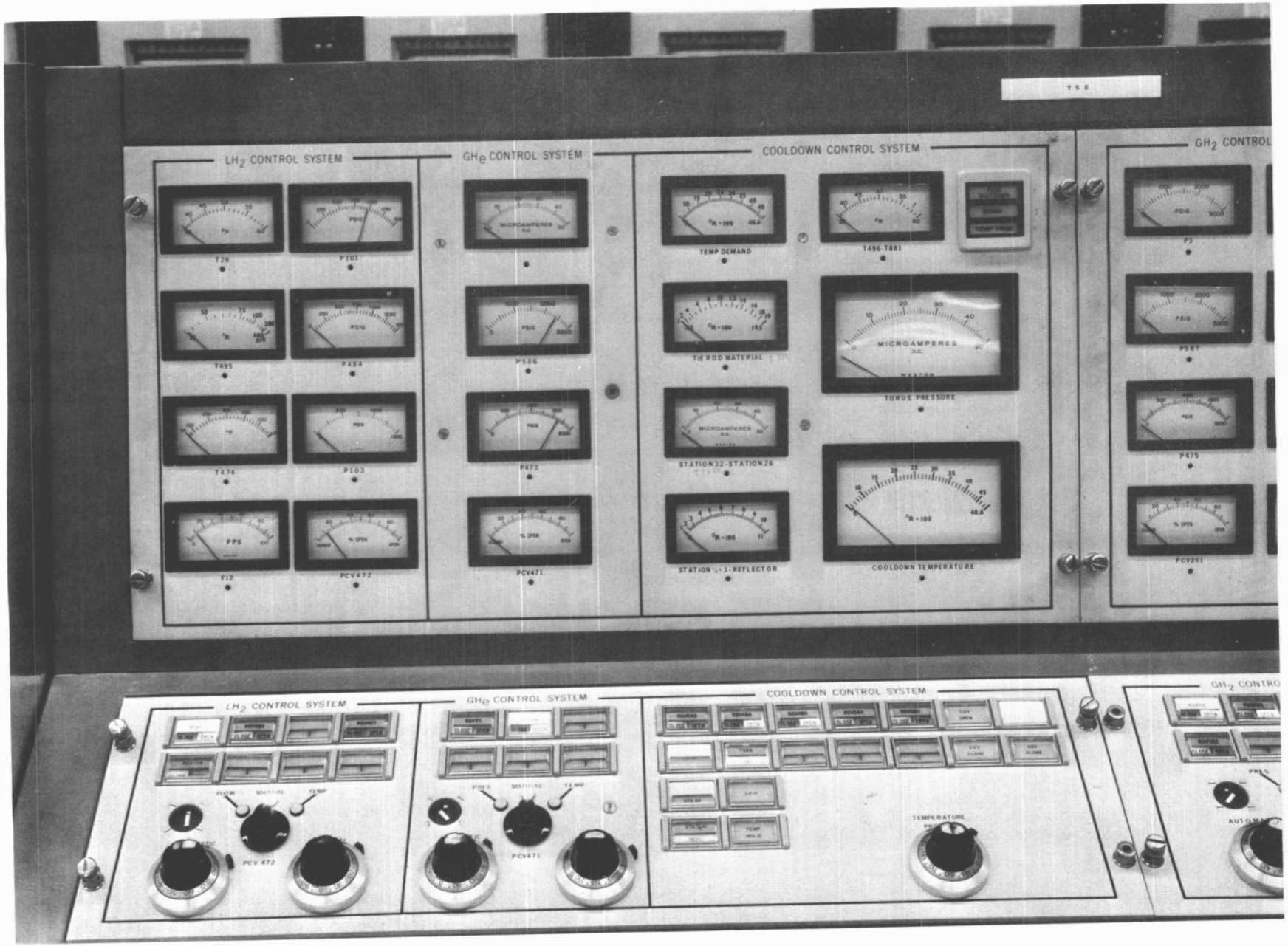


Figure 30 - TSE Console, Left Half

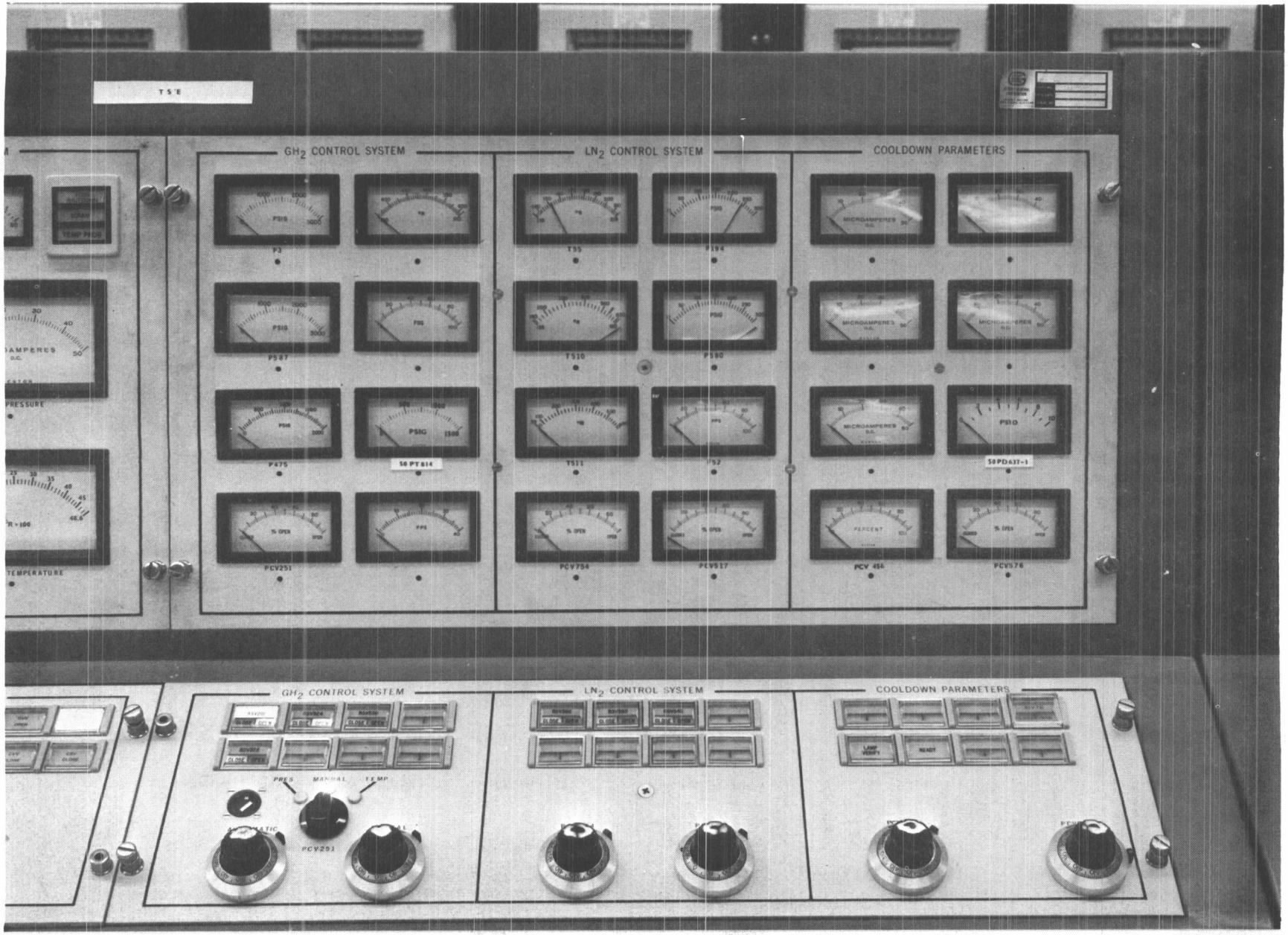


Figure 31 - TSE Console, Right Half

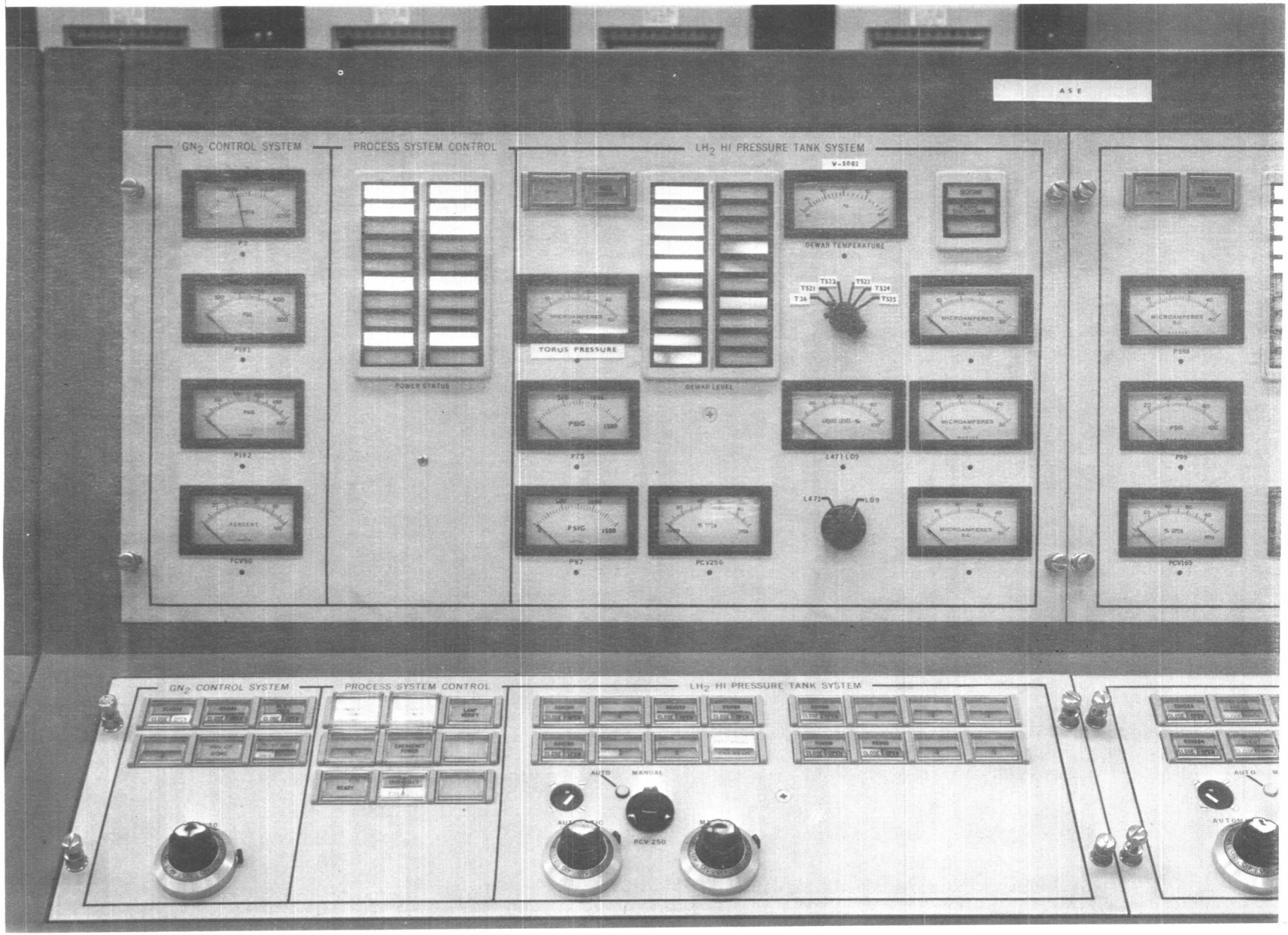


Figure 32 - ASE Console, Left Half

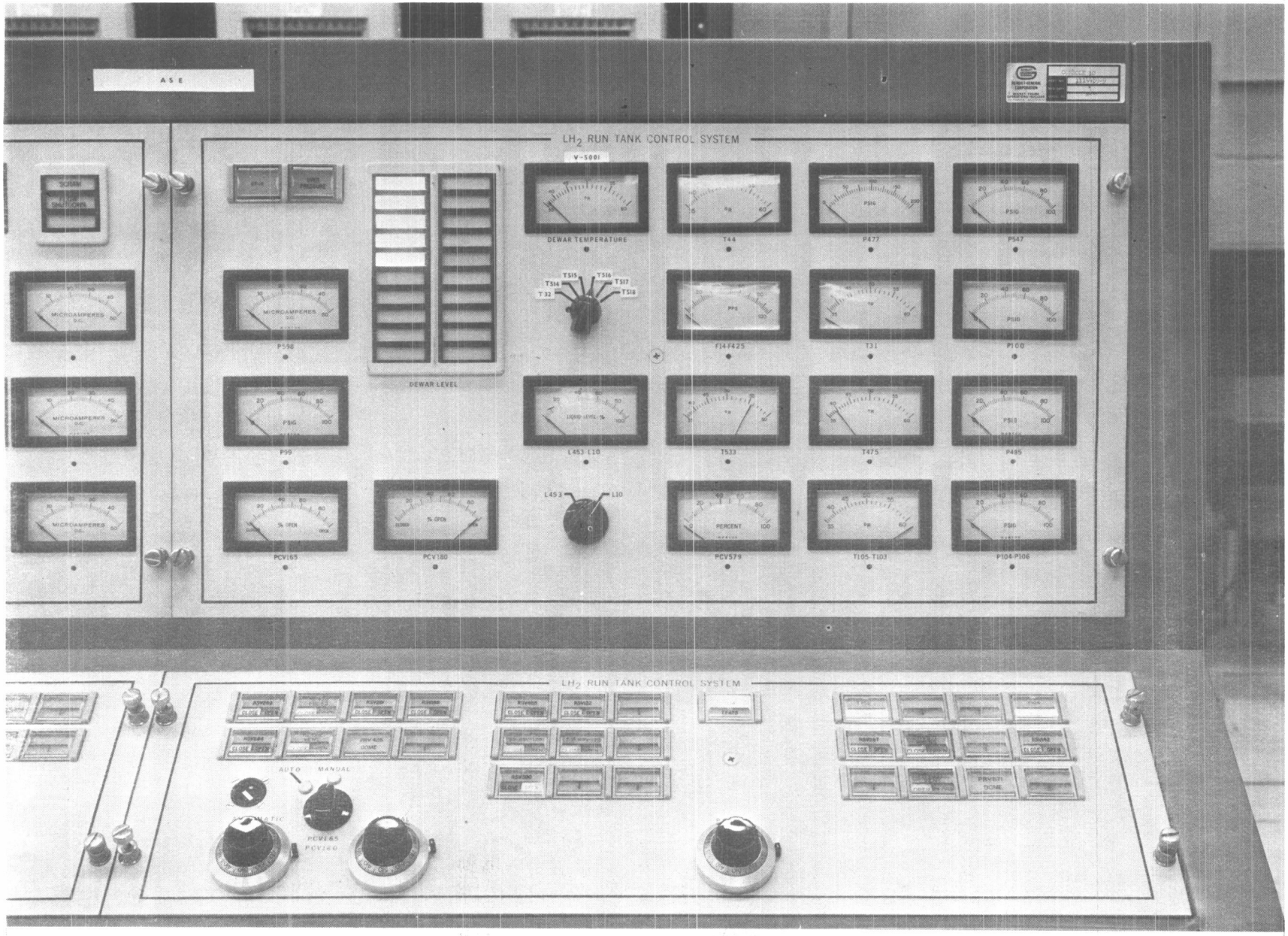


Figure 33 - ASE Console, Right Half

6. Systems Analysis (1.8)

a. X-Engine Systems Analysis (1.8.0)

The predicted behavior of the XECF system during each test planned for the XECF test program is reported in RN-S-0354, XECF Test Predictions. Report RN-S-0314, XECF Test Specification, including Modification No. 2, dated 12 April 1967, was considered the primary authority for establishing the test conditions and operation sequences. The predicted engine characteristics were obtained by using transient engine simulation program 16179, with the print-out time interval generally set for 1 sec. The test-prediction analysis indicated that no test-parameter limits were exceeded.

Program 16179 assumes that, at the time of test initiation (time zero), the PDSV or PSV steps open and system pressures and flow rates are instantaneously established. Therefore, as can be seen in the plots of predicted engine characteristics, the system pressures and flow rates are fully developed at the start of each test. Several modifications have been made to improve this program to enable the prediction of engine parameters during chilldown and initial system startup. These modifications include simulation of the turbopump suction and discharge lines, pump-bearing coolant flow, nozzle-bolt coolant flow through the core inlet orifices. The results of recent turbopump tests at the Lewis Laboratory were combined with Aerojet turbopump data to provide a best estimate of pump efficiency. The combined turbopump data were based on the Lewis Laboratory data at 1500 rpm, and on Aerojet data for pump speeds above 8000 rpm, with a smooth merging of data at intermediate speeds between these values.

The ability of the computer program to predict engine start-transient characteristics was tested by performing posttest computer runs for CFDTS tests conducted at XECF back-pressure conditions. In general, the computed parameters agree well with test data; however, discrepancies were noted

for some parameters, particularly at reduced run-tank pressures. The probable influence of these discrepancies at XECF test conditions is presented in discussions applicable to each particular test in RN-S-0354.

Typical predictions for XECF are shown by the predictions for Phase I, Run 1. The run-tank line and the pump will be chilled until LH_2 conditions exist at the pump discharge. Initial run-tank pressure will be set at 35 psia. Prior to initiation of flow, the reactor temperature (as indicated by reactor-core temperature measurements) will be 500 to 560°R. The engine-test-compartment pressure will be 7.5 psia. The test will be initiated by opening the PDSV with the TPCV closed and the pressure-control loop opened. The temperature of the nozzle-tube outlet fluid will decrease to 200°R approximately 12 sec after initial opening of the PDSV, at which time the pressure-control loop will be closed and a chamber pressure of 60 psia will be demanded. Closing of the pressure-control loop will initiate opening of the TPCV and allow GH_2 to flow to the turbine from the dome and hot-bleed port. The turbopump will accelerate from 0 rpm at 15 sec to about 750 rpm at 21 sec, after which it will accelerate more rapidly to a maximum speed of 8440 rpm at approximately 30 sec. Under XECF test conditions, the TPCV will require approximately 14 sec to open from 0 to 80° and will therefore reach the 80° open position at 26 sec. The system plenum pressures approximately follow the increase in pump speed, with the pump discharge pressure reaching a maximum pressure of 172 psia at 30 sec. Flow rates also increase with pump speed but decrease at a slower rate after the maximum pump speed is attained, because of reduction in engine flow impedance as the engine is chilled by the liquid hydrogen. Predicted plots of major engine parameters as a function of test time are presented in Figures 34, 35, and 36.

The conditions for this test are similar to the conditions during CFDTS Test No. 1.2-02-NNS-015, and the predicted engine performance agrees closely with the test results. During CFDTS Test -015, a maximum pump speed of 8210 rpm was attained 29.5 sec after test initiation.

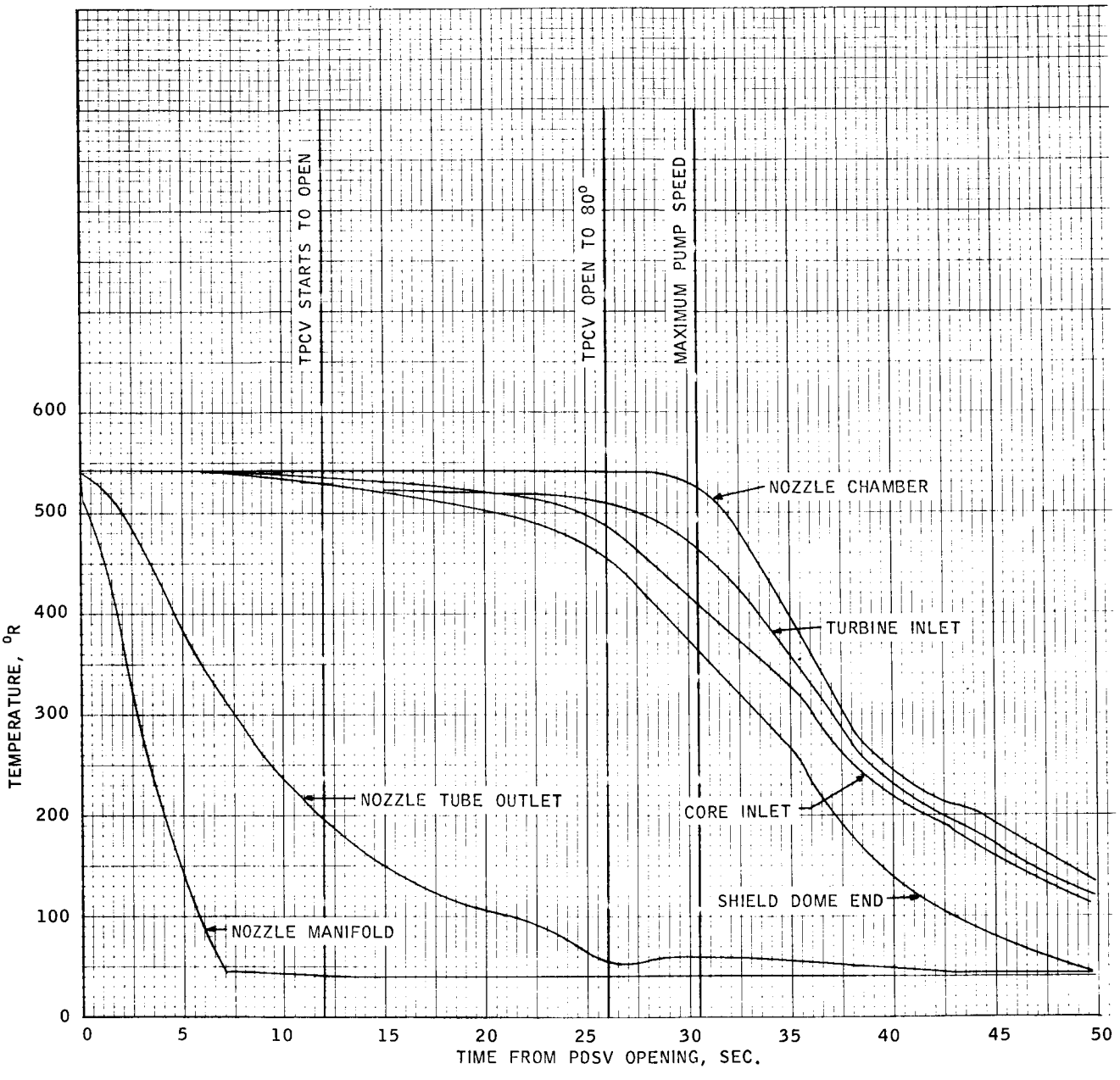


Figure 34 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, P_T = 35 psia, Temperature vs Time from PDSV Opening

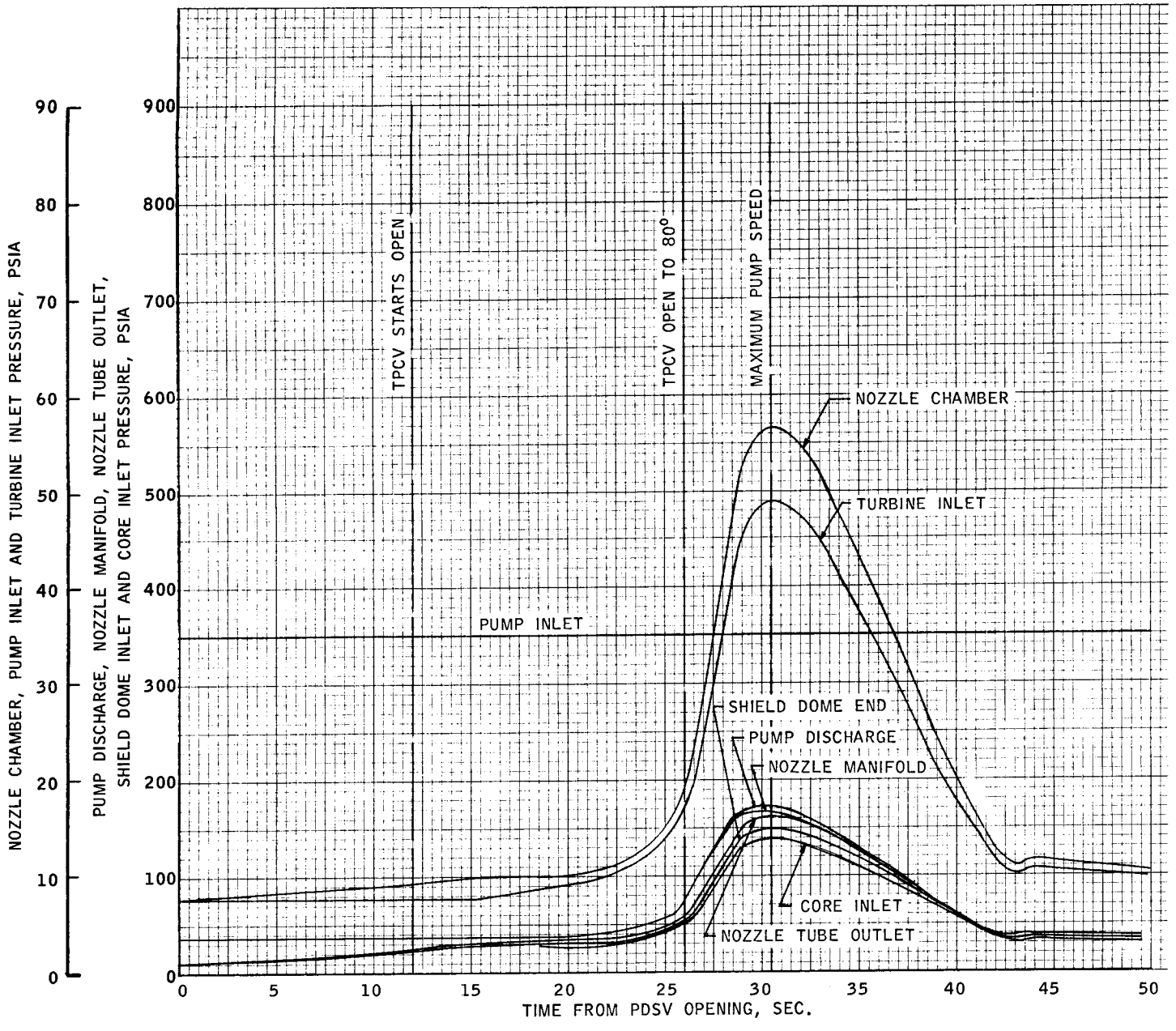


Figure 35 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, P_T = 35 psia, System Pressures vs Time from PDSV Opening

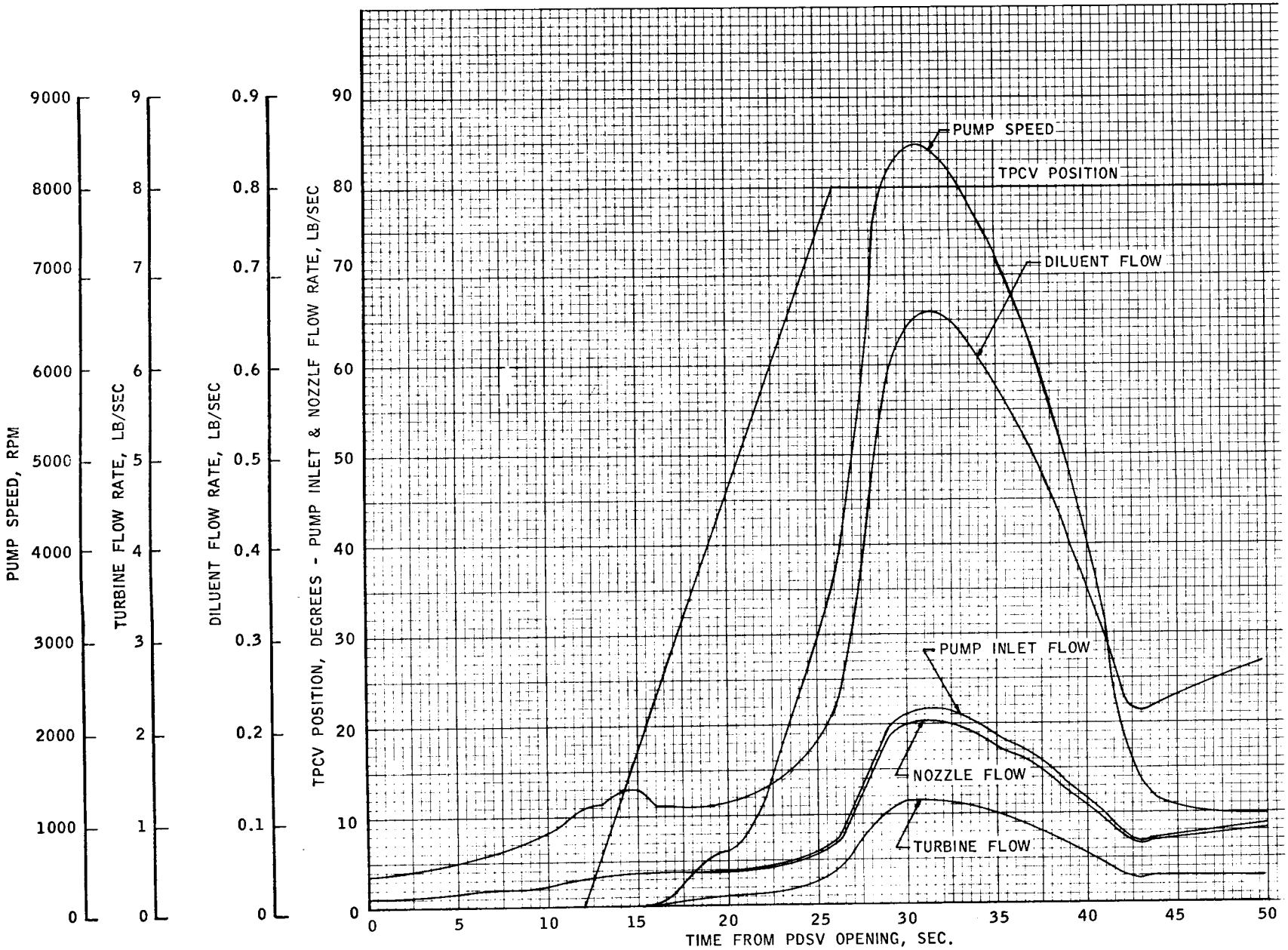


Figure 36 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, P_T = 35 psia; Pump Speed, Turbine Diluent Pump Inlet, and Nozzle Flow Rates; and TPCV Position vs Time from PDSV Opening

(1) X-Engine Cooldown

The total XE-Engine cooldown system must be capable of providing provision for a safe shutdown at any point during the engine test.

There are currently three different engine cooldown systems designed for use with XE-Engine in Engine Test Stand No. 1: (a) normal cooldown; (b) scram shutdown; and (c) emergency cooldown with and without inert propellants.

The normal cooldown is defined as the method of retreat from power for the termination of a normal run. Scram shutdown is the retreat used if a malfunction occurs that is not associated with interruption of the normal propellant flow path. Emergency cooldown is the method of retreat used when the normal flow path is interrupted. The emergency cooldown system automatically supplies liquid hydrogen propellant to the engine from high pressure Dewar V-5002, but at the discretion of the test operator helium can be introduced if there is danger of fire or explosion.

The planned cool-down systems for XE-Engine have been designed to be compatible with ETS-1. The fluid supply systems that will support engine cooldown are: (a) gaseous helium system; (b) gaseous hydrogen system; (c) liquid hydrogen system; and (d) a liquid nitrogen system. Although these systems will be used for cooldown, they will also be used for other functions, and the total system capacities are not available for cooldown.

The analyses performed have perfected the proposed cooldown schemes as indicated below. These systems meet all requirements for normal, scram, and emergency cooldown.

(a) Normal Cooldown

Normal cooldown (Figure 37) may be implemented in two ways that differ relative to the amount of time that the

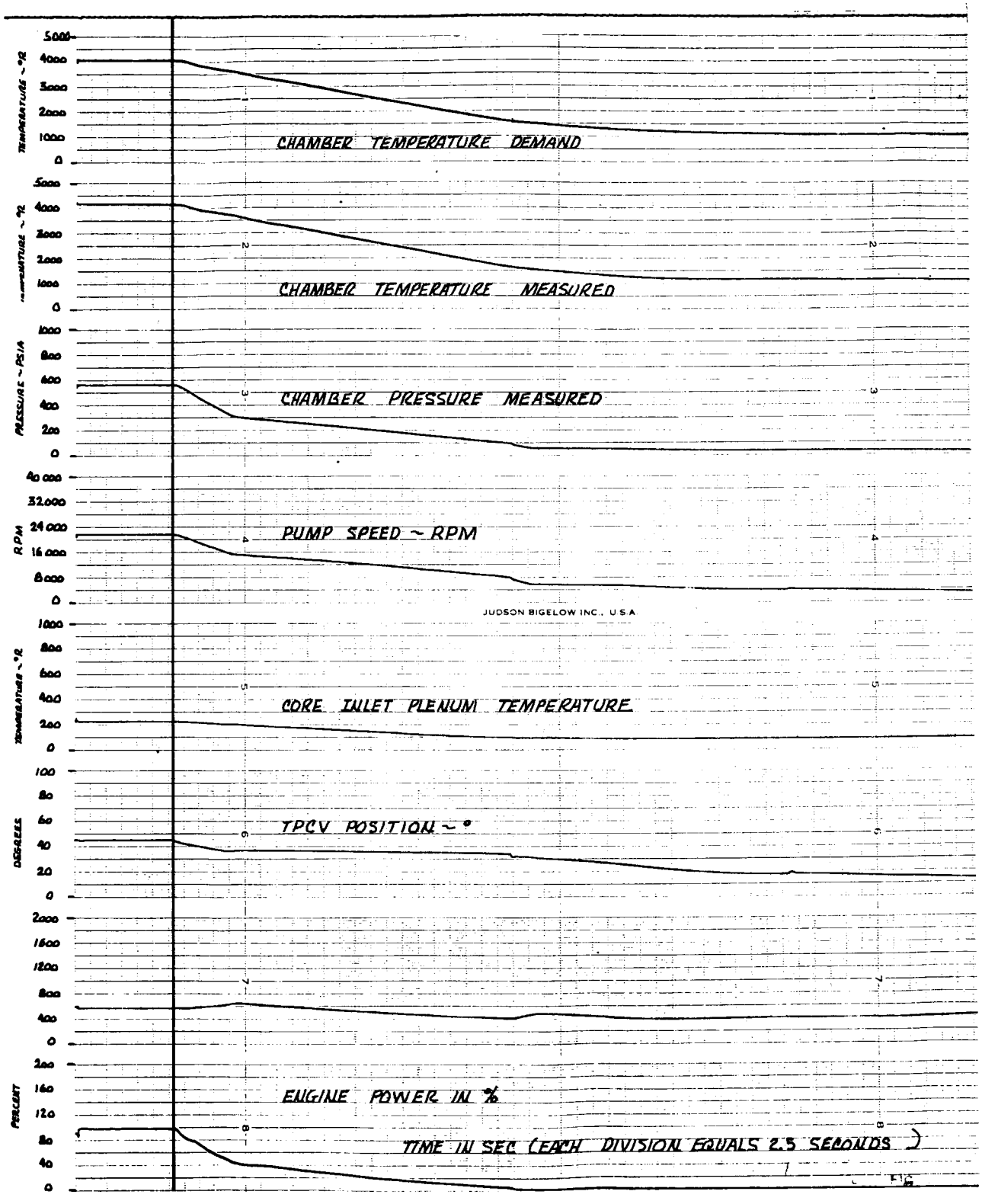


Figure 37 - Normal Cooldown

propellant is supplied from the run tank. The actual normal cooldown will switch to inert propellants (nitrogen) as soon as feasible, but tests are planned for the X-Engine to prove the feasibility of a complete cooldown using a pulsing technique with liquid hydrogen supplied wholly from the run tank.

The normal cooldown will start at the end of the planned test profile. If the end of the profile occurs at a temperature higher than 1600°R the engine will be returned to the nearest point on the normal operating line. The engine will be programmed along the normal operating line at a predetermined temperature ramp (50 or 100°R/sec) to 1600°R. If the end of the planned profile occurs below 1600°R, the engine will be returned to the nearest point on the operating line. From this point (1600°R or below) the engine will be scrammed and the chamber temperature will be scheduled down exponentially to 1000°R; the chamber temperature during this period will be controlled with the turbine power control valve. The chamber temperature of 1000°R will be held until the chamber pressure reaches approximately 20 to 25 psia. At a chamber pressure of 20 to 25 psia the control system will be reset, which closes the TPCV. The engine will be permitted to cooldown under run tank pressure until the chamber temperature reaches 800°R.

At 800°R the engine flow will be terminated by closing the pump shutoff valve. Under no-flow conditions the core will be permitted to warm up until a predetermined in-core material temperature has been reached. If pulse cooling is to be used this cycle will be continued until the pulse cooling technique has been satisfactorily tested, i.e., flow until chamber temperature reaches 800°R, and no flow until the desired incore temperature or a reactor test parameter limit has been reached. The standard normal cooldown, however, will have only one no-flow period; the second flow pulse will be effected by using gaseous hydrogen from the facility supply system at 5 lbm/sec until the core exit temperature has reached 800°R. With the reactor overcooled, the propellant will be switched to nitrogen at full Dewar pressure of 250 psig. During the initial flow period, the nitrogen flow will vaporize as it chills down the facility piping and the upstream parts of the engine system.

The gaseous nitrogen will choke the nozzle tubes and with the driving pressure available will not produce enough cooling to maintain the previously achieved chamber temperature of 800°R. As the nozzle tubes unchoke and the reactor begins to cool, the nitrogen flow will be scheduled to achieve and maintain 1200°R, and when the flow decays to 5 lbm/sec pulse cooling will be initiated.

(b) Scram Shutdown (Figure 38)

Scram shutdown will be initiated automatically with a command from the scram chain. The signal from the scram chain will cause the drums to roll in at their maximum rate and schedule the chamber temperature down exponentially to 1000°R with the turbine power control valve. From this point the remainder of the scheme will be identical to the normal cooldown.

(c) Emergency Cooldown (Figure 39)

The emergency cooldown consists of a primary scheme that will use liquid hydrogen from high pressure Dewar V-5002 as the prime coolant and an alternate inert scheme that will utilize gaseous helium. The emergency cooldown system can be initiated either manually or by the flow shutdown control chain. The alternate cooldown system can only be initiated manually by the test operator after flow shutdown has been initiated.

At the initiation of emergency cooldown the reactor is scrammed, the turbine blocking valve is closed, and facility liquid hydrogen control valve, PCV-472, will be stepped open to 30%, and held at 30% for 200 millisec. The valve will then be stepped to 10% and scheduled to provide a smooth decay in chamber temperature. In the event of instantaneous loss of the normal propellant supply, flow will be maintained to the nozzle tubes (until PCV-472 can be opened) because of the expansion of the fluid trapped in the facility piping to PCV-472 at pump discharge pressure. The liquid hydrogen flow from the high pressure Dewar will be scheduled down under chamber-temperature control to 1000°R similarly to normal cooldown, and the 1000°R

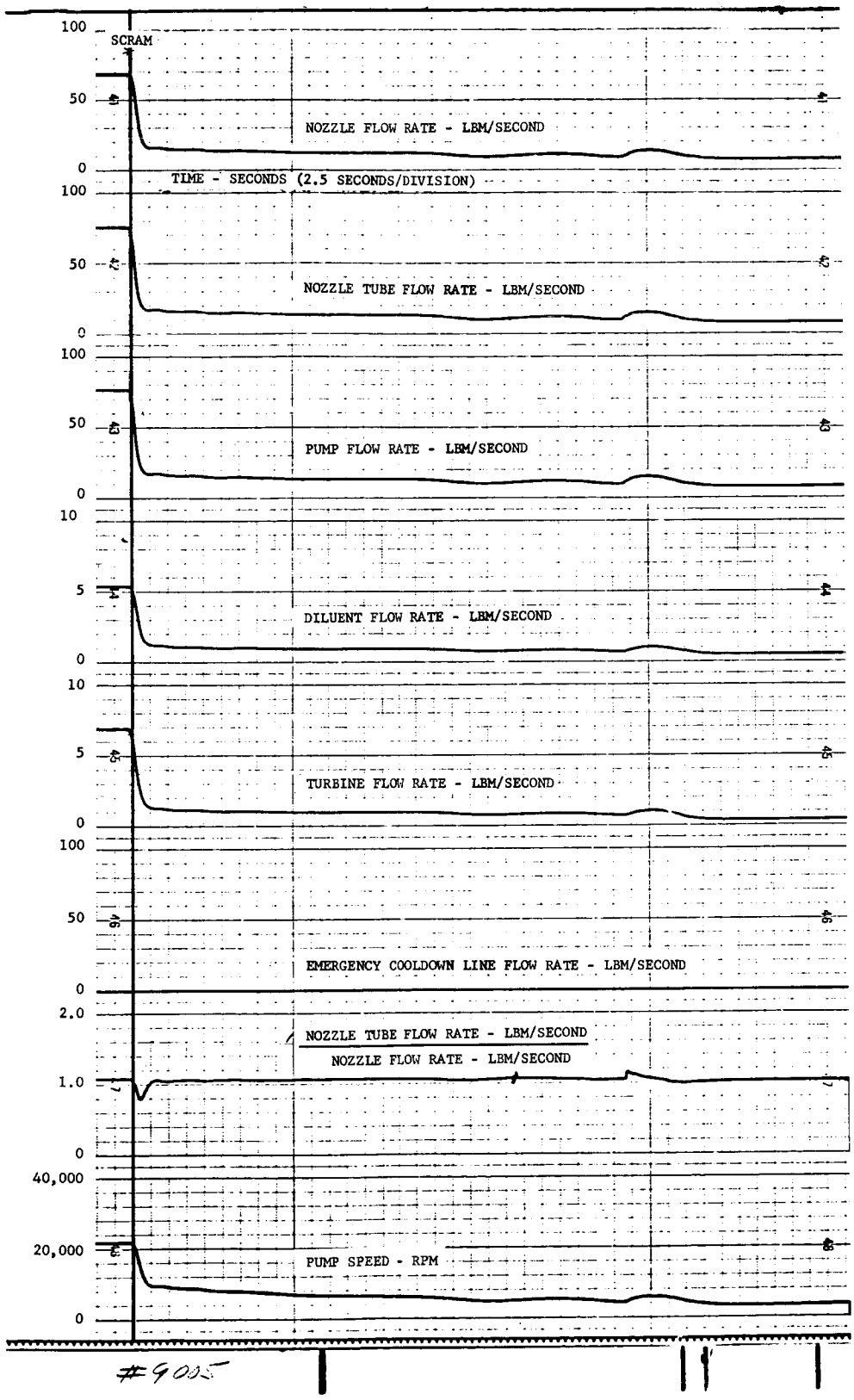


Figure 38 - Scram Shutdown

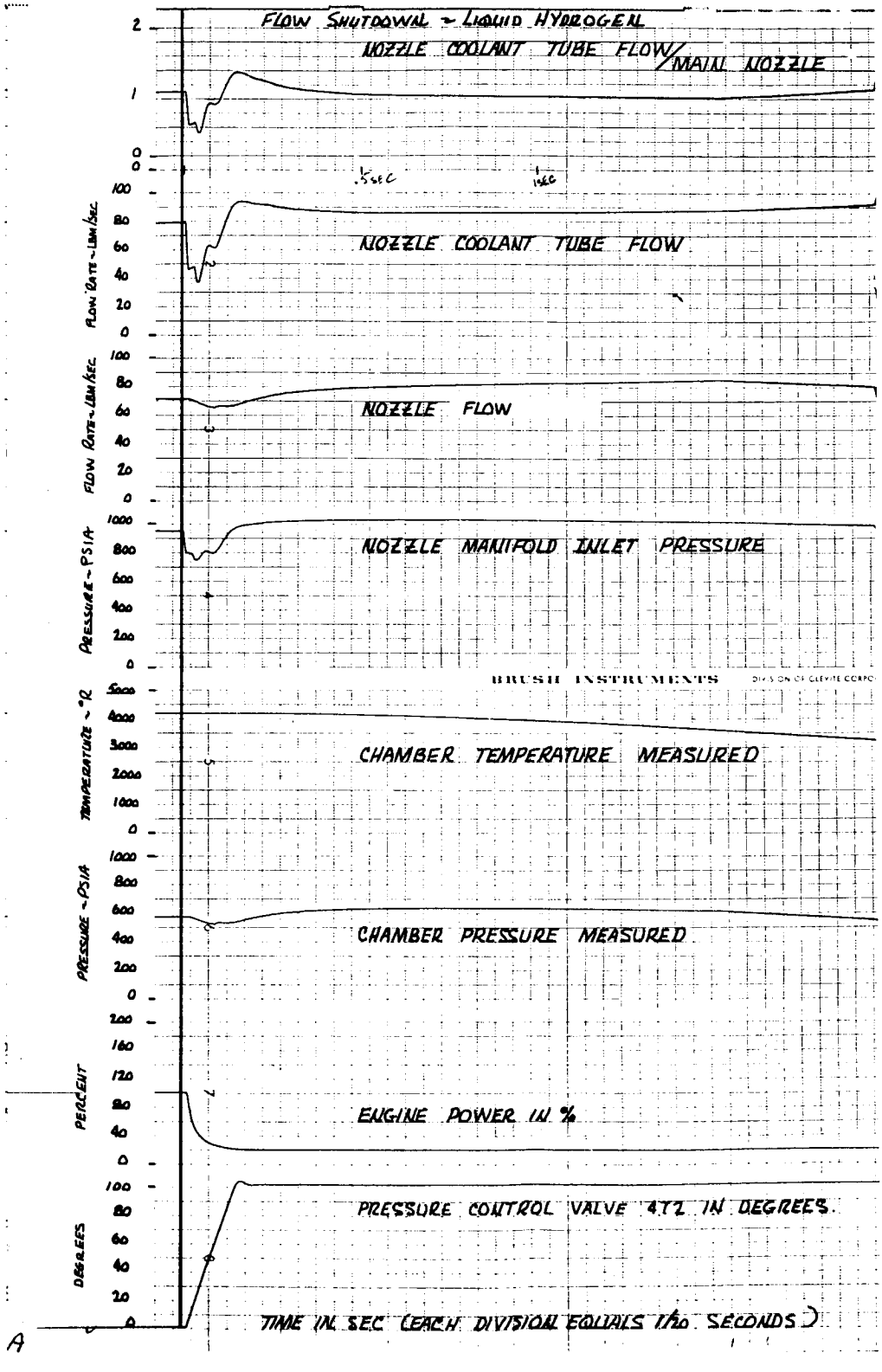


Figure 39 - Emergency Cooldown

temperature will be held until PCV-472 has been closed or until the minimum flow rate is reached and the control system is reset. The remainder of the scheme will be the same as for normal cooldown.

The alternate emergency cooldown using inert propellants can be initiated at the discretion of the test operator and is essentially manually controlled. The system will be initiated demanding 1100 psia at the nozzle inlet (1100 psia is a test parameter limit). The 1100 psia nozzle torus pressure will be maintained until the chamber temperature reaches 1600°R. The flow rate will then be tailored to decay chamber temperature exponentially to 1400°R. A temperature of 1400°R will be maintained until the flow rate reaches 20 lbm/sec. The flow will then be held constant until the chamber temperature has decayed to 900°R. The switch to liquid nitrogen can be effected at this point.

(d) XE-1 Malfunction Analyses

An XE-1 malfunction analysis is currently being performed using the XE-1 Common Analog Model. Most of the malfunctions being investigated at steady-state conditions have been completed. Malfunctions at transient conditions will be run on the CAM in the near future.

Review of runs completed to date indicates that the XE-1 system can withstand malfunctions of the engine components from any point on the operating map. However, failure of the facility liquid hydrogen cool-down valve, PCV-472, will adversely affect the engine system. Analysis showed that when PCV-472 opened to 30% at the maximum rate, the chamber temperature cooldown rate was as high as 2050°R/3 sec, but the limit is 900°R/3 sec. Modifications are currently being investigated to alleviate this problem.

A list of the XE-1 malfunction runs from initial steady-state conditions is presented in Table 6. The chamber conditions and control mode for each run are included in the table.

TABLE 6

XE-1 MALFUNCTION
ANALYSES AT STEADY-STATE
CONDITIONS

STEADY-STATE	TPCV Closure (Max Rate)	TPCV Opening (Max Rate)	Drum Roll-in (100°/sec)	Drum Roll-in (45°/sec)	Drum Roll-in (25°/sec)	Drum Roll-in (1.5°/sec)	Drum Roll-out (100°/sec) with and without Drum Override	Drum Roll-out (25°/sec)	Drum Roll-out (3°/sec)	Drum Roll-out (1.5°/sec)	PSV Closure (Max Rate)	Pump Explosion	PDVV Fails Open (Max Rate)	PDSV Closure (Max Rate)	PCV-579 Fails Open	TSV Max Rate Closure	PCV-472 Max Rate Open	PCV-472/PCV-251 Max Rate Open	Temp Demand Zero	Temp Demand to 5000°R	Temp Measured to Zero	Temp Measured to 5000°R	Pressure Demand to 750 psig	Pressure Demand Zero	Pressure Measured to Zero	Pressure Measured to 750 psia	Temp Demand Ramps Up at 50°R/sec	Temp Meas. Ramps Up at 50°R/sec	Pressure Ramps Down at 5 psia/sec
T_c = 4090°R P_c = 563 psia	C	X	C	C			C	C	X	X	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
		X					C	C	X	X	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 4090°R P_c = 250 psia	C	X	C	C	C			C	X	X	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 3500°R P_c = 573 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 3000°R P_c = 490 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 2200°R P_c = 300 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 2200°R P_c = 170 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 2200°R P_c = 90 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 1000°R P_c = 60 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 3500°R P_c = 170 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
T_c = 1600°R P_c = 60 psia											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
											C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

P_c + T_{sp} Control	
P_c + T_c Control	
TPCV + Drum Control	
P_c + T_{sp} Control	
TPCV + Drum Control	
TPCV + Tsp Control	
TPCV + Tsp Control	
P_c + T_{sp} Control	
P_c + T_{sp} Control	
P_c + T_{sp} Control	
TPCV + Drum Control	
P_c + T_{sp} Control	
TPCV + Drum Control	
P_c + T_{sp} Control	
TPCV + Drum Control	
P_c + T_c Control	
P_c + T_{sp} Control	
TPCV + Drum Control	
P_c + T_{sp} Control	
P_c + T_{sp} Control	
R_c + T_{sp} Control	

C - Completed
X - Not Completed

The malfunctions selected for evaluation were coordinated with Safety, XE-1 Project, and Westinghouse personnel. These malfunctions appear to be the most important for demonstrating the adequacy of the XE-1 engine system. Additional runs may be necessary as a result of these runs; however, in most cases the effect of other malfunctions on the engine system can be related to those being analyzed.

The effect of each malfunction analyzed to date on the XE-1 system and component limits exceeded are discussed below.

1 TPCV Closure at Maximum Rate

The loss-of-flow detector in the pump discharge line tripped the emergency flow system at all chamber conditions analyzed, except at 2200°R and 90 psia. At this chamber condition, chamber pressure dropped to 20 psia and chamber temperature increased to a maximum of 2700°R.

No limits were exceeded when the emergency flow system was activated. At chamber conditions of 2200°R and 90 psia, the tie-rod temperature reached a maximum limit in 10 sec. Manual activation of emergency flow shutdown within 10 sec, however, prevented exceeding the tie-rod temperature limit.

2 TPCV Open at Maximum Rate

All runs were made without TPCV position override to simulate a failure within the TPCV actuator. Failure of the electronics in the TPCV is precluded by the TPCV position override. Opening the TPCV causes the pump to speed up, which results in an increase of chamber pressure and temperature. In all cases analyzed, chamber conditions increased to a maximum of 630 psia and 4150°R where the TPA overspeed trip of 24,000 rpm activated an emergency flow shutdown.

The pressure differential across the core reached 156 psi at the time of overspeed trip, which slightly exceeds the present limit of 150 psi.

Additional runs of this malfunction are required to obtain a more detailed analysis of nozzle performance after emergency shutdown.

3 Drum Roll-In

Runs were made at drum roll-in rates of 100, 45, 25 and 1.5 deg/sec. A scram shutdown was activated by the drum roll-in detector in all cases except at 1.5 deg/sec. At this rate, chamber conditions decreased at 20 psi/sec and 400°R/3 sec. No component limits were exceeded.

4 Drum Roll-Out

Runs were conducted with and without drum position override controls at 100 and 25 deg/sec. With drum override controls the total angle of drum roll-out was limited and no change in engine parameters was noted. Without drum override controls, a scram shutdown was activated by the 200% fixed power limit without exceeding any component limits.

More detailed runs at 3 and 1.5 deg/sec are being conducted to represent slow drum roll-outs.

5 PSV Closure at Maximum Rate

Closing the PSV stops propellant flow to the pump. An emergency flow shutdown occurred immediately from a loss-of-flow trip or overspeed trip. No component limits were exceeded.

6 Pump Explosion

The loss-of-flow detector immediately initiates emergency flow with no component limits exceeded.

7 PDVV Opens at Maximum Rate

Opening the PDVV reduces the pump discharge pressure and flow to the engine. Since a 1-in. orifice in the vent line limits the flow, the pressure in the pump discharge line does not decrease sufficiently to cause a loss-of-flow trip. In pressure control, the TPCV opens to account for the loss of flow. In position control, chamber temperature increases to a maximum of 4290°R. No component limits were exceeded.

8 PDSV Closes

Closing the PDSV stops propellant flow to the engine and drives the pump into a hard stall. An emergency flow shutdown is activated by the loss-of-flow detector when the pump is stalled.

9 PCV-579 Fails Open

Opening PCV-579 bleeds propellant from the propellant inlet line. Since the flow rate through this valve is only 5 lb/sec, little effect was noted on engine parameters.

10 TBV Closes at Maximum Rate

Closing the TBV stops flow to the turbine. The loss-of-flow detector initiated an emergency flow shutdown.

11 PCV-472 Opens at Maximum Rate to 30%

Opening PCV-472 will enable liquid hydrogen from the emergency Dewar (V-5002) to flow through the engines. The loss-of-flow detector initiated the emergency flow procedure in all cases, except when chamber conditions were 3500°R and 170 psia, 2200°R and 170 psia, and 1000°R and 60 psia with V-5002 at 500 psia. At these chamber conditions the engine did not shut down but moved to a new stable operating condition at higher pressures.

When the engine shut down, an excessively high rate of reactor cooldown occurred. The reactor cooldown rate as measured by chamber temperature was as high as 2050°R/3 sec. Also, one run conducted with the engine in position control indicated that flow oscillates between the pump and V-5002 as the pump moves in and out of stall. To preclude exceeding the chamber cooldown rate limit and pump stall, alternate systems (such as open-valve system or refining V-5002 pressure) are being evaluated.

12 PCV-471 or PCV-251 Fails Open

Opening PCV-471 or PCV-251 will enable gaseous helium or hydrogen to flow through the engine. In all cases the loss-of-flow detector initiated an emergency flow shutdown. The reactor cooldown rate could not be evaluated since the common analog model data was valid for only 0.5 sec after shutdown.

13 T8 Demand Fails to Zero

The drums roll-in at 20 deg/sec and a scram shutdown will be initiated by the drum roll-in detector.

14 T8 Demand Fails to 5000°R

The drums roll out at 16 deg/sec. The drum position override will return the drums to tracking control.

15 T8 Measured Fails to Zero

The drums will roll out at 16 deg/sec. Drum position override will return the drums to tracking control.

16 T8 Measured Fails to 5000°R

At design point drums will roll in at 10 deg/sec. A scram shutdown was initiated by the drum roll-in detector. At chamber conditions of 2200°R and 300 psia, the drums will roll in at 20 deg/sec and a scram shutdown will be initiated by the drum roll-in detector.

17 P8 Demand Fails to Zero

The TPCV will close to zero, which will stop flow to the turbine. The loss-of-flow detector will initiate emergency flow shutdown.

18 P8 Demand Fails to 750 psia

The TPCV will open, but the TPCV position override will limit the movement to 6 degrees. At design point the chamber conditions increased to 4360°R and 600 psia. T_{26} override will be activated to limit the temperature rise.

19 P8 Measured Fails to Zero

The TPCV will open, but is limited by the TPCV position override. Chamber conditions did not change significantly.

20 P8 Measured Fails to 750 psia

The TPCV will close causing the loss-of-flow detector to initiate emergency flow shutdown.

21 T8 Demand Fails and Ramps up at 50°R/sec

The drum position will increase at about 1 deg/sec. The chamber temperature reached 4290°R in 5 sec and continued to rise to 4550°R. T_{26} override will reduce the rate of chamber temperature rise. Sufficient time will be available for operator action to prevent exceeding temperature limits.

22 T8 Measured Fails and Ramps up at 50°R/sec

A run was conducted with chamber conditions at 3500°R and 170 psia. Chamber temperature of 4290°R was reached in 18 sec, and continued to rise to 5000°R. T_{26} override action will limit temperature rise. By switching to position control or scram, no temperature limits will be exceeded.

23 P8 Demand Fails and Ramp Down at 5 psi/sec

TPCV will close slowly, reducing flow to the engine. When this occurs, chamber temperature will increase to 4200°R and tie-rod temperature will increase and exceed the limit in 18 sec. Sufficient time will be available for operator action.

(e) Analysis of ETS-1 Data

The report RN-S-0433, Evaluation of Data from ETS-1 Checkout, covers the data analyses of the ETS-1 facility checkout tests (FEP-I through IV) and the Nuclear Exhaust System (NES) Phase I and Phase II

NEPN-1 tests. Test series relative to the facility systems were performed from September 1966 to March 1967, while the NES Phase I tests were performed from 19 January 1967 to 7 February 1967, and the NES Phase II tests were started in June 1967 with the NEPN-1 tests. The primary purpose of these tests was to evaluate the capabilities of the facility systems and the NES in support of the X-Engine testing.

Results of the facility checkout tests were reported in detail in the NTO Test Summary Report and FDET memoranda.

Data analysis was made primarily to obtain the flow resistances in the facility purge and cooldown lines from the test data. These flow resistances were then used to upgrade the computer models for the engine system analytical programs.

The SPEAR committee evaluated the NES Phase I and NEPN-1 test results. Data from these tests were further analyzed to evaluate the start, pull-in, and shutdown characteristics of the NES duct, the steam generator performance at quasi-steady-state operating conditions, the simulated malfunction shutdowns, and various methods of preventing air backflow into the duct that could occur during certain modes of malfunction shutdowns.

1 NES Duct Test Data Analysis

Data analysis was concentrated on determining the operating characteristics of the system, comparison with subscale data, and performing studies to further assure system safety. NES is designed to accomplish safe burning of the engine exhaust gas in the atmosphere, prevention of air backflow during normal or malfunction engine operation conditions, and altitude simulation by aerodynamic pumping action of the engine exhaust gas. This system consists mainly of the shielded and vacuum-tight engine test compartment (ETC), water-cooled exhaust duct with a secondary ejector.

Prior to the engine startup, the secondary ejector will be placed in operation. Initially, the ETC pressure will be reduced to about 10 psia with one steam generator brought up to full steam, and with the normal two-module operation the ETC pressure will be further reduced to about 7.5 psia. During start, as the nozzle chamber pressure is increased, the ETC pressure will decrease smoothly. The nozzle will start to flow full at the chamber pressure of about 150 psia (a conservative estimate). At chamber pressure of about 160 psia, the pull-in point will be reached where the ETC attains a minimum operating pressure of about 0.3 psia. Beyond this point, the engine operation will be stable with fully expanded flow at the nozzle exit.

Shutdown will follow the duct start operating line (ETC pressure vs nozzle chamber pressure) but will be reversed in the direction from the start and pull-in, provided the nozzle-chamber pressure ramp-down rate is not excessively high.

Other operating characteristics of the NES are:

a The steam generators, if maintained at a specified operating condition, will reproduce steam of consistent quality and quantity.

b Start (or shutdown) operating line (ETC pressure vs nozzle chamber pressure) agrees well with the scale-model test prediction.

c In the runs that have no flow through the turbine exhaust nozzles, as the pull-in point is approached, pressure oscillations (corresponding to chamber pressure, 130 to 150 psia) occur in the ETC. With flow through the turbine exhaust nozzles, there is, however, no unstable pressure region as predicted from the scale-model tests.

d During a rapid startup ramp (150 psi/sec in NEPN-1 Run 4), the ETC pressure lags the operating line equilibrium pressure, but during a rapid shutdown ramp the ETC pressure again deviates from but remains lower than the equilibrium pressure.

e Equilibrium pressure will be reached in the ETC at a hold condition after a rapid startup or shutdown ramp.

Results of the tests showed that air backflow occurs when the steam-generator shutdown coincides with a low or no primary flow (P_c less than 30 psia), or when the primary flow is cut off at a high rate (252 psi/sec) with the secondary ejector not operating.

Analytical models have been developed to predict the ETC over-pressurization due to a malfunction shutdown and the purge requirement to prevent the air backflow into the duct. The mass balance analytical model to calculate air backflow into the duct agrees well with the experimental data. Calculations taking into account of 35 mph head-on wind on the duct opening and condensation of steam on the duct and the walls show that an on-line steam accumulator of 2000 cu. ft. will prevent the air backflow. An alternate approach using helium gas to prevent air backflow shows that 30 lbm/se helium flow rate is established within 0.3 sec after a malfunction in the steam generator system.

2 Facility Gas and Liquid Systems

The test data were analyzed for five of the facility gas and liquid systems. Flow resistances were computed for each system and compared to values based on standard loss coefficients and material obtained from vendors literature. The following summarizes the findings:

System	Overall Flow Resistance, K/A^2, $in.^{-4}$ Test Data	Theoretical	Corrected Theoretical
Liquid Nitrogen	0.26	0.29	0.25
Gaseous Helium	0.16	0.18	0.18
Gaseous Hydrogen	0.12	0.12	0.12
Liquid Hydrogen	0.11	0.05	0.10
Pump Inlet Line	0.0039	0.0032	0.0034

The major discrepancies were in valves and filters; data pertaining to these components were based on vendors literature. The data were frequently erroneous, and the corrected numbers shown are based on measured values. The remaining errors appear to be as good as could be expected in analyzing system losses. Measurement errors in defining each of the systems and variations from theoretical account for errors of this magnitude.

The actual loss-coefficient data were used to prepare models with the analog and digital computers. The following have been modeled.

Analog - High Pressure Liquid Hydrogen System
Digital - High Pressure Liquid Hydrogen System
Gaseous Helium Cooldown Line
Gaseous Hydrogen Cooldown Line
Liquid Nitrogen Cooldown Line

Dynamic response of the high-pressure liquid hydrogen system on the analog computer has been used as a basis for defining and analyzing the emergency cooldown system. The helium data were used on the digital computer to establish the feasibility of a helium emergency cooldown.

3 XE-1 Test Prediction Report

A draft of the XE-1 test prediction report has been prepared. A review copy of the report is expected to be issued early in the next contract year.

This report made maximum use of experience obtained in the NRX/EST.

The report includes the following material:

1. Introduction and Test Objectives

2. Measurements of Engine Operating Characteristics

   This provides installation details for the engine parameter transducers.

3. Test Facilities and Measurements

   Background information is given for the facilities most important to the engine and for installation details of selected measurement transducers.

4. Engine Component Limits

   The XE-1 Test Specification provides the engine operating limits envelope. That envelope is rather general and does not define in detail the true capabilities of the components under all conditions. This section will provide data to help evaluate components if excursions are made outside of the test specification limits.

5. Steady State Maps

Maps will be provided of all major measured parameters wherein the parameters are plotted vs chamber pressure and temperature or other convenient independent variables.

6. Phase I - Checkout and Calibration

Descriptions and predictions will be given of the initial checkout and calibration operations.

7. Cold-Flow Tests

The two cold-flow tests will be predicted. Also, the engine chilldown characteristics will be presented.

8. Phase III - Intermediate Power Tests

The basic data here will be plots vs time of 32 engine parameters. These will be generated by the Common Analog Model. In addition, steady-state hold tabulations will be shown plus any other digital program plots that are especially pertinent for each test.

9. Phase IV - Full-Power Tests

Data will be similar to that of Section 8.

10. Phase V - Remote Handling Demonstration

No predictions are required.

11. Transfer Function Tests

Predictions will be shown for all of the planned dynamic response tests.

12. Engine Cooldown

Normal, scram, and emergency shutdowns will be described. Also, predictions of pulse cooldown characteristics will be presented.

A malfunction report is being generated separately from the test prediction report. Therefore, this subject is not included except for some cooldown data in Section 12.

Most of the preceding data for the report has been assembled. A preliminary set of CAM predictions has been made and reviewed. A delay occurred when the analog computer facilities were damaged by fire and some changes in test plans are expected due to XE-1 reactor core difficulties. However, no problems in meeting the report schedule are expected.

(f) Narrow-Band Data Analyses

Aerojet-General is developing an automatic process to handle test data for the NERVA engine test program. The objective of the data program is to perform the routine data reduction so that engineering personnel can concentrate on the analysis of data. The program utilizes the capabilities of the third-generation IBM 360-65 computer. The report RN-S-0427, XE Data Analysis Program, describes the first phase of the Aerojet NERVA data-analysis program (narrow-band), which is currently operational and has been used with facility test data from ETS-1.

Specifically, the program performs the following functions:

1 Multiple plots of test data, permitting a rapid comparison of the performance of various engine parameters.

2 Performance of engineering calculations, such as flow rate and thermal power, which are required for engineering system evaluation.

3 Data smoothing to minimize the noise from the data for evaluation.

4 Steady-state summaries of selected time slices for component and system evaluation.

5 Measurement anomalies to identify missing or off-scale data and indicate bad data channels.

6 Event listing for the evaluation of test-system performance.

The preceding objectives are met by generating cathode-ray-tube multiple plots for transient conditions and a digital listing for events, measurement anomalies, and steady-state summaries. The program has been designed for rapid operation to meet the requirements of the NERVA program. In particular, the program can complete its work within one day after the receipt of data tapes, including up to 1100 channels of measurements, from the NERVA test operations and can provide the information to the Systems Performance, Evaluation, and Analysis Review team (SPEAR) for their evaluation. Since the NERVA test operations will require one day to generate the necessary engineering-unit tapes required as input to the Aerojet NERVA

data-analysis program, the data will be available at NERVA test operations in a processed form for detailed engineering evaluation two days after an experiment test is run. Also, the output of the program is of sufficient detail that it can be used as a preliminary data-analysis report for each engine test. The use of the program will enable efforts to be concentrated on system performance anomalies, upgrading of computer models, and performance evaluations to relate experimental tests, information available on the hardware, and previous system and component tests. The program format is flexible so that it can be adapted to the analysis of data generated at any point in the NERVA engine program by changing the tape-read routines. In fact, the program can be used to efficiently analyze data from any source where a large number of channels are being measured at a given time.

Phase 1 of the data-analysis program is operational and has been placed on production in the Computing Sciences Library at Aerojet-Sacramento. The program was checked out on tapes obtained from NEPN-1 (a duct test conducted in ETS-1). The program successfully produced cathode-ray-tube multiplots of the data, digital listings of the engineering-unit data, and steady-state averages of all data over selected time periods. Data were averaged, smoothed, and used in special calculations.

Programming is under way for the second phase of the program. In this effort, emphasis is being placed on statistical analysis of steady-state holds, incorporation of instrumentation uncertainties, and inclusion of analytical programs for comparison with test results. Improving the program with the addition of new features will be a continuing effort, which will be completed in phases in order to ensure that an operational version of the program is always available for test analysis.

(g) Wide-Band Data Analysis

The report RN-TM-0427, Wide-Band Data-Processing and Analysis Capability, describes the high-frequency (0 to 20,000 cps) data-analysis capability and the procedures that are used to evaluate NERVA data at Aerojet-Sacramento.

The ultimate purpose of wide-band data analysis is to support the systems-evaluation requirements of the NERVA engine. To achieve this, all variables that can influence the test data must be accounted for and be fully understood so that the data can be properly interpreted.

The program for the data processing and data analysis that will be performed at Aerojet once the FM analog tapes (FM-FM multiplex tapes for NRX tests) are received has been developed. The objective of NRO data-processing and data-analysis programs is to establish an automatic data-processing program that will rapidly yield valid data for use in interpreting test data.

Magnetic tapes are received from the NERVA test operations with the test data recorded in the form of voltages. The tape is processed in accordance with the block diagram shown in Figure 40. Included in the data processing are quality-control checks for validity, special provisions for efficiency and economy of time, and options for performing special-purpose analyses. All wide-band data analysis and special-purpose analyses are requested on a special form to expedite the processing and analysis of wide-band data and to ensure that the request is made correctly.

Computer programs for analyzing transfer functions for the XE test program have been developed by Aerojet General. Report RN-S-0429, Transfer Function Analysis Program, describes the test data demonstration programs used to prove the validity and applicability of these programs. The Aerojet transfer function analysis system accepts 32- and

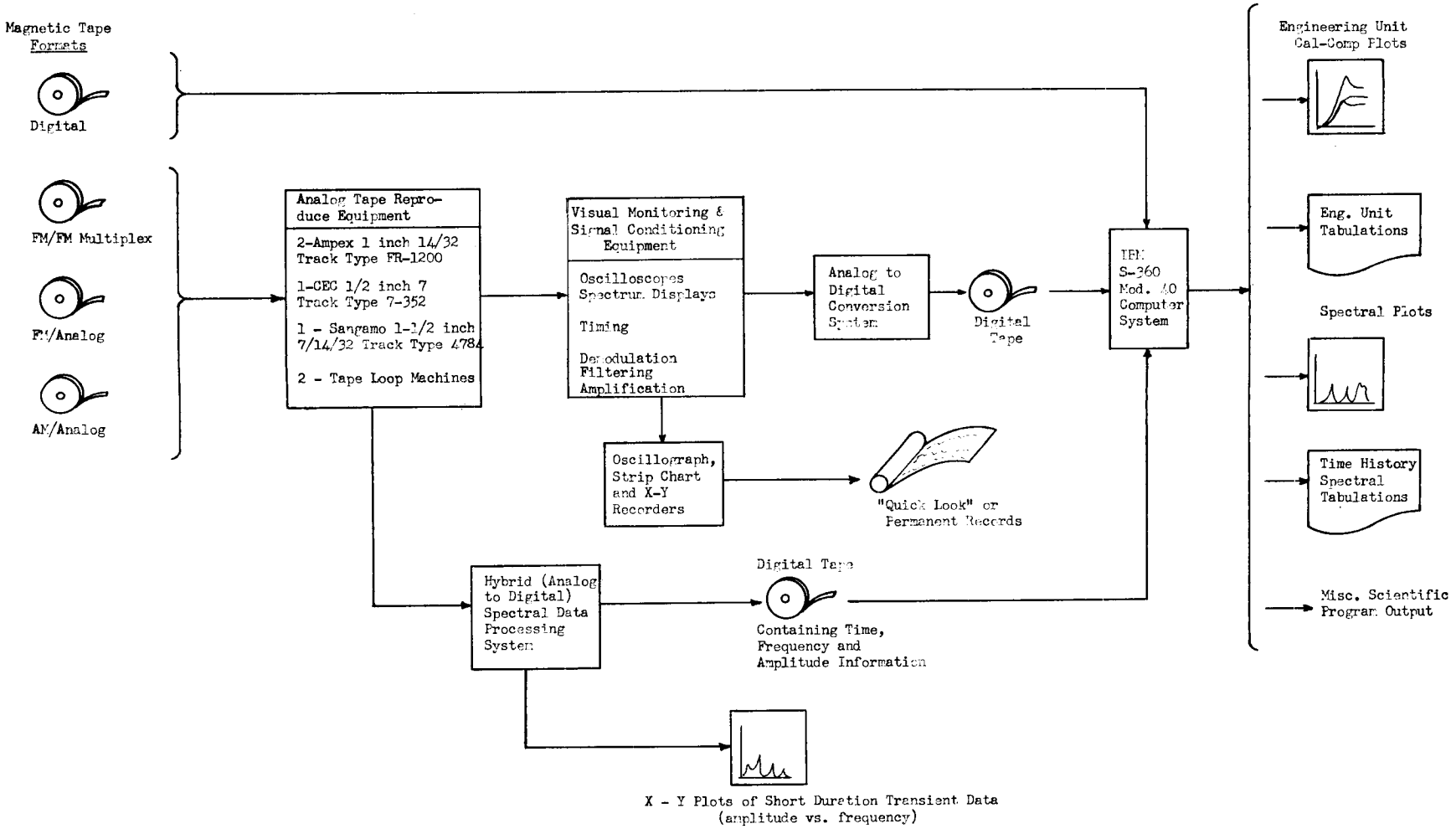


Figure 40 - Equipment Block Diagram for Processing Wide-Band Data

14-channel FM analog tape from NTO AW tapes and, through an integrated processing and analytical system, is able to produce transfer functions (phase and gain) as plots and listings in a short period of time to satisfy the needs of the XE test program.

Two separate programs are used for Aerojet transfer function analyses. The random transfer function program, Job 2907, accepts random inputs, such as random noise, pseudo-random functions, or other appropriate functions, and the deterministic transfer function program, Job 2909, accepts deterministic functions such as step, sine, impulse, or arbitrary functions. The primary difference between the two programs is that for finite-time increments, random noise or pseudo-random inputs (Job 2907) require a larger number of points and also spectral-smoothing methods to assure valid results. The programs were designed specifically for the XE tests and the NERVA program, and several options were built into the program to enable the analyses to be sufficiently flexible and useful to both design and analysis engineers. The demonstration program was also designed to check out these options.

The objective of the demonstration program is to verify that the analytical programs are correct and that the transfer functions can be produced in the three-day period proposed to satisfy SPEAR data requirements. The method used to verify the analytical programs was to numerically program a known second-order transfer function on analog tape. A known input is utilized and by comparing output with input, a transfer function is obtained that can be compared to the true or known transfer function. In all cases in the demonstration test the Aerojet programs performed as required.

The transfer functions are obtained through the use of an integrated processing and analysis system at the Aerojet-Sacramento test area. The processing system has been used for more than 15 years by Aerojet solid and liquid rocket operations. The system includes extensive hardware and software that enable flexibility and utility in the application to the NERVA program. Aerojet Reports No. RN-TM-0427, Wide-Band Data-Processing and Analysis Capability, and RN-TM-0440, Hybrid Spectral Analysis System, describe some of the existing facilities to be used for NERVA programs. With adequate definition and planning and establishment of the necessary controls based on design tests similar to those defined in this report, transfer functions needed for the SPEAR team can be completed within three days after receipt of the AW tapes and well within the seven days to meet Aerojet engineering requirements. By satisfying these time requirements, the transfer function data can be analyzed and appropriate decisions can be made between experimental plans of the XE test program.

In addition to using numerical tapes for checkout of the transfer function programs, an XE simulation transfer function test and analysis was made. A second-order transfer function, similar to that typical of XE equipment, was simulated with an analog computer. Sine, step, and pseudo-random inputs were applied to simulate the actual inputs of the XE tests. The XE simulated-transfer function tests enable evaluation of the processing portion of the transfer function analysis and a better understanding of the use of the different data types.

(h) Hybrid Spectral-Analysis System

Report RN-TM-0440, Hybrid Spectral-Analysis System, summarizes the methods of analysis and processing that will be performed by NRO on X-engine wide-band data to obtain power-spectral-density plots and listings. The system that has been developed and is currently in production at Aerojet-Sacramento is an analog-digital hybrid system that

accepts data directly from 14-channel or 32-channel NTO analog tapes. This system is tied into an IBM 360 Model 40 computer, which completely processes the data and plots or lists the results (or both) in a standard form for a specified level of precision and accuracy.

The hybrid spectral-analysis system has been developed so that valid data can be obtained quickly and economically. It is planned that all significant power-spectral-density plots and listings required by the SPEAR team will be available within three days after receipt of the W-1 wide-band tapes and that all analyses for wide-band data will be completed within a week after receipt of the W-1 tape. This time schedule includes quality-control checks and processing of other non-NERVA data. The hybrid system is a completely self-contained integrated system and will not interfere with other analyses and procedures being performed for wide-band data analyses, except for the use of the computer and plotting equipment.

The hybrid spectral-analysis system is a completely integrated system that enables the mean power spectral density (PSD) and a mean spectral listing to be obtained directly from NTO FM tapes. The hybrid spectral-analysis system consists of three main portions: the input, spectrum-analysis, and output portions. The input portion accepts the FM tape, reproduces it to an analog signal, and amplifies the signal for acceptance into the spectral-analysis portion. The input portion also provides for visual monitoring.

The spectrum-analysis portion, denoted as the Model SA-12 spectrum analyzer, is the major portion of the hybrid spectral-analysis system that processes the data for its desired end use.

The output system includes an X-Y plotter that presents an on-line time history for continuous or memory-stored transient data and presents PSD plots and spectral listings. The PSD and spectral

listings are obtained by sending the signal to the analog-to-digital converter, to the digital tape recorder, and to the IBM 360-40 computer.

b. NERVA Engine Systems Analysis - Development (1.8.1)

RN-S-0435, Systems Analysis of NE and NR Systems Status Report, describes the contribution made by Systems Analysis Department to the NERVA engine program. Parametric studies were made for 15 different engine concepts, ranging in power from 2900 to 5000 Mw. From these parametric and reactor studies by Westinghouse and mission studies by STL, an engine of 200,000-lb-thrust and 4200 Mw was selected. Also, studies of the engine components, flight safety, availability of engine and components, test facility requirements and limitations, and other special studies were performed in support of the NERVA program.

The Systems Analysis Department computer programs, which had been developed for modeling the technology engine, were modified to model the NERVA engine and engine components.

Two of the programs were used to compute NERVA engine system state points for engines operating at a chamber temperature of 4500°R, 3500 to 5000 Mw, and with chamber pressures at 350, 450, 525, and 625 psia. A second series of parametric NERVA engine cases were predicted that covered chamber temperatures from 4250 to 4500°R, and 2900 to 5000 Mw, with chamber pressures of 450 to 625 psia, for low- and high-void fuels.

Facility requirements, as well as flight safety studies, were evaluated for the 5000 Mw engine. The 5000 Mw engine was selected for these studies because it is the largest engine under consideration; therefore, this safety system would be capable of handling all engines under consideration.

After the decision was made to concentrate the effort on the 200,000-lb-thrust engine, special studies were made relative to insertion of low-void fuel, to operation of the engine at an actual 4200 Mw power level, to variations in structural coolant flow to determine the effect on the nozzle-tube pressure drops, and to flight safety and engine component availability. Studies were made for the acceptance testing of the TPA and the turbine inlet and exhaust lines.

NERVA engine system studies were performed to assist in selection of an engine size and optimization of this engine. A 4200-Mw, 200,000-lb-thrust NERVA engine was tentatively selected and special component studies were performed. Optimization of the components and engine system has started.

(1) NERVA Engine Studies

(a) Nuclear Rocket Engine Optimization Program (NOP)

Initially, the NOP program developed by TRW was used to evaluate different NERVA engine designs. This approach was abandoned because the pressure drops across some of the engine components did not agree with those from the Aerojet 16178 program due to simplifications in the NOP program. The NOP program does not include the time-consuming complex analytical computations required to study the thermal and hydrodynamic characteristics of every component for example, NOP program emphasis had been placed on studying the principal variables across major components, so that numerous cases can be studied over a wide range of operating conditions within a limited time. Because of these simplifications, the actual pressure required at the pump discharge, as predicted by the NOP program, is lower than would actually occur. The results from the NOP program would bias the system weight to favor the lower thrust chamber pressures. It was later learned that

the integral relations to compute the heat and momentum transfer, especially for the nozzle and the core, had been modified. Also, the program has an option that makes it possible to carry out systems optimization studies with a fixed core.

(b) NERVA Engines Considered

The following data pertain to the first series of NERVA engines analyzed. The study covers engines at three power levels with four different chamber pressures at each power level.

FIRST SERIES OF NERVA ENGINES EVALUATED

Case No.	Power, Mw	Thrust Chamber		Nozzle Throat Area, ft^2
		Temperature, °R	Pressure, psia	
1	5000	4500	625	1.529
2	5000	4500	525	1.8202
3	5000	4500	450	2.1236
4	5000	4500	350	2.7303
5	4250	4500	625	1.2996
6	4250	4500	525	1.5472
7	4250	4500	450	1.8051
8	4250	4500	350	2.3210
9	3500	4500	625	1.0703
10	3500	4500	525	1.2742
11	3500	4500	450	1.4865
12	3500	4500	350	1.9112

The mathematical model and input in the 16178 program for this study contained the NERVA main nozzle (ε = 4:1), skirt (ε = 4:1 to 40:1), skirt extension (ε = 40:1 to 100:1), structural support, and turbine and pump, including bearing and bolt coolant. For all of the

above runs the current NERVA pump-head curves were used, but the efficiency was held constant at 75% and the turbine efficiency at 63%. A plot of I_{sp}, power and thrust is shown in Figure 41.

(c) Second NERVA Engine Series Evaluated

With new input from the components groups and Westinghouse, a second series of parametric NERVA engine cases was calculated. These engine cases are designated by letters, as indicated below:

BASIC CHARACTERISTICS, NERVA SYSTEM CONFIGURATION

November 1966 Series

Case	Nominal Power Level, Mw	Thrust Chamber Pressure, psia	Thrust Chamber Temperature, °R	Nozzle Flow Rate, lb/sec	Remarks
A	5000	625	4500	280	High-void fuel
B	5000	525	4500	280	
C	5000	450	4500	280	
D	4000	625	4500	224	
E	4000	525	4500	224	
F	4000	450	4500	224	
AA	5000	625	4500	280	Low-void fuel
BB	5000	525	4500	280	
CC	5000	450	4500	280	
DD	4000	625	4500	224	
EE	4000	525	4500	224	
FF	4000	450	4500	224	
G	5000	625	4250	308	High-bypass flow
H	2900	625	4250	179	Low-void fuel, low power; present fuel design
D-5	5000	625	4500	285	Advanced concept

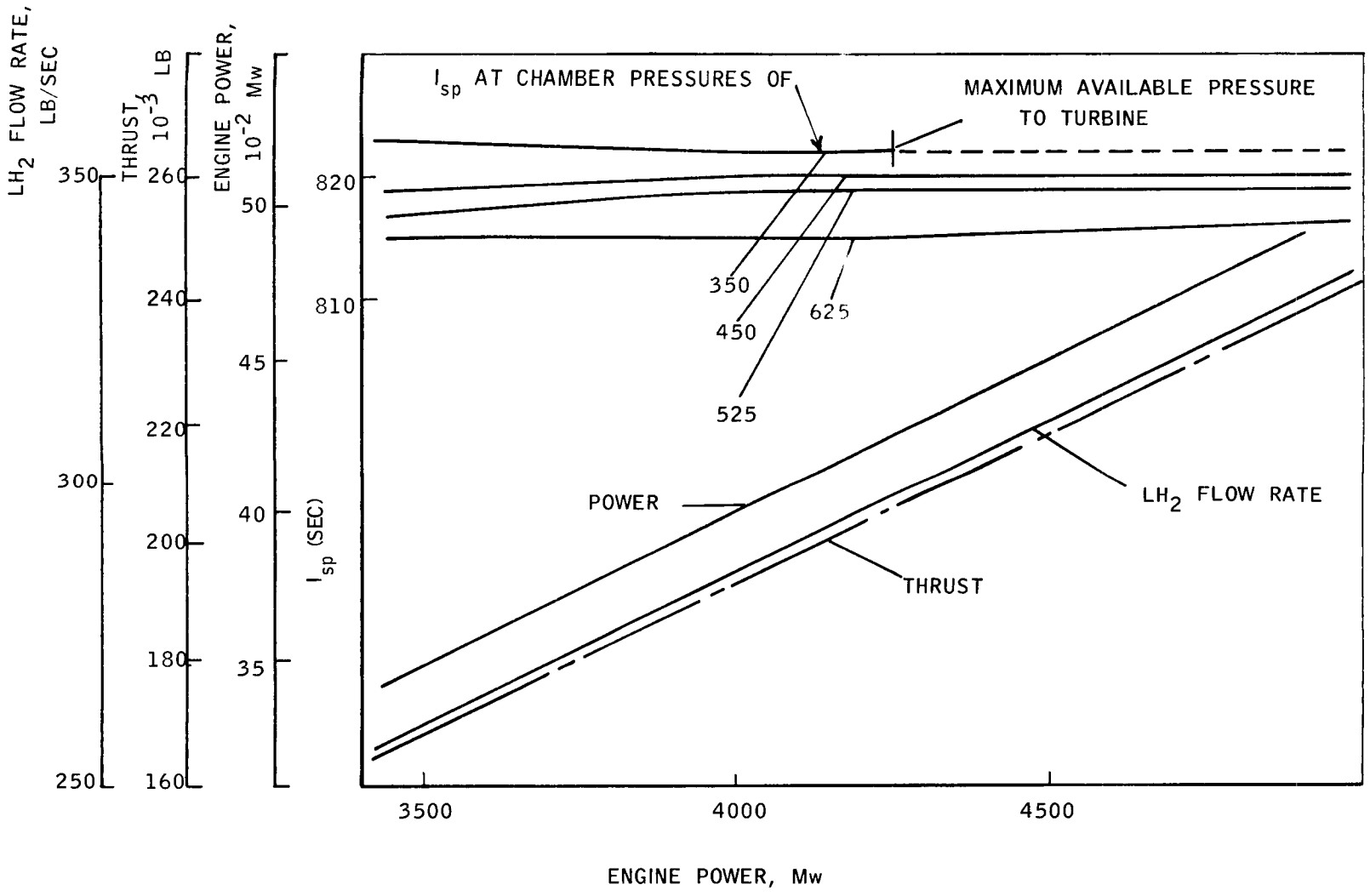


Figure 41 - NERVA Engine Performance Curves

NERVA engine system state points for the preceding engines were obtained by systems analysis based on the STL mission studies, input by Westinghouse the NERVA Project, and the customer. This coordinated effort reduced the number of NERVA engines to types "A" and "D". These two engines were 5000 Mw, 242,000-lb-thrust and 4000-Mw, 194,000-lb-thrust engines.

(d) Third NERVA Engine Series Evaluated

The 4000-Mw engine Case "D" nozzle throat was increased to give a flow rate of 230 lb/sec at T_c = 4500°R and P_c = 625 psia. Several variations were considered: low-void fuel, low flow, structural coolant, increased flow through the engine to produce an exact power of 4200 Mw, and many others. The NERVA engine then settled to a 4200 Mw (nominal) and 200K NERVA engine, P_c = 625, T_c = 4500°R, and nozzle flow rate of 230 lb/sec. Tables 7, 8, and 9 are steady-state point values at 100, 60, and 30% of engine power for this engine.

These state point values are being refined with a new and more detailed transient computer program D31201. New component input reflecting the latest improvements to the components is now being reduced for input into this program.

(2) Availability Studies

A method has been established for comparing the thermodynamic behavior of various NERVA engine systems as well as the individual components that make up the system. This comparison can be used to identify promising areas of engine system or component modifications, that would increase overall engine specific impulse.

TABLE 7

NERVA ENGINE (100% Power)

DATE 29 May 1967

Engine: Pc = 625 psia; Tc = 4500°R; Thrust = 199,949 lb; Impulse = 822.8 sec; Power Level = 4096 Mw; TPCV = 50.9 degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm	5,520	16,746	5,520	16,746
Power, Mw	0.76	20.7	0.76	20.7
Efficiency, %	58	67.3	22	64.81
NPSP, psi	0	38		
Quality, %	.3			

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp. °R	Heat Flux Mw
Dewar Outlet	243	30	30	40.8	
Inducer Inlet	243	29.7	30	40.8	
Pump Inlet	243		70	41.9	
Pump Leakage	1.01		1301	60.7	
Pump Outlet	242		1301	60.7	
Structure Support	32		799	296	
Structure Bypass	17.5		799	60.7	
Nozzle Manifold Inlet	124		1263	60.7	
Nozzle Outlet	114		872	198	62
Bolt Coolant	10		1263	60.7	
Skirt Outlet	68		872	189	
Reflector Inlet	184		872	182	42
Reflector Outlet	184		803	238	
Periph. Shield Outlet	184		799	240	
Support Plate Inlet	233.6		799	235	
Central Shield Inlet	233.6		793	237	
Core Inlet	233.6		772	263	3990
Core Outlet	233.6		625	4500	

TABLE 7 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	230		625	4500	
Diluent Bleed Inlet	8.43		872	182	
Diluent Bleed Outlet	8.43				
Hot Bleed	3.90		625	4500	
Mixing Ring Outlet	12.33		623	1660	
TPCV Inlet	12.33		592	1660	
Main Turbine Inlet	12.33	470	470	1660	
Inducer Turbine Inlet	12.33		67.3	1212	
Inducer Turbine Outlet	12.33	57	60.6	1192	
Skirt Extension Inlet	13.34		30	1100	
Skirt Extension Outlet	13.34	3.6	8.1	1663	

12013 Restart 240567 S 21165
time = 62 sec

Skirt maximum material temperature = 1742°R

TABLE 8

NERVA ENGINE (60% Power)

DATE 8 June 1967

Engine: Pc = 456 psia; Tc = 3400°R; Thrust = 144,183 lb; Impulse = 699 sec; Power Level = 2525 Mw; TPCV = 49.72 degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm	5,080	14,055	5,080	14,055
Power, Mw	.63	12.4	.63	12.4
Efficiency, %	59	67.17	35.6	64.62
NPSP, psi	0	38		
Quality, %	.3			

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	206.5	30	30	40.8	
Inducer Inlet	206.5	29.8	30	40.8	
Pump Inlet	206.5		70	41.9	
Pump Leakage	.86		936	55.3	
Pump Outlet	205.6		936	55.3	
Structure Support	32		584	210	
Structure Bypass	9.5		584	55.3	
Nozzle Manifold Inlet	103.5		908	55.3	39
Nozzle Outlet	96.4		637	152	
Bolt Coolant	7.12		637	55.3	
Skirt Outlet	60.5		637	134	
Reflector Inlet	157		637	138	26
Reflector Outlet	157		587	184	
Periph. Shield Outlet	157		584	186	
Support Plate Inlet	198		584	181	
Central Shield Inlet	198		580	182	
Core Inlet	198		564	203	2464
Core Outlet	198		456	3400	

TABLE 8 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	195		456	3400	
Diluent Bleed Inlet	7.19		637	138	
Diluent Bleed Outlet	7.19				
Hot Bleed	3.23		456	3400	
Mixing Ring Outlet	10.42		454	1182	
TPCV Inlet	10.42		438	1182	
Main Turbine Inlet	10.42		335	1182	
Inducer Turbine Inlet	10.42		47.76	860	
Inducer Turbine Outlet	10.42	36.6	39.2	844	
Skirt Extension Inlet	11.28		22	780	
Skirt Extension Outlet	11.28		6.13	1174	

12013 Restart 030667 S 21167
time = 79 sec

Skirt maximum material temperature = 1276°R

TABLE 9

NERVA ENGINE (30% Power)

DATE 8 June 1967

Engine: Pc = 284 psia; Tc = 2300°R; Thrust = 89,290 lb; Impulse = 567 sec; Power Level = 1266 Mw; TPCV = 46.44 degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm	4,600	10,568	4,600	10,568
Power, Mw	.515	5.26	.515	5.26
Efficiency, %	.55	66.99		63.35k
NPSP, psi	0	38		
Quality, %	.3			

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	157.8	30	30	40.8	
Inducer Inlet	157.8		30	40.8	
Pump Inlet	157.8		70	41.9	
Pump Leakage	.67		558	49.54	
Pump Outlet	157.1		558	49.54	
Structure Support	31.3		363	106	
Structure Bypass	0				
Nozzle Manifold Inlet	78.5		541	49.54	21
Nozzle Outlet	72.4		394	105	
Bolt Coolant	6.12		394	49.54	
Skirt Outlet	47.26		394	95	
Reflector Inlet	120		394	95	13
Reflector Outlet	120		366	125	
Periph. Shield Outlet	120		363	126	
Support Plate Inlet	152		363	122	
Central Shield Inlet	152		361	123	
Core Inlet	152		351	139	1237
Core Outlet	152		284	2300	

TABLE 9 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	149		284	2300	
Diluent Bleed Inlet	5.53		541	49.54	
Diluent Bleed Outlet	5.53				
Hot Bleed	2.15		284	710	
Mixing Ring Outlet	7.68		282	710	
TPCV Inlet	7.68		248	710	
Main Turbine Inlet	7.68		191	710	
Inducer Turbine Inlet	7.68		27.4	520	
Inducer Turbine Outlet	7.68	21	22.9	502	
Skirt Extension Inlet	8.35		15	502	
Skirt Extension Outlet	8.35		3.5	767	

12013 Restart 030667 S 21167
tiem = 98 sec

In the past, problems have resulted from comparison of actual to ideal cycles that were based on an isentropic or a constant pressure ideal cycle. Using either of these ideal cycles, the heat-exchange portion of the engine cycle is penalized relative to the turbo-pump and lines, since the items being compared are not relative to the same datum state.

A method for improving this comparison is to use a reversible heat engine for the ideal cycle comparison. Thus each fluid state point in the engine will be coupled thermodynamically to a fixed datum state point by a reversible heat engine, and the resulting work will be calculated. This method gives an accurate thermodynamic comparison of various components and the cycles from which they come.

The individual component heat losses within the engine system are calculated as the percentage of the total lost heat and the actual effective efficiency of the engine component. The total lost heat from a component is indicative of the relative effect that each component has on the overall engine efficiency, while the effective efficiency is a measure of the thermodynamic effectiveness compared with an ideal reversible cycle operating between the same state points. These two measures of component efficiency are related to give an overall engine effect by a calculated improvability as defined: Improvability = (100 - efficiency percent) x (percent of total loss).

This approach is used to indicate the potential for engine system efficiency improvement by showing the effect that each component can have on the system. A component with a large improvability factor decreases the overall efficiency of the system more than a component with a smaller factor, indicating where effort should be concentrated to improve the system specific impulse.

This method of cycle/component comparison has been used to evaluate and compare NERVA engine cases. From these studies, the comparison of actual to reversible heat engines was shown to be a satisfactory method of evaluating engine components. Subsequently, a computer program was written to accept thermodynamic steady-state data from the 16178 program and to calculate the component and system availabilities and irreversibilities. These data are then compared with those for the reversible cycle. Thus, by independently varying such parameters as temperature, pressure, flow rate, pressure drop, etc., of various components, the net effect on that component and the entire system can be shown. A study has been made of NERVA Case "D" with this program.

A more intensive study is being prepared, of the NERVA 4200 Mw, 200,000-lb-thrust engine in which each component is independently varied relative to operating conditions to show overall engine performance as a function of component variation.

(3) Test Stand and Cooldown Studies

During the past year, study of the operations of a NERVA engine system relative to static ground-test facilities was separated into two major areas of effort. First, a study was made of the feasibility of testing NE-1 in ETS-1, with major emphasis given to evaluation of system-startup capability and an assessment of emergency fluid system adequacy. Secondly, the emergency cooldown scheme was evaluated to verify existing E/STS 2-3 facility design criteria. In addition, a matrix of candidate cooldown schemes was developed as a basis for E/STS 2-3 emergency cooldown optimization. Reports covering this work have been issued.

(4) Flight Safety

Because of the importance of system integrity in suborbital paths, the requirements of a 5000 Mw NERVA engine emergency-cooldown system were explored. The basic requirements are to maintain the engine system integrity until the engine can be disposed of.

(a) Coolant Flow Path

The effect of variations in the coolant flow path was studied. Various methods of introducing coolant for emergency cooldown were analyzed including dome, structural support system, and pump discharge. Apparently the best approach appears to be to use the normal flow path and to introduce coolant at the pump discharge.

(b) Emergency Cooldown Systems

An emergency system supplying coolant to the pump discharge line is capable of handling any malfunction upstream of the entry point, from the TPA through the main LH_2 supply tank. If this section remains operational, the engine system can be shut down using the TPA in the fast shut-down mode.

(c) TPA and Inlet Lines Intact

The 16178 computer program was used to generate a fast shut-down curve if a failure occurs during flight to determine the time from scram to discard the reactor. The times calculated before the core material temperature reaches 5000°R are as follows:

TIME FROM SCRAM TO DISCARD REACTOR

Close TPCV at T_c = °R	4500	4090	3400	2400	1000	890
Time, sec	1.7	14.4	27.3	42.8	*	*

*As long as LH_2 lasts in propellant feed tank

(d) TPA Failure

Studies were made of the emergency cooldown system requirements for the case in which the normal flow path remains intact and failure of the TPA occurs. With no auxiliary cooling, the time to discard the reactor would be the same as that described in Section 4.3.

A preliminary investigation of the requirements of a system to supply auxiliary coolant at rates specified by WANL for the nuclear subsystem indicated that a simple blowdown tank at 350 psia was feasible. Nozzle considerations did not increase the engine system requirements for the accident being investigated. An auxiliary tank containing 3100 lb of LH_2 at 350 psia and with an ullage of 0.2 will supply adequate coolant for the engine system.

(5) Special Studies

(a) NERVA Engine Specific Impulse

At the beginning of the program, I_{sp} for the NERVA engine was tentative and was not critical since most of the work was on a comparative basis. Work continued in establishing the best actual value of I_{sp} for the NERVA engine by a special study group and these values are now used in predicting NERVA engine thrust and I_{sp} as of June 1967.

(b) Turbopump Assembly

1 NERVA Engine Turbine Constraints for 200,000-lb-Thrust Engine

The maximum turbine inlet temperature and speed were investigated for three possible design turbine inlet temperatures (1660, 1600, and 1500°R) in case the TPCV fails in the open position.

The TPCV was fully opened in 0.1 sec to simulate a TPCV failure for turbine design inlet temperature of 1660°R, 1600°R, and 1500°R. The turbine constraint curve would be exceeded if the TPCV fails open at the turbine inlet temperature of 1660°R, which would rise to 1853°R with a TPA shaft speed of 18,315 rpm. At the 1500 and 1600°R design inlet turbine temperature the turbine constraint curve is not exceeded.

2 200,000-lb NERVA Engine TPA Acceptance Test

Six points which bound a NERVA engine constraint map were selected as points for TPA acceptance testing. Point "A" is beyond the following data shows the values recommended for a TPA acceptance testing program by Systems Analysis for the 200,000-lb-thrust NERVA engine.

SYSTEMS ANALYSIS TPA TEST POINTS

	Description	Point A	Point B	Point C	Point D	Point E	Point F
T_c	Thrust Chamber Temp, °R	4,650	4,180	5,000	5,000	1,000	1,000
P_c	Thrust Chamber Pressure, psia	745	680	598	300	40	220
T_{11}	Turbine Inlet Temp, °R	1,910	1,740	1,630	1,050	300	750
P_{11}	Turbine Inlet Pressure, psia	630	568	440	120	80	260
N_T	TPA Speed, rpm	18,500	17,700	16,600	12,000	840	11,500
ΔP_{1-2}	Pump Head Rise, psid	1,515	1,410	1,195	600	200	590
$\dot{w}_p$	Pump Flow Weight Rate, lb/sec	287	275	220	108	35	185

(c) NERVA Engine (200,000-lb-Thrust) Tolerance Study

A pressure tolerance study for the NERVA engine, with varying degrees of conservation in ΔP uncertainty, was made to determine the maximum most probable pressure the pump may be required to deliver. Using the root mean square method with a mean value ΔH of 1271 psid, the most probable design pump head rise would be 1297 psid.

(d) Turbine Inlet Line

A study of the turbine inlet line was made using existing technology engine hardware and ideal hardware for the NERVA engine. The present turbine inlet line for the NERVA engine requires two hot-bleed ports and two sets of TPCV's and weighs about 496 lb. A single 5 in. (ID) ideal line would weigh about 280 lb.

(e) Turbine Exhaust Line

Several turbine exhaust line sizes that were evaluated are shown below. Two 8 in. ID lines were selected for the turbine exhaust system. This will give a turbine discharge pressure of ~49 psia with an exit Mach number of 0.3.

TURBINE EXHAUST LINE
WEIGHTS

Line ID, in.	For Two Exhaust Lines lb	lb/ft
6	133	2.72
7	155	3.17
8	177	3.62
9	199	4.0

(f) TPA Affects I_{sp}

Turbine inlet temperature and the effect of pump and turbine efficiencies on engine I_{sp} at the 100% power design point were investigated and reported.

(g) Engine Operating Map

Two engine operating maps were completed: one for the 5000-Mw engine and the other for the 4200-Mw engine (Figures 42 and 43).

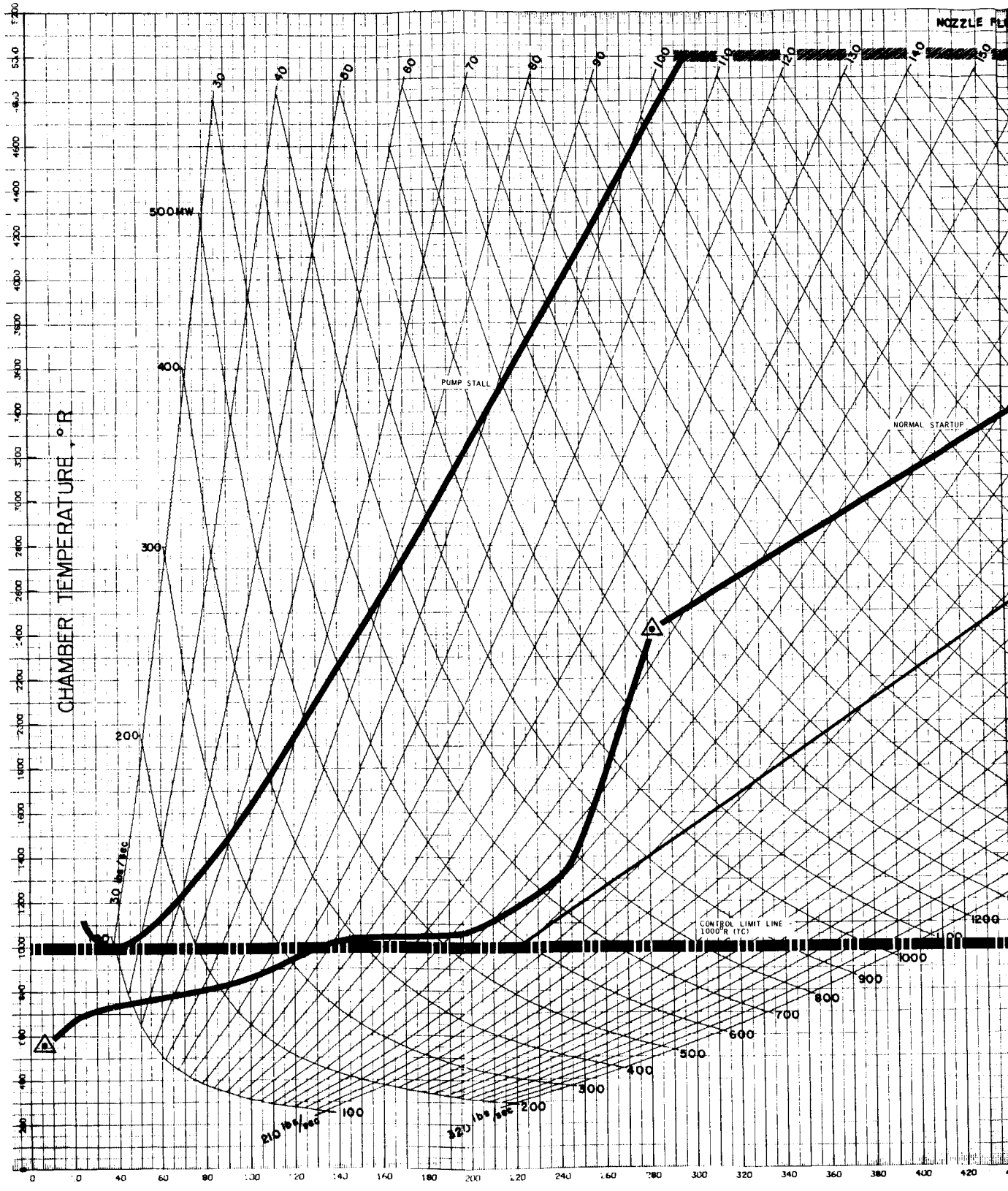
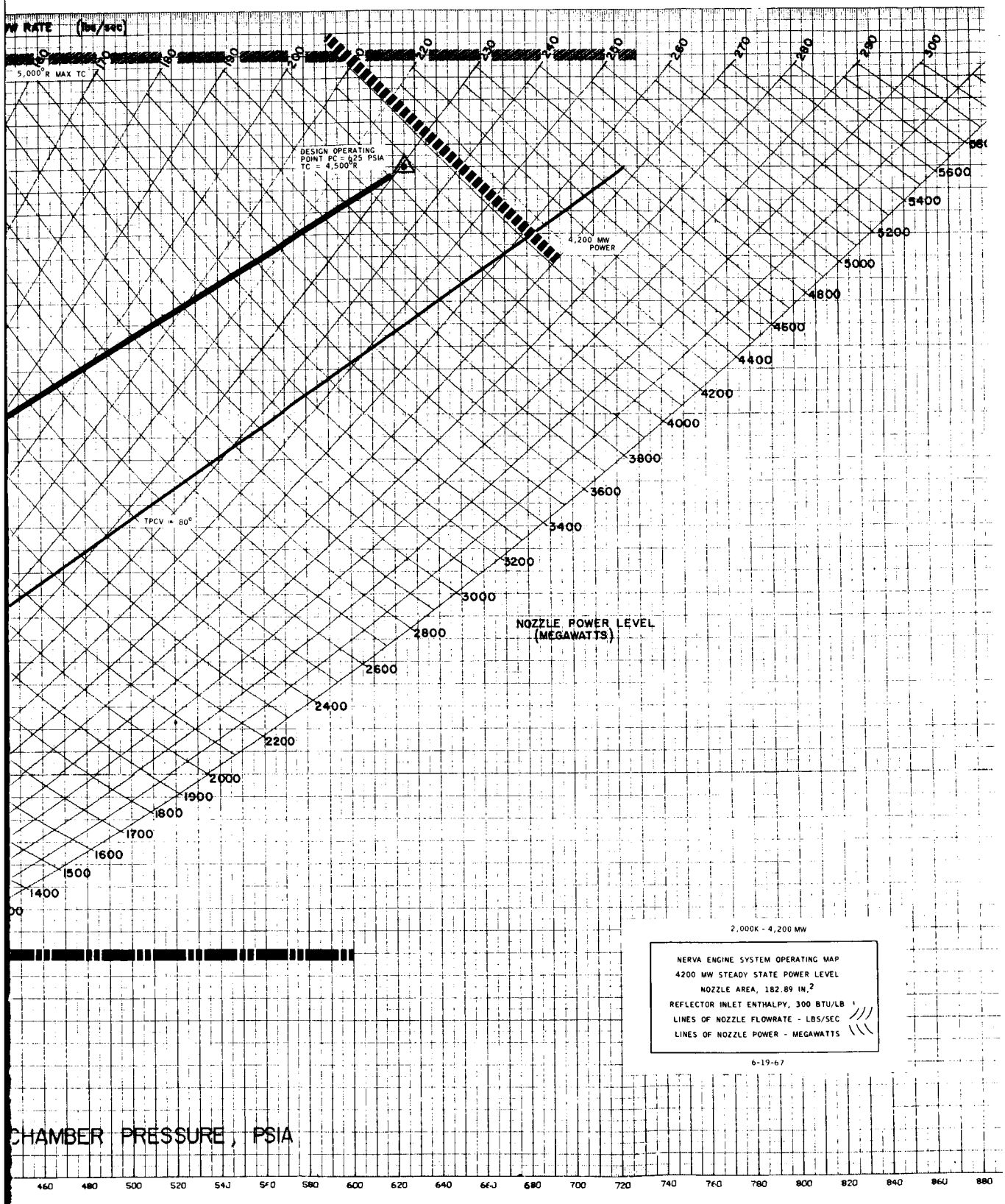
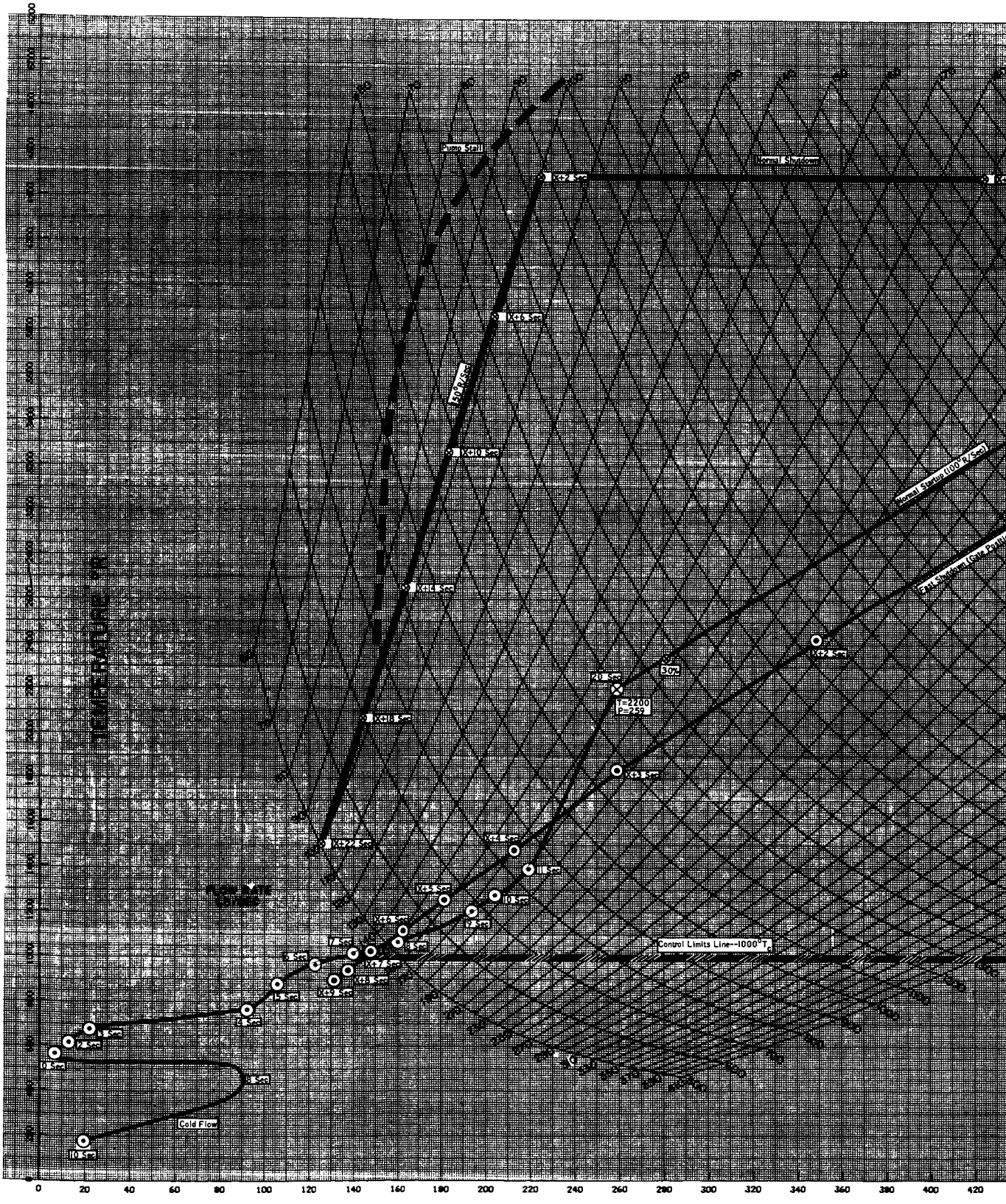


Figure 42 - Engine Operating Map, 4200 Mw Engine


W RATE (lbs/sec)
5,000°R MAX TC
DESIGN OPERATING POINT PC = 625 PSIA TC = 4,500°R
4,200 MW POWER
TPCV = 80°
NOZZLE POWER LEVEL (MEGAWATTS)
2,000K - 4,200 MW
NERVA ENGINE SYSTEM OPERATING MAP
4200 MW STEADY STATE POWER LEVEL
NOZZLE AREA, 182.89 IN.²
REFLECTOR INLET ENTHALPY, 300 BTU/LB
LINES OF NOZZLE FLOWRATE - LBS/SEC
LINES OF NOZZLE POWER - MEGAWATTS
6-19-67
CHAMBER PRESSURE, PSIA

2-16-2


Jump Stall
Normal Shutdown
Normal Startup (100°R/Sec)
Fast Shutdown (Safe Path)
Control Limits Line--1000°T
Cold Flow
TEMPERATURE °R
FLOW RATE
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420

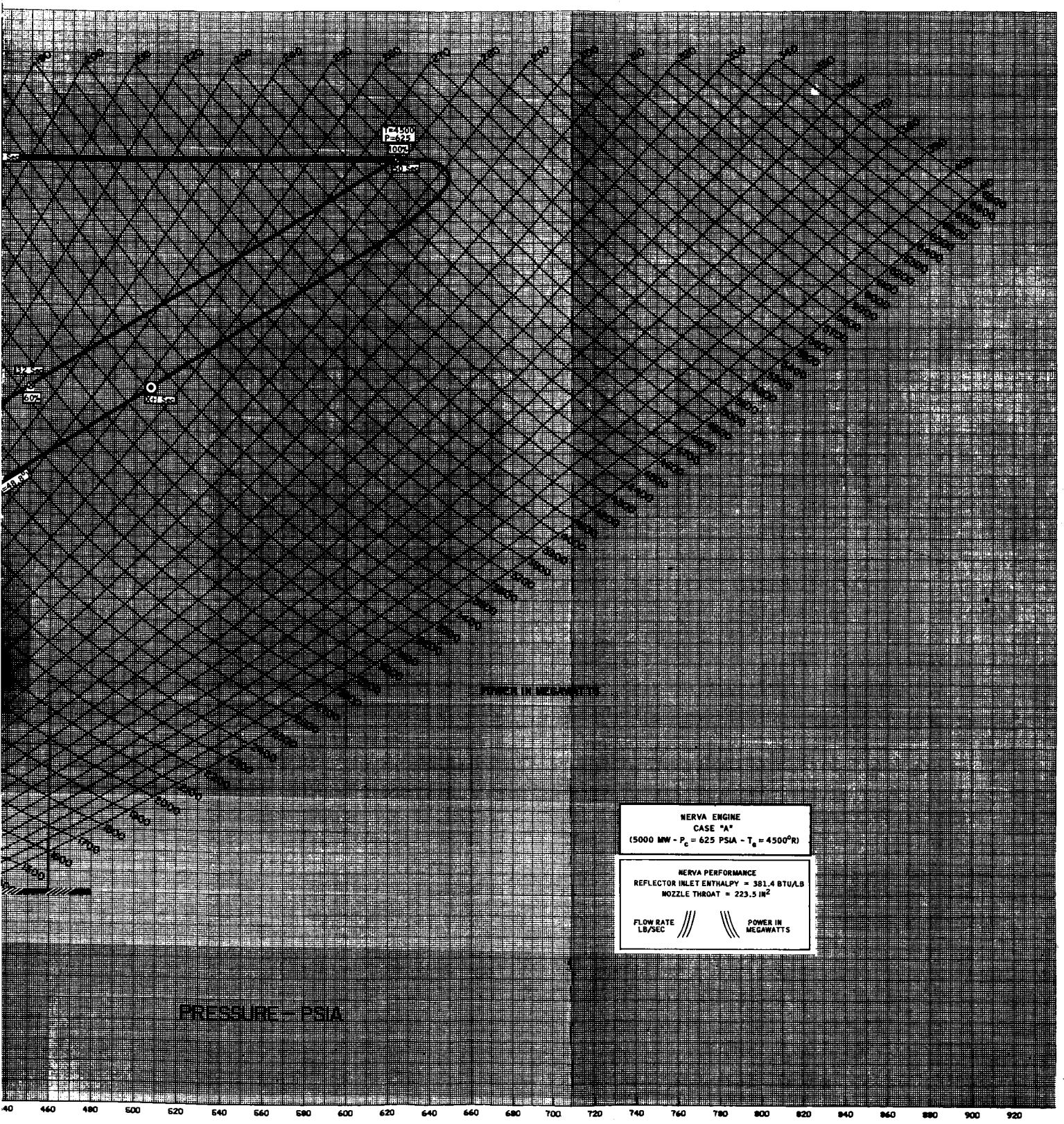


Figure 43 - Engine Operating Map, 5000 Mw Engine

(h) Engine System Digital Computer Program Development

The report, RN-S-0432, Transient Engine Simulation Program (FORTRAN IV), documents the present status of the transient engine simulation program (Program 31201) and shows the development of the equations, together with the logic used in their solution. The basic aim in the development of this program was to provide a mathematical model of the various NERVA engine systems that could be used to study the performance and operating characteristics of these systems and to provide valuable design information.

The current program is the result of several years of development effort. The earlier versions of the program were written in IBM 7094 machine language. As the program developed, options were added, and program complexity was increased until the size limitations of the 7094 computer were reached. As additional operating capability was needed, several special-purpose versions of the program were made, each one oriented toward a specific engine system configuration. When the IBM 360/65 computer was acquired, a decision was made to rewrite the program in FORTRAN IV specifically for this new computer. All of the special routines in the different versions of the program were to be included, as well as several new options that appeared to be desirable. The program was to be general enough so that almost any nuclear engine system could be analyzed by setting up the proper input.

The program in its present form provides the desired versatility. Any of the nuclear engine systems now under study (X-engine, NERVA, NRX) can be modeled by proper choice of input. In addition, the arrangement of the program into many short subroutines provides for ease of modification and of replacing portions of the program with an alternate calculation procedure.

c. NRX Systems Analysis (1.8.2)

The NRX-A5 Data Analysis Report (RN-S-0317) was issued in October 1966.

Technical support was supplied for the NRX-A6 and A-7 reactor systems, including review of test plans, test specifications, and systems analysis activities at WANL. A common analog model was developed for NRX-A6 in conjunction with WANL for systems analysis and control design.

Steady-state points for NRX-A6 at 100, 60, and 30% of full power were run incorporating the reactor configuration data obtained from WANL (Table 10). WANL's proposed start-up ramps for NRX-A6 were analyzed to determine if the operating line would intercept the region that produced oscillations in the NRX/EST system test. Finally it was determined that the test set-up would not provide the desired data.

An analysis was performed to determine the difference between the mixed mean temperature at the core exit plane of the NRX-A6 test article and at the chamber temperature probes. Chamber temperature of the NRX-A6 test article is monitored by measurement channels AT-138-CA through AT-141-CA. The probes for these measurement channels are located at Station 68.8, several inches downstream of the core exit plane. Because the probes are located some distance from the core exit plane, the temperature recorded will be lower than that which actually exists at the core exit plane. This decrease in temperature is due to the heat transferred through the nozzle tubes to the relatively cool fluid entering the system. The total fluid temperature at Station 68.8 (the station of the temperature probes) was determined from an energy balance on the nozzle tubes. Although the gases do not stagnate adiabatically about the probe, the error in temperature due to nonadiabatic recovery is not significant.

TABLE 10

POWER LEVEL STATE-POINT PARAMETERS FOR NRX-A6*

Parameter	100% 1125 Mw	60% 675 Mw	30% 338 Mw
Flow Rate, lb/sec	71.3	56.3	40.7
Nozzle Inlet Pressure, psia	883	614	374
Nozzle Inlet Temperature, °R	53	53	53
Reflector Inlet Pressure, psia	739	517	317
Reflector Inlet Temperature, °R	155	128	102
Shield 1 Inlet Pressure, psia	712	499	305
Shield 1 Inlet Temperature, °R	195	161	126
Shield 2 Inlet Pressure, psia	709	496	304
Shield 2 Inlet Temperature, °R	197	163	128
Core Support Plate Inlet Pressure, psia	708	495	303
Core Support Plate Inlet Temperature, °R	200	165	129
Core Inlet Pressure, psia	704	493	301
Core Inlet Temperature, °R	210	174	136
Core Outlet Pressure, psia	571	398	242
Core Outlet Temperature, °R	4090	3250	2340
Pressure Drops, psi			
Nozzle	145	96	57
Reflector	26	18	12
Shield 1	3.7	2.6	1.7
Shield 2	1.0	0.6	0.4
Core Support Plate	4.3	3.1	2.0
Core	133	94	59
Fluid Temperature Rises, °R			
Nozzle	102	74	49
Reflector	40	34	24
Shield 1	2.4	2.1	1.6
Shield 2	2.1	1.8	1.4
Core Support Plate	10	8.8	6.8
Core	3881	3076	2204

*Based on an as-measured nozzle throat area of 59.173 $in.^2$

An availability analysis of the NRX-A6 system was performed using the 16178 computer program.

A nozzle chamber operating map was issued for NRX-A6 showing chamber pressure, temperature, flow rate, and reactor power as well as the engine operating constraints.

A study was made with a proposed NRX-A7 to determine the maximum chamber pressure and power that would be reached before exceeding the maximum reflector inlet pressure of 890 psia. The limits in the nozzle chamber were relaxed for this study. The conclusions were that a power increase of from 32 to 40% may be obtained with the NERVA core without redesigning the nozzle if chamber pressures of approximately 750 psia are acceptable. A 57% increase in power results when the nozzle throat diameter is increased to 10 in., with an attendant chamber pressure of 610 psia. The NERVA-type core, used in conjunction with a nozzle throat increased to 10 in., resulted in a power increase of 75%. The chamber pressure was nearly 700 psia.

d. NERVA Reactor Systems Analysis (1.8.3)

A series of parametric studies was performed in conjunction with the parametric and optimization studies on the NERVA engine system to define the NR reactor system. Various combinations of high- and low-void fuel fractions were investigated for reactor power levels between 2900 and 5000 Mw. Data for the 100%, 60%, and 30% NR engine system are presented as Tables 11, 12, and 13.

TABLE 11

NERVA ENGINE CASE D
(100% Power Point)

NR

DATE 12 April 1967

Engine: Pc = 636 psia; Tc = 4500°R; Thrust = 208,607 lb; Impulse = 906 sec;
Power Level = 4000 Mw; TPCV = (None) degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm				
Power, Mw				
Efficiency, %				
NPSP, psi				
Quality, %				

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	120.0		1313	50	
Inducer Inlet					
Pump Inlet					
Pump Leakage					
Pump Outlet					
Structure Support	40.0		1313	50	
Structure Bypass					
Nozzle Manifold Inlet	120.0		1278	50	
Nozzle Outlet	120.0		892	183	
Bolt Coolant					
Skirt Outlet	70.3		892	194	
Reflector Inlet	190.3		892	187	
Reflector Outlet	190.3		815	233	
Shield 1 Inlet	230.2		815	245	
Shield 1 Outlet	230.2		806	246	
Shield 2 Outlet	230.2		798	261	
Core Inlet	230.2		784	275	
Core Outlet	230.2		636	4500	

TABLE 11 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	230.2		636	4500	
Diluent Bleed Inlet					
Diluent Bleed Outlet					
Hot Bleed					
Mixing Ring Outlet					
TPCV Inlet					
Main Turbine Inlet					
Inducer Turbine Inlet					
Inducer Turbine Outlet					
Skirt Extension Inlet					
Skirt Extension Outlet					

TABLE 12

NERVA ENGINE CASE D
(60% Power Point)

NR

DATE 15 April 1967

Engine: Pc = 347 psia; Tc = 3460°R; Thrust = 111,368 lb; Impulse 768 sec;
Power Level = 2400 Mw; TPCV =(None) degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm				
Power, Mw				
Efficiency, %				
NPSP, psi				
Quality, %				

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	(PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	144.9		688	50	
Inducer Inlet					
Pump Inlet					
Pump Leakage					
Pump Outlet					
Structure Support	26.6		688	50	
Structure Bypass					
Nozzle Manifold Inlet	76.5		674	50	
Nozzle Outlet	76.5		489	148	
Bolt Coolant					
Skirt Outlet	41.8		489	151	
Reflector Inlet	118.4		489	150	
Reflector Outlet	118.4		448	191	
Shield 1 Inlet	144.9		443	200	
Shield 1 Outlet	144.9		438	201	
Shield 2 Outlet	144.9		438	214	
Core Inlet	144.9		430	225	
Core Outlet	144.9		347	3460	

TABLE 12 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	144.9		347	3460	
Diluent Bleed Inlet					
Diluent Bleed Outlet					
Hot Bleed					
Mixing Ring Outlet					
TPCV Inlet					
Main Turbine Inlet					
Inducer Turbine Inlet					
Inducer Turbine Outlet					
Skirt Extension Inlet					
Skirt Extension Outlet					

TABLE 13

NERVA ENGINE CASE D
(30% Power Point)

NR

DATE 19 April 1967

Engine: Pc = 226 psia; Tc = 2338°R; Thrust = 71,059 lb; Impulse = 613 sec;
Power Level = 1200 Mw; TPCV =(None) degrees

Turbopump:	Inducer	Pump	Ind. Turbine	Turbine
Shaft Speed, rpm				
Power, Mw				
Efficiency, %				
NPSP, psi				
Quality, %				

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	(PO) Total	Temp, °R	Heat Flux Mw
Dewar Outlet	115.9		452	50	
Inducer Inlet					
Pump Inlet					
Pump Leakage					
Pump Outlet					
Structure Support	21.2		452	50	
Structure Bypass					
Nozzle Manifold Inlet	59.6		443	50	
Nozzle Outlet	59.6		324	116	
Bolt Coolant					
Skirt Outlet	35.1		324	102	
Reflector Inlet	94.7		324	111	
Reflector Outlet	94.7		296	144	
Shield 1 Inlet	115.9		296	145	
Shield 1 Outlet	115.9		292	149	
Shield 2 Outlet	115.9		289	161	
Core Inlet	115.9		283	169	
Core Outlet	115.9		226	2338	

TABLE 13 (cont.)

State Point Description	Flow lb/sec	Pressure, psia (PS) Static	Pressure, psia (PO) Total	Temp, °R	Heat Flux Mw
Nozzle Chamber	115.9		226	2338	
Diluent Bleed Inlet					
Diluent Bleed Outlet					
Hot Bleed					
Mixing Ring Outlet					
TPCV Inlet					
Main Turbine Inlet					
Inducer Turbine Inlet					
Inducer Turbine Outlet					
Skirt Extension Inlet					
Skirt Extension Outlet					

Table 14 provides the state point conditions within the engine for a 4200 Mw reactor system.

A common analog model for the NR system has been developed in conjunction with WANL. This model will be used for controls and system analysis.

An investigation was made of the differences in temperature between the core exit plane and the chamber temperature probe. Since an exact location for the probes is not yet fixed, a location 16 in. downstream of the core exit plane was assumed. At full power it was found that a probe placed at the assumed location would read approximately 23°R lower than the temperature to core exit plane. Nearly all the difference is due to heat transfer through the nozzle tube wall. Less than one degree is due to nonadiabatic recovery.

(1) Nitrogen

The nitrogen properties program was converted to a pressure-enthalpy entry version. The new version with the pressure-enthalpy entry option has been placed in production and has been successfully used for cooldown studies.

(2) Helium

The existing literature has been searched for experimental helium P-V-T (pressure-volume-temperature) data points over the region from 3 to 1500°K. Six available equations of state for helium have been compared by using 1242 experimental P-V-T measurements that have been placed on cards. Preliminary comparisons indicate that the existing equation of state in the current helium properties subroutine is in considerable error

TABLE 14

STEADY-STATE SUMMARY
NERVA CASE D

NR

Tc = 4500°R; Pc = 652 psia

$Q_{reactor}$ = 4200 Mw

Date: 6 September 1967

State Point Description	Flow, lb/sec	Pressure, psia	Temp, °R
Dewar Outlet	240.3	1315	50
Structural Support	50.0	1315	50
Nozzle Manifold Inlet	120.1	1281	50
Nozzle Outlet	120.1	910	183
Skirt Outlet	70.2	910	194
Reflector Inlet	190.3	910	187
Reflector Outlet	190.3	838	243
Shield 1 Inlet	240.3	838	264
Shield 1 Outlet	240.3	831	248
Shield 2 Outlet	240.3	826	250
Core Inlet	240.3	802	302
Core Outlet	240.3	652	4500
Nozzle Chamber	240.3	652	4500

at low temperatures and high pressures. Work is in progress to find improved sets of equations of state that will more accurately describe the properties of helium for cooldown studies over the range of 36 to 5000°R, at up to 3500 psia. Continued work on helium properties has indicated that the NBS equation of state for the low-temperature region is not very accurate. The optimization program indicates that an improvement in the standard deviation of compressibility factor between experimental data and calculated values is on the order of 0.005 from an original value of 0.082. A new equation of state may have to be worked out to obtain low-temperature density values that are accurate to within 3%.

(3) A hydrogen properties deck for use on the 1130 computer is now available for general use.

7. Radiation Effects Program (1.9)

a. Integration, Analyses, and Documentation (1.9.0)

(1) Objectives

The purpose of the radiation effects program is to provide assurance, through testing and analyses, that the NRX, XE, NR and the NE engine components will perform satisfactorily under operational conditions Test plans, schedules, specifications, procedures, preirradiation analyses, radiation effects tests; analyses of test data, and test reports are being used to achieve the program objective.

(2) Test Summary

Fifty-two radiation effects tests have been performed by or under the cognizance of NRO through September 1967; three were performed during CY 1967. Reactor run GTR-21, which includes five component tests, currently is in progress at the Ground Test Reactor in Fort Worth. The status of these tests is described in Section 1.9.6. The types of materials and components tested, as well as the number of tests performed are summarized below. Discussions of test results are contained in Sections 1.9.1, 1.9.4, 1.9.6, 2.4.6 and 2.8 of this report.

AEROJET RADIATION-EFFECTS TEST STATUS

Component Description	Test Completed in CY 67	Total Number of Tests Completed Through CY 67
Diagnostic Instrumentation	1	25
TPA Bearings	0	5
Mechanical Components	0	4
Electrical Components	0	5
Materials	1	7
Explosives	1	6

(3) Coordination

Sub-subtask 1.9.0 presents the overall management and coordination of all NERVA radiation-effects activities at Aerojet, Westinghouse, and the various test facilities. Four planning and coordination meetings were held during this year to finalize the GTR-19 and GTR-21 test programs, and to outline the CY 68 radiation-effects program at GD/FW. Participants included personnel from SNPO-C, WANL, NBS, GD/FW, and NRO. Meetings also were held at WANL, SNPO-C and GD/FW to discuss technical and schedule problems.

(4) Test Analyses

(a) NRX/EST Tests

A report summarizing the radiation effects information derived from the NRX/EST test series has been completed. It includes the results of postoperative tests of nozzle specimens and nozzle closure bolts made at General Dynamics, Fort Worth. The significant findings from these tests are summarized in the following paragraphs.

Linear Variable Differential Transformer (LVDT) pressure transducers were unsuitable for engine-mounted applications. Consequently, LVDTs have been eliminated from the Aerojet development program for control pressure transducers. Test-car-mounted pressure transducers performed satisfactorily with only one anomaly (not attributable to radiation effects.) Some thermocouple readings were affected by radiation effects on the reference junctions. Most Resistance Temperature Transmitters (RTTs) functioned satisfactorily. The observed anomalies were not attributable to radiation effects.

Most strain gages functioned satisfactorily. The failures that occurred were attributed to vibration and thermal cycling rather than to radiation effects.

Eight of the 12 accelerometers tested functioned satisfactorily. Mechanical failures rendered the remaining four units inoperable.

During NRX-A3, one of the high-level multiplexers drifted significantly during the high power runs due to the effects of radiation on the 2N761 transistors. These transistors were replaced with 2N914 transistors and no drift occurred during the NRX/EST test series. Radiation rates affected the oxygen analyzers located in the engine compartments and the flow control room. A Beckman polarographic oxygen analyzer was compared with the facility analyzers. No rate effects were noted. Television cameras located in high flux regions malfunctioned during the runs. Two leak-measurement systems were used. One of these failed at the conclusion of the last experimental plan.

An examination of the disassembled TPA revealed no adverse effects attributable to radiation. Although problems were encountered with the TPCV actuator, none were attributed to radiation effects. The DCV was radiation-hardened and performed its design function throughout the test series. The remaining valves, which had Teflon seals and were located in shielded regions, functioned satisfactorily.

Tensile and metallographic tests revealed that radiation effects on the nozzle material were insignificant. Nozzle and closure bolts were undamaged by radiation. The irradiated bolts tested in tension and stress rupture at 1200° and 1500°F showed increased notched sensitivity and a probable loss of elongation. No abnormalities in pressure vessel performance occurred during the test series.

(b) NRX-A5 Tests

The significant findings from the NRX-A5 test series and the NRX-A5 post operative tests are as follows. Reactor-mounted

pressure transducers were subject to anomalies. Test-car-mounted pressure transducers operated satisfactorily, and some of the thermocouples operated satisfactorily. The remainder were subject to data anomalies caused by radiation effects (drift) on the reference junctions. One RTT failed mechanically, was replaced, and the replacement performed satisfactorily. Transient effects were detected in some of the strain gages. Accelerometers were not affected by radiation from the test as indicated by the data and the postoperative inspections. The leak measurement system performed satisfactorily. The hydrogen analyzer was unaffected by radiation; however, the oxygen analyzer data drifted as much as 12% due to radiation effects. Television cameras again malfunctioned because of radiation effects. Plate-out of fission products on nozzle tubes is primarily a surface effect and does not affect tube strength. Fission product plate-out on the tungsten probe also had no effect on the physical properties of the probe.

(5) Design Review

Technical support provided to the NERVA program included radiation effects evaluations of various engine component designs, control systems, instrumentation, and NRDS test facility items.

Radiation effects work performed by other agencies was added to the available data. Radiation-effects literature of potential interest to the NERVA program was acquired from various sources, including the Battelle Memorial Institute and added to the existing radiation effects information file.

(6) Subcontracts

Subcontract SNP-000140 was issued to General Dynamics, Fort Worth, for postmortem tests of sections from the NRX/EST nozzle. Mechanical-property tests of pressure-vessel bolts from NRX/EST have been completed. The results of the program are discussed in Sections 1.9.6 and 2.8.

(7) Reports

The status of all reports associated with the CY 1967 radiation effects program is summarized on Table 15.

b. Countermeasures Radiation-Effects Program (1.9.1)

The countermeasures radiation effects program was formulated to provide radiation effects information about explosives and propellants needed for the NERVA countermeasures system. This work was coordinated with Frankfort Arsenal, Sandia Corporation, and Picatinny Arsenal. Personnel from Picatinny actively participated in all facets of this program.

The countermeasures radiation effects program was terminated in March 1967 due to redirection of NERVA guidelines related to the destruct system. Phase I testing and qualification of Phase II capsules were completed and are discussed below.

(1) Phase I-A

Eighteen 1.8-gm samples of high explosives and propellants, plus three prototype exploding-bridgewire detonators, were irradiated in the Z-trail cable facilities of the General Electric test reactor at Vallecitos, California. Irradiation was performed at two radiation exposure rates: fast neutron flux of 1.3×10^{13} nv ($E > 1.0$ Mev), thermal neutron flux of 1.4×10^{14} nv ($E < 0.48$ ev) and a gamma dose rate of 7.8×10^{10} ergs/gm(c) hr; and fast neutron flux of 8.8×10^{11} nv ($E > 1.0$ Mev), thermal neutron flux of 1.2×10^{13} nv ($E < 0.48$ ev) and a gamma dose rate of 8.7×10^{9} ergs/gm(c) hr.

Three new high-temperature-stable main charge explosives were irradiated during these tests at two integrated dosages. Although

TABLE 15

STATUS OF REPORTS, CY 67

Report No.	Title
RN-S-0343	GTR-19 Final Test Specifications
RN-S-0318	Radiation Effects Summary Report on NRX-A2 and -A3
RE-EDP-1	Experimental Design Plan for GTR-19 (LN_2 - LH_2 Comparison)
RN-S-0290	Final Test Report, GTR-16 Radiation Effects Test on Structural Materials at -423°F
RN-S-0347	NERVA Radiation Effects Program Plans
RE-EDP-2	Experimental Design Plan for GTR-20
RN-S-0325	Final Test Report 23/R510 Radiation Effects Test on Pressure Transducers
RN-S-0326	Final Test Report 23/R511 Radiation Effects Test on Pressure Transducers
RN-S-0327	Final Test Report on GTR-17, Radiation Effects Test on Organic Materials
RN-S-0368	Phase I Summary Report for the Explosives Irradiation Program
RN-S-0383	Final Test Report, Qualification Test Firings of Phase II Containment Capsules
RN-S-0406 plus Revision	Final Test Specification for Test 23/R512 (Pressure Transducers)
RN-S-0347	NERVA Radiation Effects Program Plans, Revision A
RN-S-0384	Test Specifications for Phase II of the Countermeasures Radiation Effects Program
RN-S-0370	Final Test Report for RTT Test 23/R104
RE-EDP-4	Experimental Design Plan for Thermal Conductivity Test 37/R104
RE-EDP-3	Experimental Design Plan for Pressure Transducers
RN-S-0420	Bearing Cage Materials Test 37/R106
RN-S-0396	Summary of Radiation Effects Information Gained from NRX/EST
RN-S-0398	Effects of High Temperature on Ductility of Structural Materials Containing Boron
RN-S-0411	Test Specifications for Test GTR-21

TABLE 15 (cont.)

Report No.	Title
RN-S-0424	Uncertainty Analysis for Thermal Conductivity Test 37/R104 and Electrical Resistivity Test 37/R201
RN-S-0367	NERVA Radiation Effects Status Report
RN-S-0397	Summary of Radiation Effects Information Gained from NRX-A5
RN-S-0399	Final Report on GTR-19
RN-S-0401	Comparison of Property Changes in Alloys after Irradiation in Liquid Nitrogen and Liquid Hydrogen
RN-S-0438	NERVA Radiation Effects Preliminary Status Report
RE-EDP-5	Experimental Design Plan for Electrical Resistivity Test 37/R201
RE-EDP-6	Experimental Design Plan for Determination of Effects of N-α Reaction on High Temperature Properties of Boron-Containing Materials
RE-EDP-7	Experimental Design Plan for Cryogenic Irradiation and Testing of Structural Alloys
RE-EDP-8	Experimental Design Plan for Evaluation of Bearing Cage Materials

these explosive samples have superior temperature stability, their ability to resist radiation was less than that of the best materials tested previously in Phase I-C.

Three prototype detonators of the exploding bridge-wire design were fabricated and tested using radiation-stable explosives. The detonators were radially cooled in the capsules. Despite the cooling, high temperatures along the axis and at the pins in the headers caused excessive explosive decomposition during irradiation at the higher flux. As a result, three detonators were irradiated at the reduced irradiation level; these units fired successfully.

The best radiation-stable primary, booster, and main charge explosives were selected as a result of these tests. Booster explosives were found to be less stable than main charge explosives. This characteristic, however, is not expected to limit the exposure of a destruct system because booster charges can be located farther from the radiation source.

Results of the complete Phase I-A testing activities are reported in Final Test Report for Phase I-A, Aerojet-General Report RN-S-0368, dated March 1967.

(2) Phase II Capsule Qualification Testing

Picatinny Arsenal developed a capsule capable of containing detonation of 80 gm of high explosives. An extensive series of development tests culminated in a final capsule design. General Electric requested a minimum of three successful proof tests of the final design with double the normal weight of explosive intended for use as proof of capsule integrity. These three tests were conducted successfully at Aerojet-Downey in cooperation with Picatinny Arsenal. The tests confirmed that the capsule could adequately withstand accidental detonation of 160 gm of high explosive.

Details of the Phase II efforts are presented in Final Test Report, Aerojet-General Report RN-S-0383, dated April 1967, and the Summary Report for Phase II, Aerojet-General Report RN-S-0384, dated July 1967.

c. Instrumentation Radiation-Effects Program (1.9.5)

(1) Pressure Transducer Test 23/R512A

Pressure Transducer Test 23/R512A was conducted at General Dynamics GTR on 21 August 1967. The test was made according to Test Specification RN-S-0406 plus Revision A. Four transducers and two instrumented dummy transducers were irradiated in the test fixture shown in Figure 44, at heating rates from about 0.25 watt/gm(c) to about 2.8 watt/gm(c) and at pressures of 0, 250, 500 and 750 psia. Preliminary data have been analyzed. No anomalies were observed before or after irradiation. Final test data have been analyzed. No anomalies were observed before or after irradiation. Final test data have been received from General Dynamics and detailed analysis of the data has begun.

(2) Resistance Temperature Transducer Test 23/R104

Data for RTT Test 23/R104 were analyzed and the test report was completed during the contract year.

Twenty platinum resistance temperature transducers (RTT) were irradiated for 200 hr during the GTR-18 test (July 1966) to assess radiation damage at liquid hydrogen temperatures. Eleven units were tested to determine the mechanism of damage to the probes, three development transducers were evaluated, and six units that had been irradiated in previous GTR tests, were reirradiated to determine the effect of extended exposure and to observe evidence of radiation hardening. Neutron exposures during the tests were 5×10^{16} n/cm^2 ($E > 1.0$ Mev) and 5×10^{16} n/cm^2 ($E < 0.48$ ev). Proton exposure was 3×10^{16} protons/cm^2. Table 16 summarizes the test conditions and results.

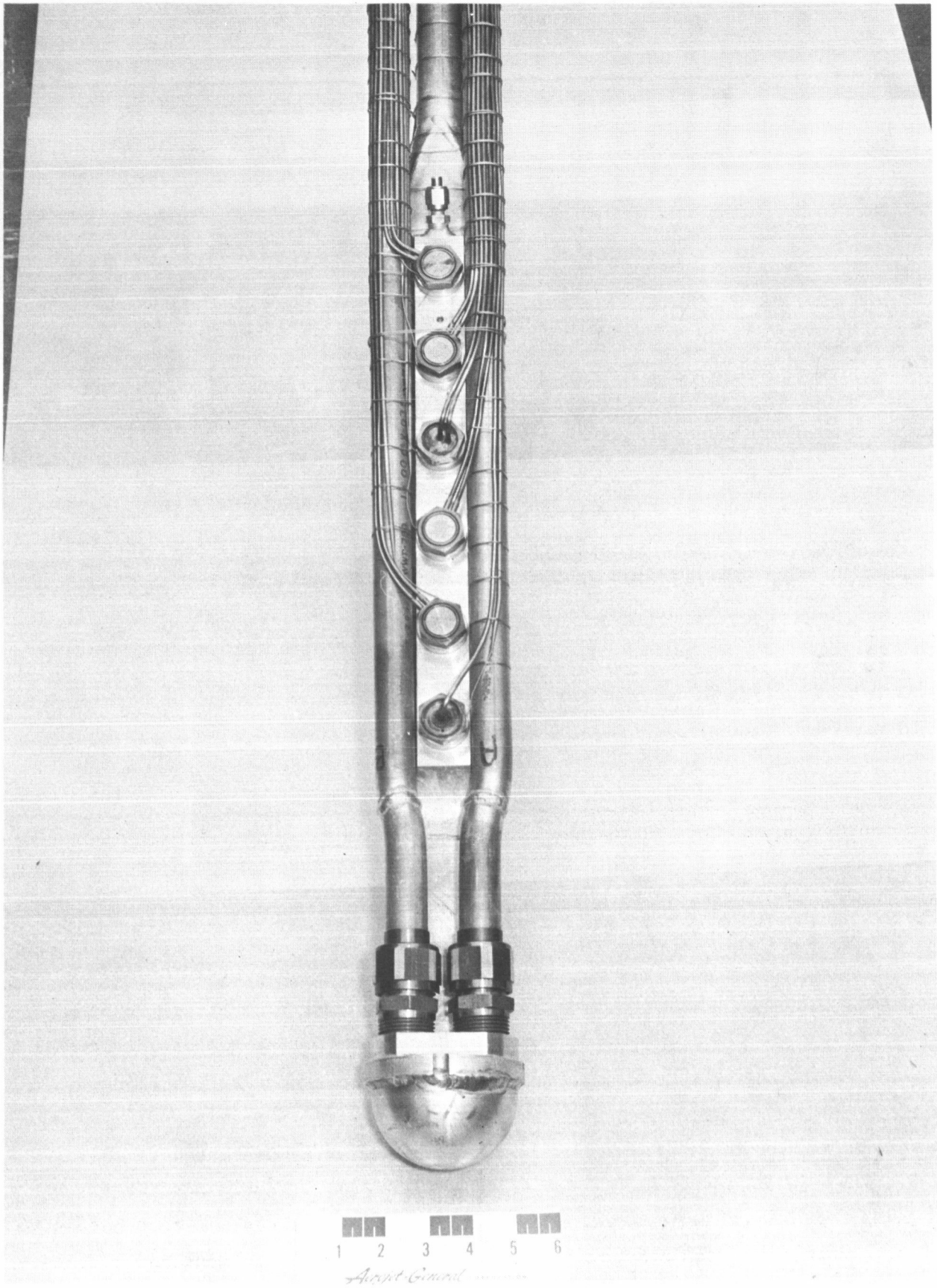


Figure 44 - Test Fixture for Pressure Transducer
Test 23/R512A

TABLE 16

RADIATION DAMAGE TO PLATINUM SENSORS IN LH_2 (36.5°R)

(Fast-Neutron Fluence = 5×10^{16} nvt; E > 1.0 Mev)

Material	Type	Attenuation	Units Tested	Fast Neutron Temperature Degradation, °R
Unmodified	None	None	2	2.48
Stainless Steel	Proton	Black	2	2.48
Cadmium and Stainless Steel	Thermal Neutron Proton	1.8×10^{-4} Black	2	2.20
Hafnium and Stainless Steel	Epithermal Neutron Proton	2.9×10^{-3} Black	2	2.48
Hafnium Cadmium- Stainless Steel	Epithermal Neutron Thermal Neutron Proton	5.3×10^{-2} 1.3×10^{-2} Black	3	2.32

The temperature deviations shown in this table are for a fast-neutron exposure of 5×10^{16} n/cm^2 (E > 1.0 Mev). Complete test results are presented in Report RN-S-0370.

Test results indicated that radiation damage to platinum RTTs was caused by fast neutrons. Significant damage caused by thermal neutrons and protons could not be detected within the accuracy of this experiment.

Three development transducers were irradiated to a fast-neutron exposure of 5×10^{16} n/cm^2 (E > 1.0 Mev). Two of the units showed a temperature deviation of 2.74°R, and one had a temperature deviation of 3.02°R.

The six units previously irradiated were recalibrated and again irradiated during the GTR-18 test. No conclusions can be reached concerning the effects of extended dosages because comparisons with previous tests were required. One reirradiated unit exhibited a temperature deviation of 2.56°R for a fast-neutron exposure of 5×10^{16} n/cm^2 (E > 1.0 Mev).

(3) Linear Variable Differential Transformer-Type Transducer Test 23/R510

Four linear variable differential transformer (LVDT) type transducers were irradiated to determine their performance characteristics in a radiation environment. Stainless-steel sheathed, magnesium-oxide insulated, copper conductor cables were used between the transducers and the instrumentation console and three additional cable/connector assemblies were tested to determine the effects of radiation on these cables. Before insertion of the units in the reactor, preirradiation reference data were obtained. These data were erratic because water leaked into the test capsule. The tests were conducted as scheduled, but water damage to the transducers before irradiation resulted in inconclusive test results.

All four transducers produced unacceptable zero-shifts at nuclear heating rates above 0.45 watts/gm. Two transducers had stable sensitivity throughout the test. Sensitivity of the only transducer which had an acceptable insulation-resistance before the test decreased approximately 15% at a nuclear heating rate of 0.75 watts/gm. Insulation-resistance was very low for all transducers at nuclear heating rates greater than 0.1 watts/gm.

As a result of these tests it was concluded that the water leak into the test capsule added an indeterminate variable to the test results. The tests showed that the transducers will operate effectively with low insulation-resistance only in reduced radiation fields. A complete description of these tests and a critical analysis of test results are contained in Report RN-S-0325.

(4) Strain Gage Pressure Transducer Test 23/R511

Eight strain-gage-type pressure transducers were irradiated to determine their performance characteristics in a radiation environment. Stainless steel sheathed, magnesium oxide insulated, copper conductor cables were used between the transducers and the instrumentation console and four extra cable/connector assemblies were included for comparison.

Prior to irradiation, water accidentally leaked into the test fixture. The capsule was withdrawn, dried and purged until insulation resistance values were satisfactory. Then the unit was rewelded and reinserted into the reactor. The tests were conducted, although the water leak affected the insulation-resistance values of the transducers.

On the basis of test results, several general conclusions were made. The water leak and subsequent degradation of insulation-resistance introduced indeterminate variables to the test data. Results showed that the transducers will operate effectively with low insulation-resistance

values only in a low-radiation environment (< 0.1 watt/gm). Sensitivity values of the transducers were stable but unacceptable zero shifts occurred. The degree of these zero shifts would have been reduced if the insulation-resistance had been maintained.

These tests are described in considerable detail and a thorough analysis of the test results are contained in Report RN-S-0326.

d. Materials Radiation Effects Program (1.9.6)

(1) Thermal Conductivity Test 37/R104

This test represents a combined effort of WANL, NBS, GD/FW, SNPO-C and NRO. The purpose is to investigate the effects of radiation on the thermal conductivity of graphite PO-3, commercial- and reactor-grade beryllium, aluminum 7039-T6 and titanium 110 AT-ELI at temperatures between 140° and 560°R. Tests will be conducted using the ground test reactor at General Dynamics, Fort Worth. Preirradiation testing using liquid nitrogen as a reference bath began on 18 September 1967. After completion of preirradiation tests, scheduled for 15 October, the specimen will be irradiated to a fast-neutron fluence of approximately 10^{18} nvt ($E > 1.0$ Mev). Data obtained after irradiation will be compared with the preirradiation data.

The test apparatus consists of five evacuated vessels such as shown in Figure 45. Each vessel contains one specimen. A heater is attached to the lower end of each specimen and a known electrical power input is applied. The heat generated in the specimen is conducted through the specimen to a liquid nitrogen reference bath, and temperatures along the specimen are measured. Conduction and radiation heat losses of the specimens are minimized by evacuating the test container to 10^{-6} mm Hg and surrounding the specimen with a shield having the same temperature distribution as the specimen.

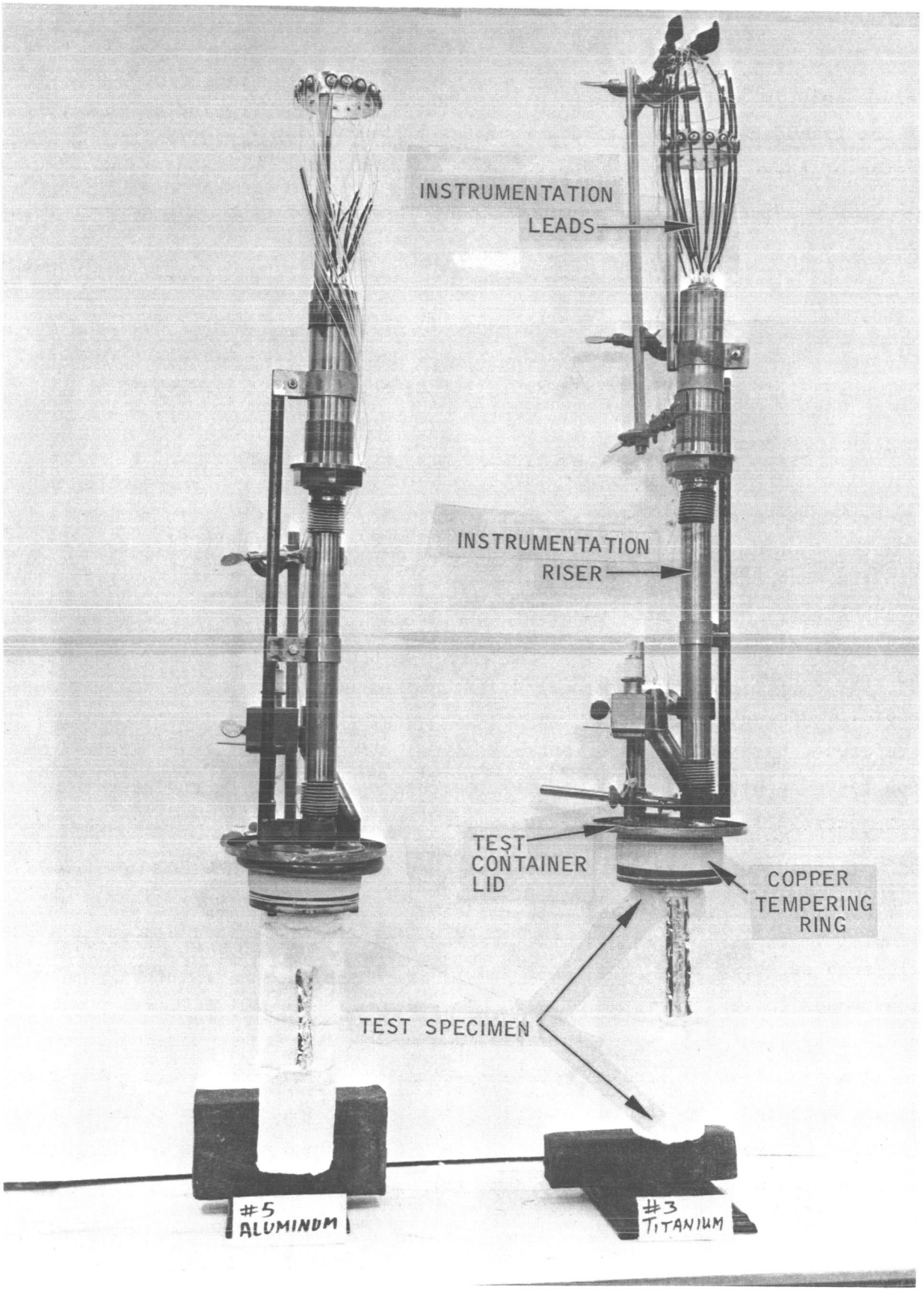


Figure 45 - Two Thermal Conductivity Experiments Before Installation in Test Vessel

The test apparatus design was evaluated at temperature differentials up to 170°K between the upper and lower thermocouples. The resultant data agreed to within ±3% of thermal conductivity data measured on the same specimen using the NBS equipment, indicating the acceptability of the design.

The test specification, experimental design plan, and uncertainty analysis for the experiment are contained in Aerojet Reports RN-S-0411, RE-EDP-4, and RN-S-0424, respectively.

(2) Electrical Resistivity Test 37/R201

Aerojet will conduct an experiment in conjunction with the National Bureau of Standards to investigate the effects of radiation on the electrical resistivity of various metals. The purpose of this test is to determine the validity of the Wiedemann-Franz law, which correlates electrical resistivity and thermal conductivity. This test complements thermal conductivity test 37/R104 in that the materials for both experiments are similar. If correlation exists, electrical resistivity data will be used as a basis for predicting thermal conductivity. Using the test fixture shown in Figure 46 electrical resistivity data will be obtained at temperatures between LN_2 and 200°F for the following materials: two specimens of aluminum 7039-T6, two specimens of beryllium, and one specimen each of Inconel 718, Hastelloy X, 347 stainless steel, PO-3 graphite, titanium 110 AT-ELI, and A-286 steel. This radiation test is part of GTR-21 and is scheduled at GD/FW in October 1967. The test fixture has been assembled, checkout tests were performed, and the test apparatus is ready for irradiation.

(3) GTR-18 Materials Properties Tests

Reactor run GTR-18, performed in July 1966 at General Dynamics, Fort Worth, incorporated four radiation-effects material tests. These included two WANL sponsored tests: beryllium mechanical properties Test 37W403 and Inconel 718 tensile Test 37W404. Two Aerojet-sponsored

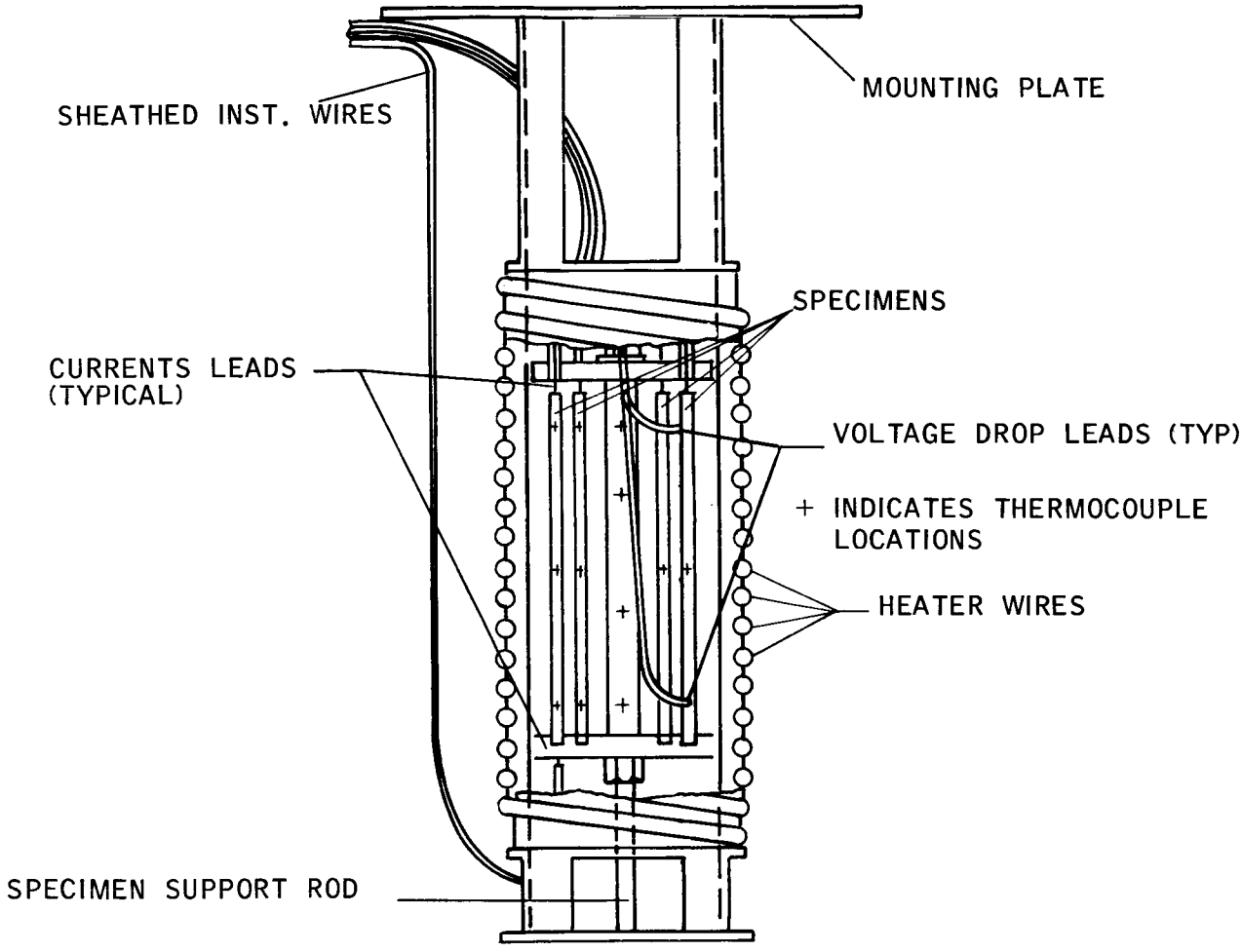


Figure 46 - Electrical Resistivity Test Specimen Container

tests also were made: radiation effects on structural materials containing boron, Test 37R105; and radiation effects on bearing cage materials, Test 37R106 Analysis of the data and preparation of reports on these tests was accomplished during CY 1967. Aerojet-General Report RN-S-0398 describes the results of Test 37R105, and Report RN-S-0420 presents the analysis of Test 37R106.

WANL Test 37W404 and the Aerojet-General Test 37R105 showed that the high temperature ductility of Inconel 718, AISI 347 stainless steel, Inconel 625, and Hastelloy X is significantly reduced by irradiation with thermal neutrons.

(4) GTR-19 Mechanical-Properties Test

Irradiation and tensile-testing of 11 materials was completed in CY 1967. The data are currently being analyzed, and test reports are being prepared. Preliminary results are given in reports RN-S-0367 and RN-S-0401. RN-S-0401 evaluates the effects of irradiation in liquid hydrogen and in liquid nitrogen on the tensile properties of seven materials. The objective of this analysis is to provide a basis for estimating properties of materials irradiated in liquid hydrogen based on data on the materials performance in liquid nitrogen. Figure 47 shows graphically the results of the testing of Al 6061-T6.

(5) GTR-21 Material-Properties Tests

Three materials tests are scheduled for GTR-21 reactor run. These are high temperature structural materials Test 37R017; cryogenic structural materials Test 37R018; and bearing cage materials Test 37R107.

Experimental design plans and test specifications were prepared to cover the test activities for reactor run GTR-21 at General Dynamics. The required test specimens were designed, fabricated, shipped to Fort Worth, and subsequently installed in the reactor facility. Preirradiation testing was in process at the end of CY 1967.

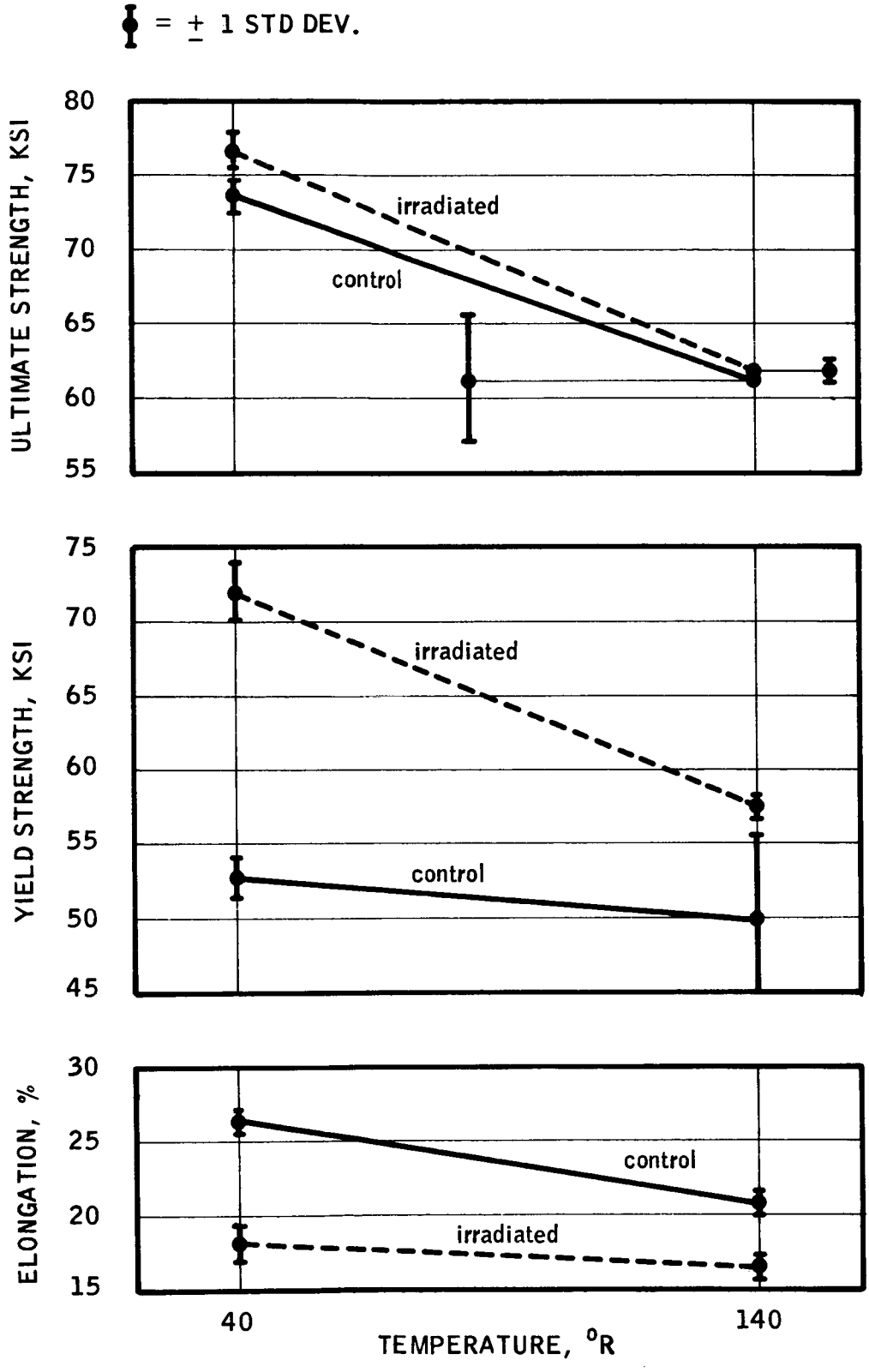


Figure 47 - Tensile Properties of Al 6061-T6 Plate in Liquid Hydrogen and Liquid Nitrogen Before and After Irradiation to a Neutron Fluence of About 3×10^{17} nvt (E>1.0 Mev)

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B. ENGINE SUPPORT SYSTEMS AND FUNCTIONS (TASK 2)

The Aerojet Nuclear Rocket Operations Program Management office held Support Equipment Management meetings attended by SNPO-C, WANL, and NTO. These meetings dealt with overall program planning, technical guidance, coordination of support equipment requirements, fabrication and delivery status, and establishment of appropriate action items.

Coordination was maintained with appropriate NRO organizations, SNPO-C, SNPO-N, NTO, WANL, LASL, (ACFI) and various subcontractors to insure integration of support equipment activities with NERVA Program objectives.

Numerous WANL functional requirements and design criteria for NRX-A6 and XE-1 support equipment were reviewed and commented on by NRO.

Special studies of rescheduled test dates for NRX-A6, XECF, XE-1, and XE-2 were conducted to determine the effect of rescheduling.

Test specifications for NRX-A6, XECF and XE-1 were reviewed.

All NTO-prepared NRX-A6, XECF and XE-1 Assembly and Checkout Operating Procedures were reviewed.

Support Equipment personnel were at NRDS full time during the development and initial usage of the provisioned support equipment.

1. Mechanical Ground Support Equipment (2.1)

a. NRX and XE Mechanical GSE (2.1.0)

(1) Engineering

Continuous coordination and review of applicable documents with the Nuclear Rocket Development Station (NRDS) and Westinghouse Astronuclear Laboratory (WANL) was provided as necessary to ensure the proper development and integration of NRX and XE Mechanical Support Equipment with the facilities and equipment at NRDS.

(a) NRX Program

Design modifications were completed on the following NRX support equipment:

P.L. Item	Nomenclature
21	Remote .812 (13/16) Bolt Removal Tool A remote, pneumatically operated and electrically actuated impact-type tool for removal of forward closure/ nozzle bolts. The modification will improve the operability and reliability for use with NRX-A6.
17	Remote Cooldown Nozzle Cover A closure containing filters to protect the NRX nozzle and reactor from contamination during postfiring cooldown. Locating wedges were modified to eliminate interference with the Test Cell C Shield Impedance Ring.

P.L. Item	Nomenclature
137	Nozzle Examination Fixture This fixture supports and remotely positions the nozzle during postoperative examination and test in the R-MAD/E-MAD. The modification eliminated an interference with a nozzle weld bead.
923	Remote Thrust Chamber/Reactor Disassembly Fixture This fixture provides for holding the thrust chamber during remote removal of the reactor when used with P.L. 1182. The modification increased the static load capacity to 40,000 lb so this item could be used for XE-1 and XE-2 disassembly.

(b) XE Program

The Operational Support Plan (OSP), RN-S-0190 for XE-1 and XECF, Volume II was published and distributed in November 1966. It was revised and reissued in June 1967.

Design criteria were prepared, approved and distributed on the following XE Support Equipment:

P.L. Item	Nomenclature	Figure
4102	Platform, Internal, UTS	-
4134	Fixture, Lifting, Insulating Shield	-

Design was completed and drawings released on the following XE Support Equipment:

P.L. Item	Nomenclature	Figure
4059	Platform, Maintenance, ETS-1	48
4102	Platform, Internal - UTS	-
4117	Coupling Device, 6.50 cc Hex	49
4118	Coupling Device, 7.62 cc Hex	50
4119	Coupling Device, 9.00 cc Hex	51
4120	Coupling Device, 7.75 cc Hex	52
4121	UTSM/TSA Coupling Device - Remote	53
4123	UTSM Shield Nut Actuation Device - Remote	54
4124	Tools, Conoseal Installation - Remote	55
4125	Parallel Target Kit - Remote	56
4126	UTSM Shipping Container	57, 58
4134	Fixture, Lifting, Insulating Shield, XE	-
4135	Protector, Flange, Pressure Vessel	-
4708	Platform, Maintenance, Engine	59

Modification design was completed and drawings released for the following XE Support Equipment:

P.L. Item	Nomenclature	Figure
453	Closure Kit, Pressure Testing, Nozzle Throat	-
4011	Positioning Head, Thrust Structure, OPS	60, 61
4088	Closure, Engine Nozzle	62
4103	Guide - Flange, Fluid Line	60, 63
4108	Closure, Turbine Exhaust Nozzle (2)	64
4122 (Mod from 4099)	Stand, Engine Assembly - Remote	65
4142 (Mod from 1143)	Lifting Fixture, Forward Closure	-

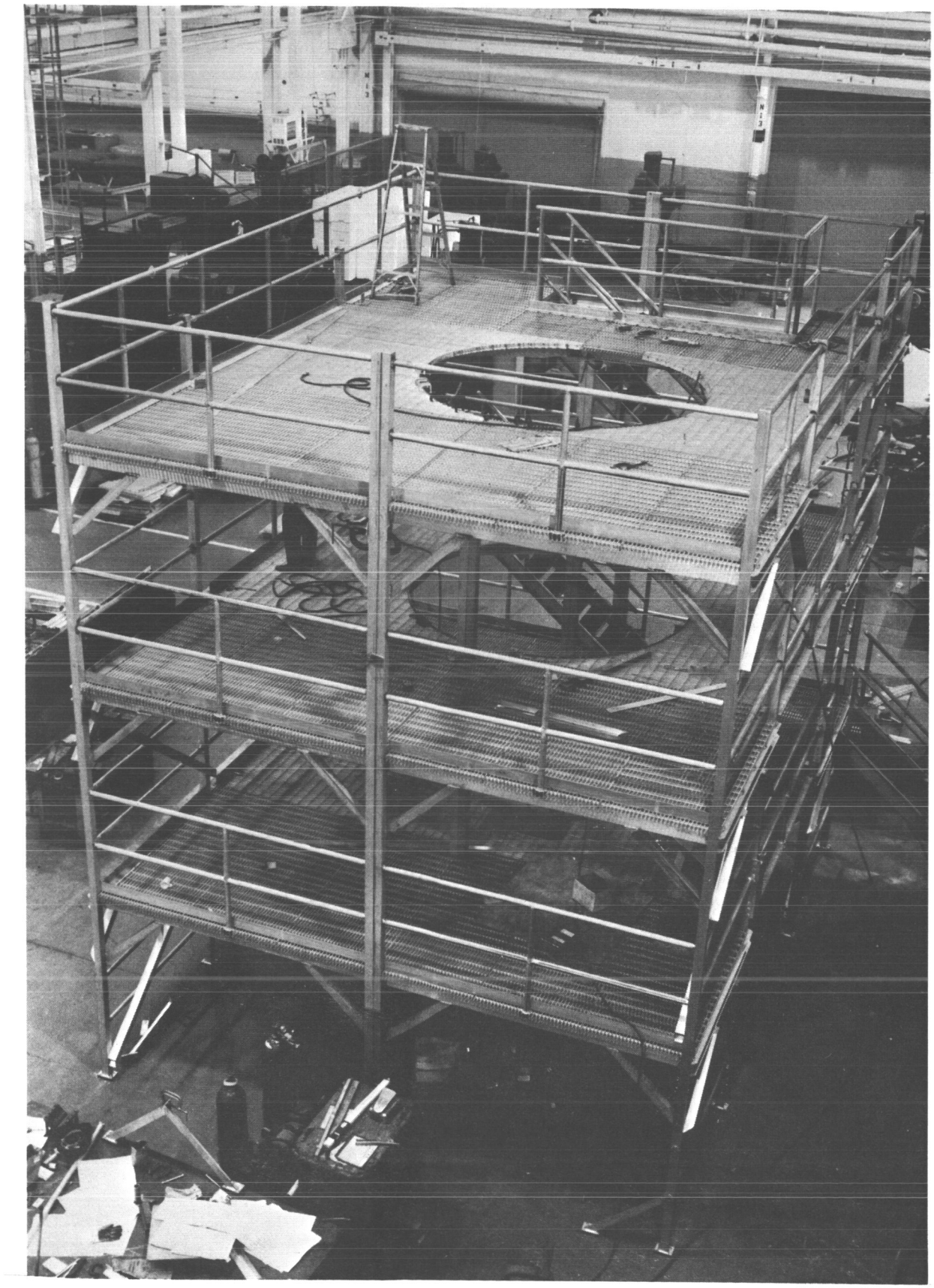


Figure 48 - Item 4059, Maintenance Platform, ETS-1

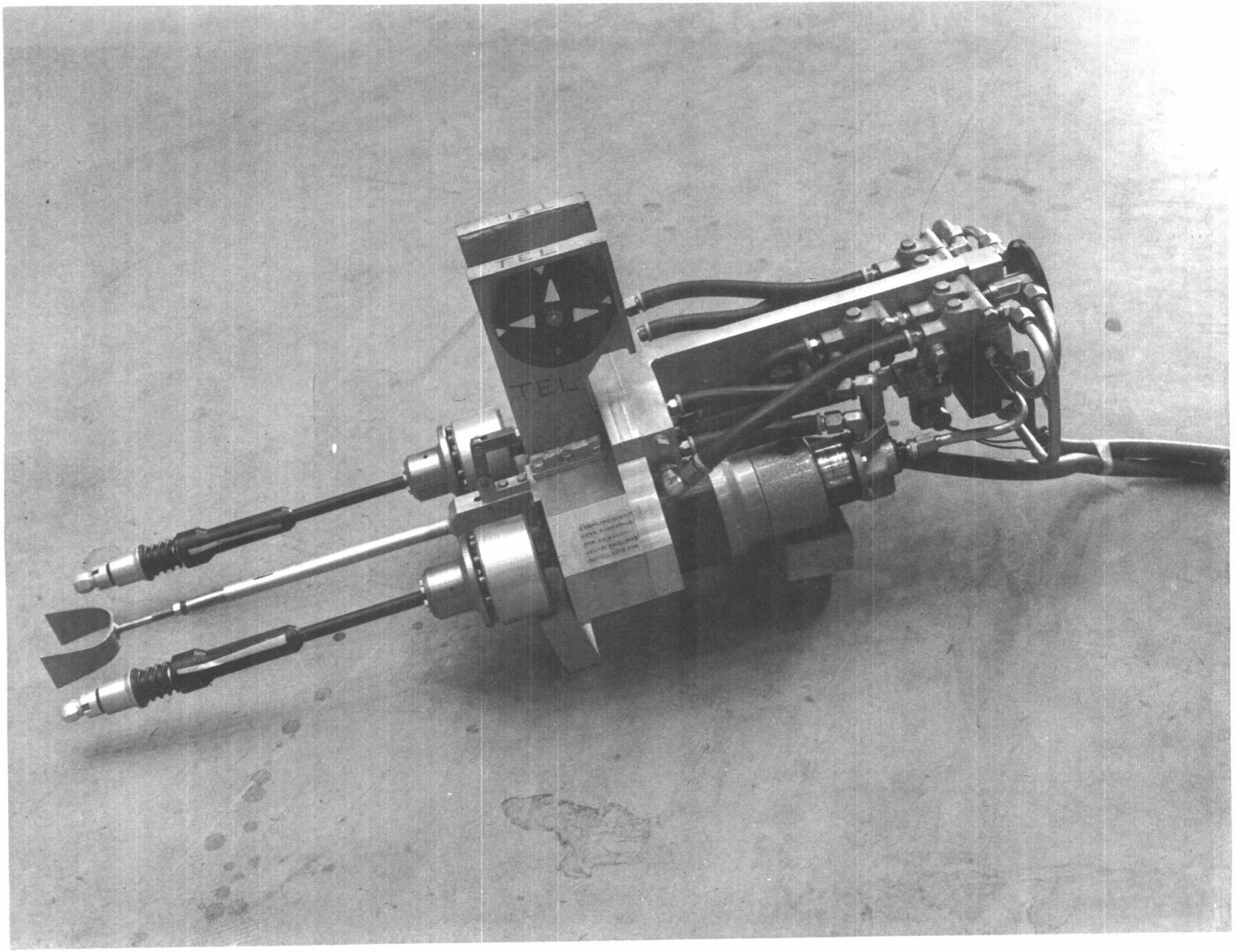


Figure 49 - Item 4117, Coupling Device, 6.50 cc Hex

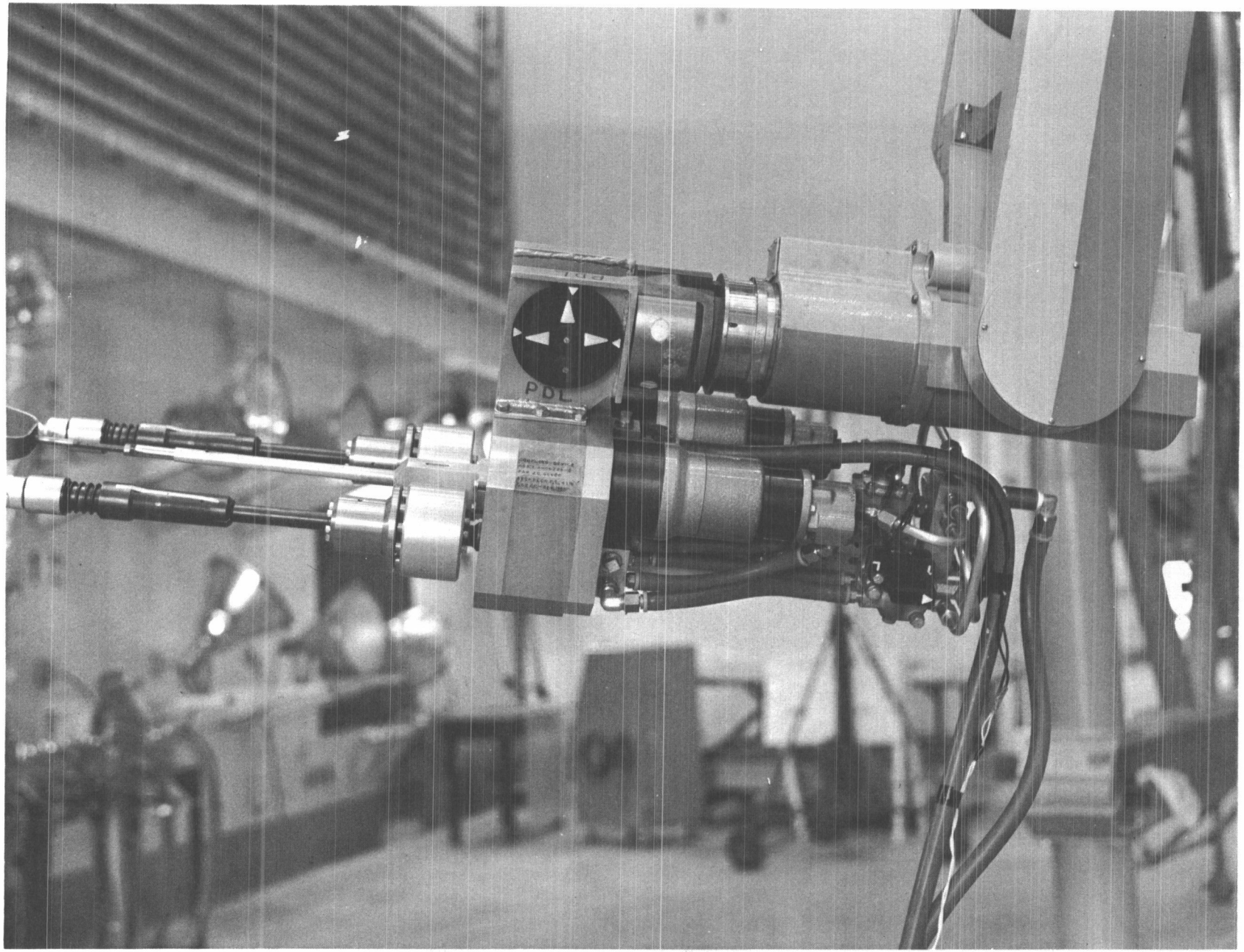


Figure 50 - Item 4118, Coupling Device, 7.62 cc Hex

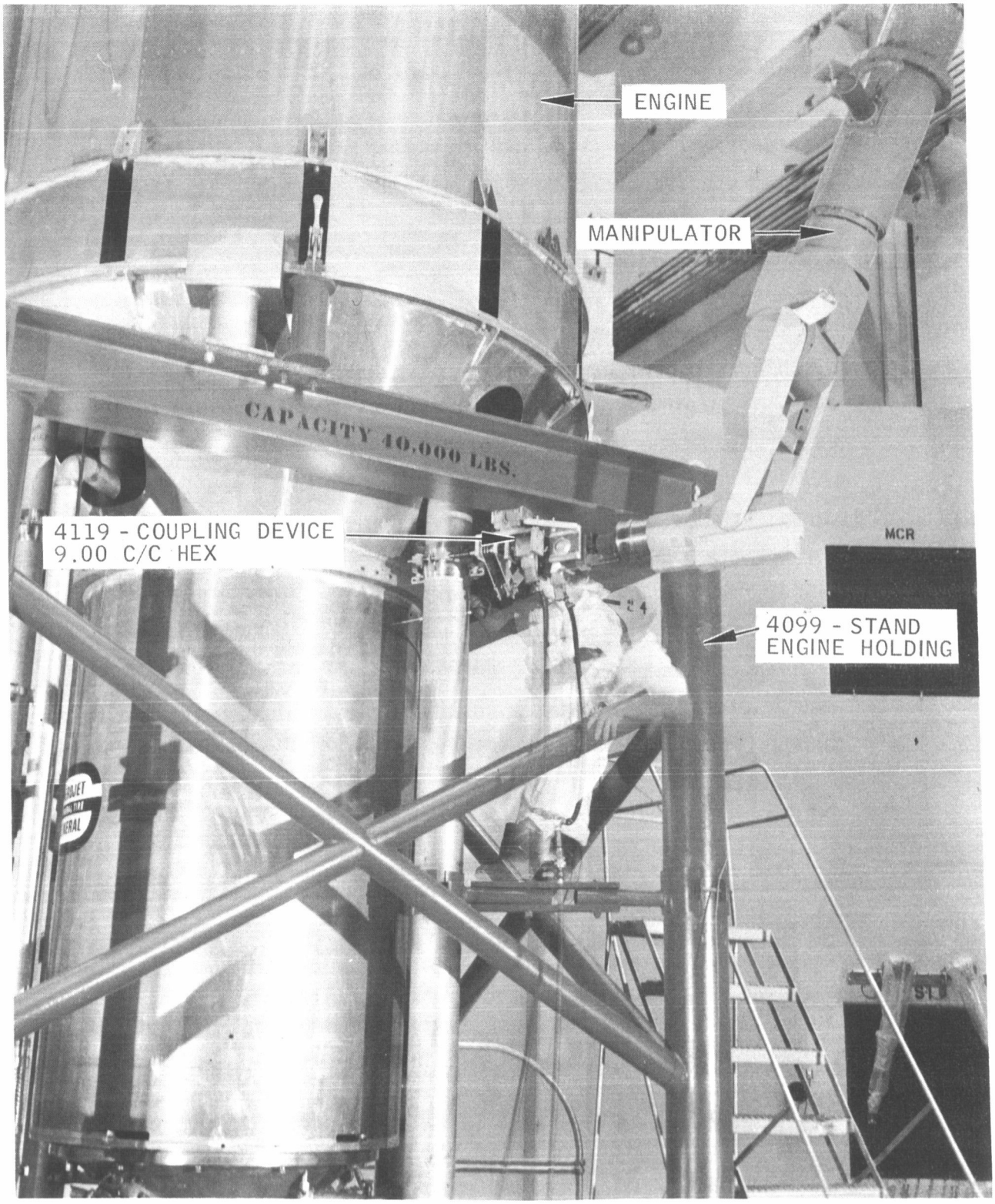


Figure 51 - Items 4119 and 4099, Engine with GSE

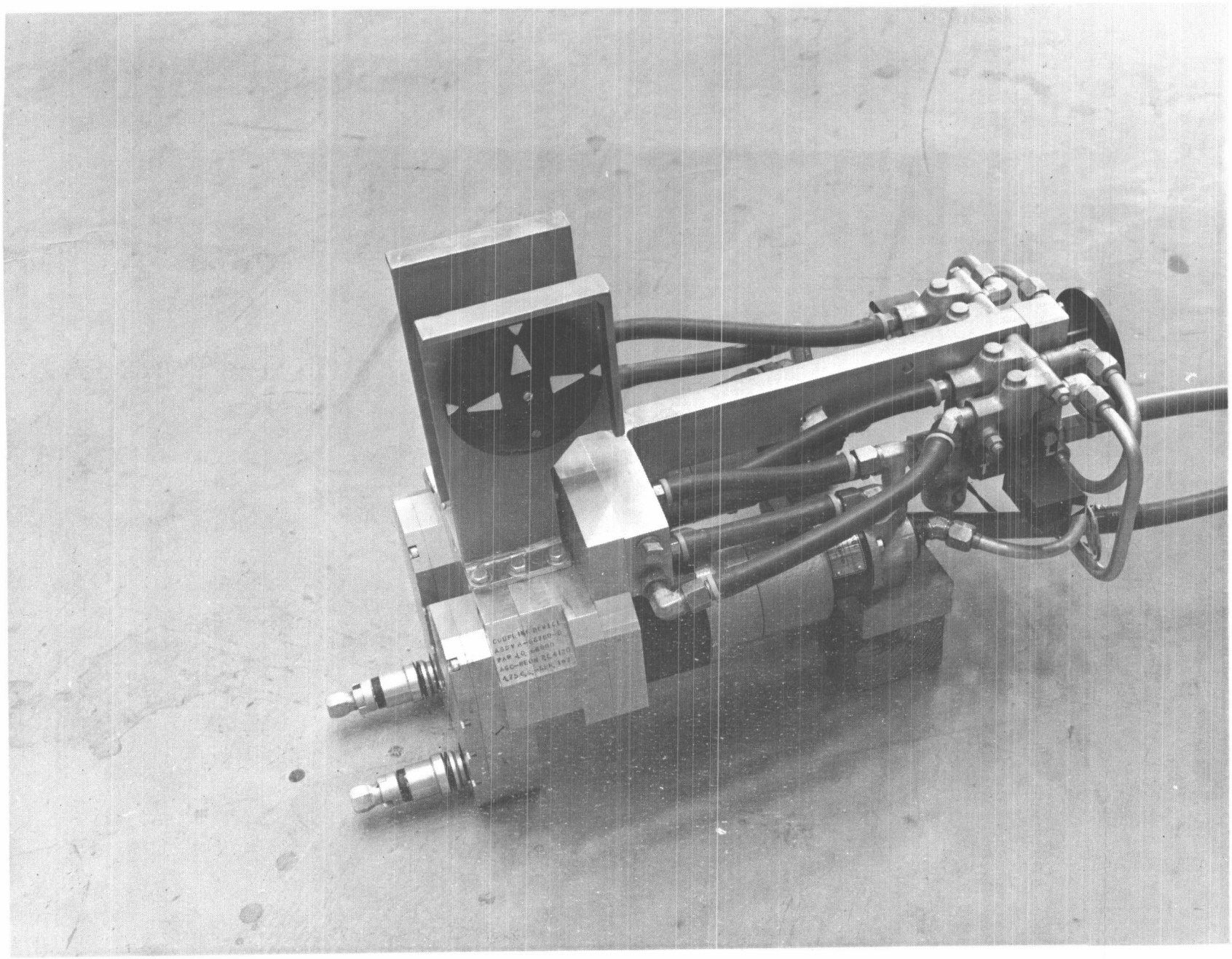


Figure 52 - Item 4120, Coupling Device, 7.75 cc Hex



Figure 53 - Items 4021, 4116, and 4708, Engine with GSE

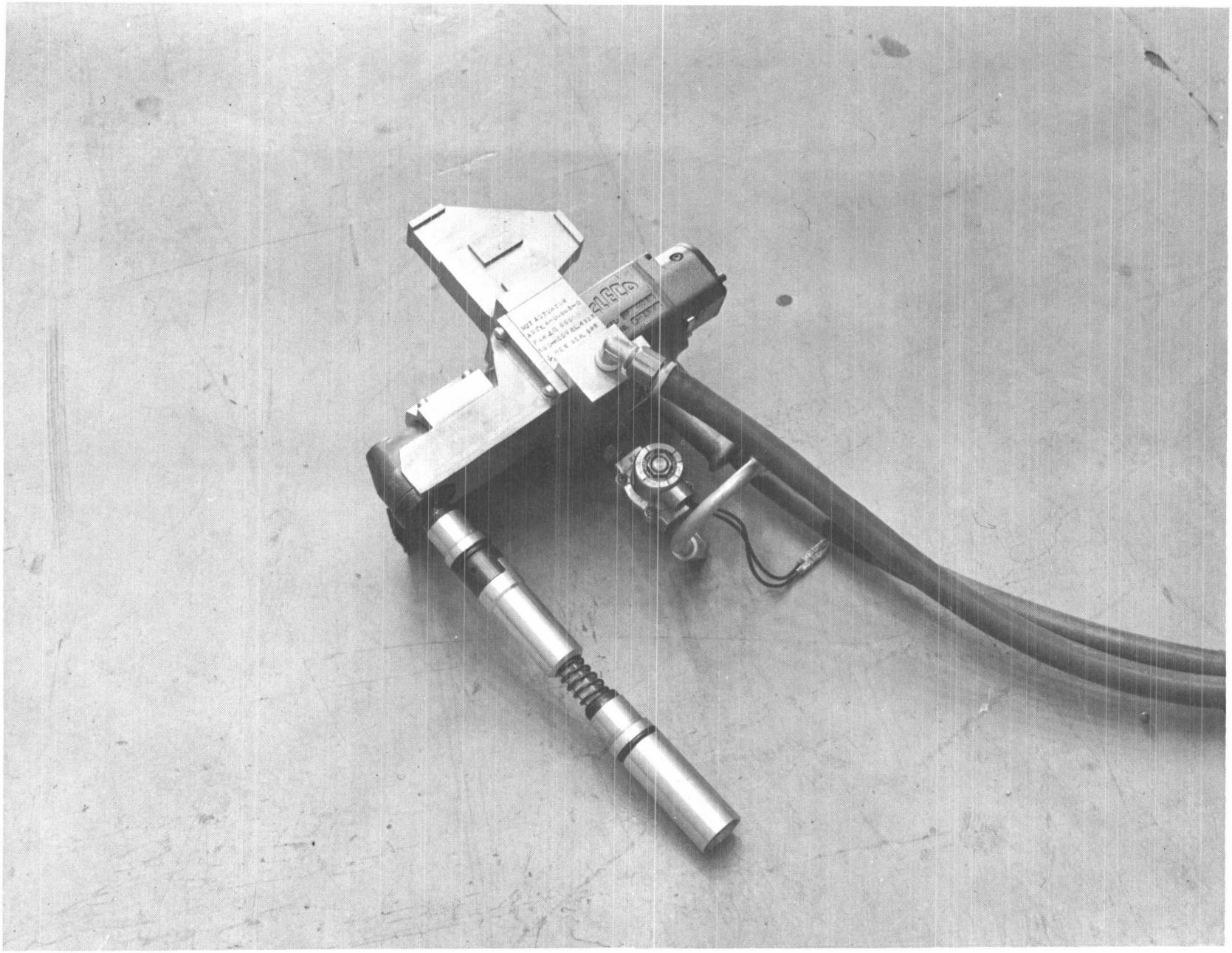


Figure 54 - Item 4123, UTSM/Shield Nut Actuation Device



Figure 55 - Item 4124, Remote Tool, Conoseal Installation

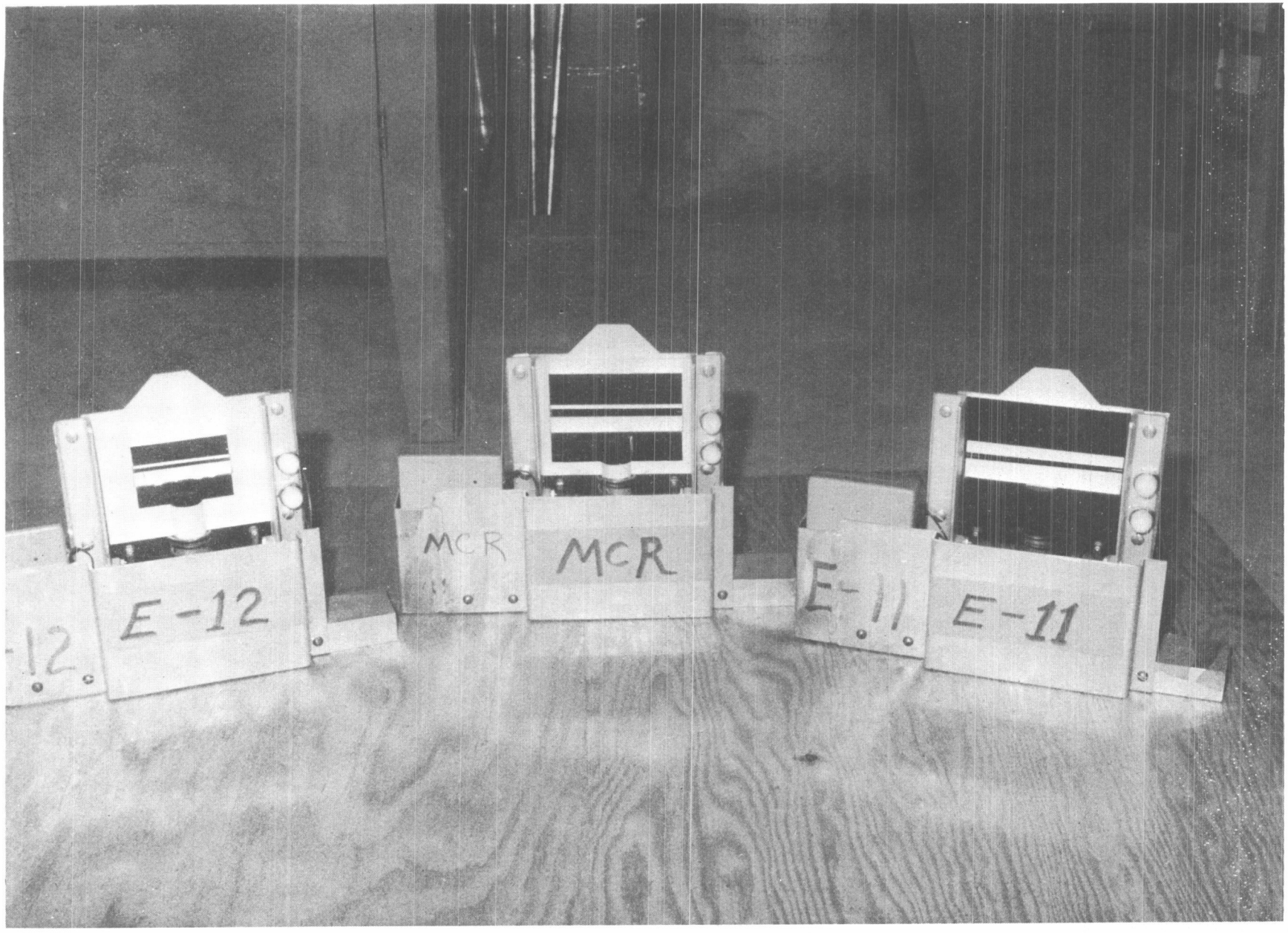


Figure 56 - Item 4125, Remote Parallel Target Kit

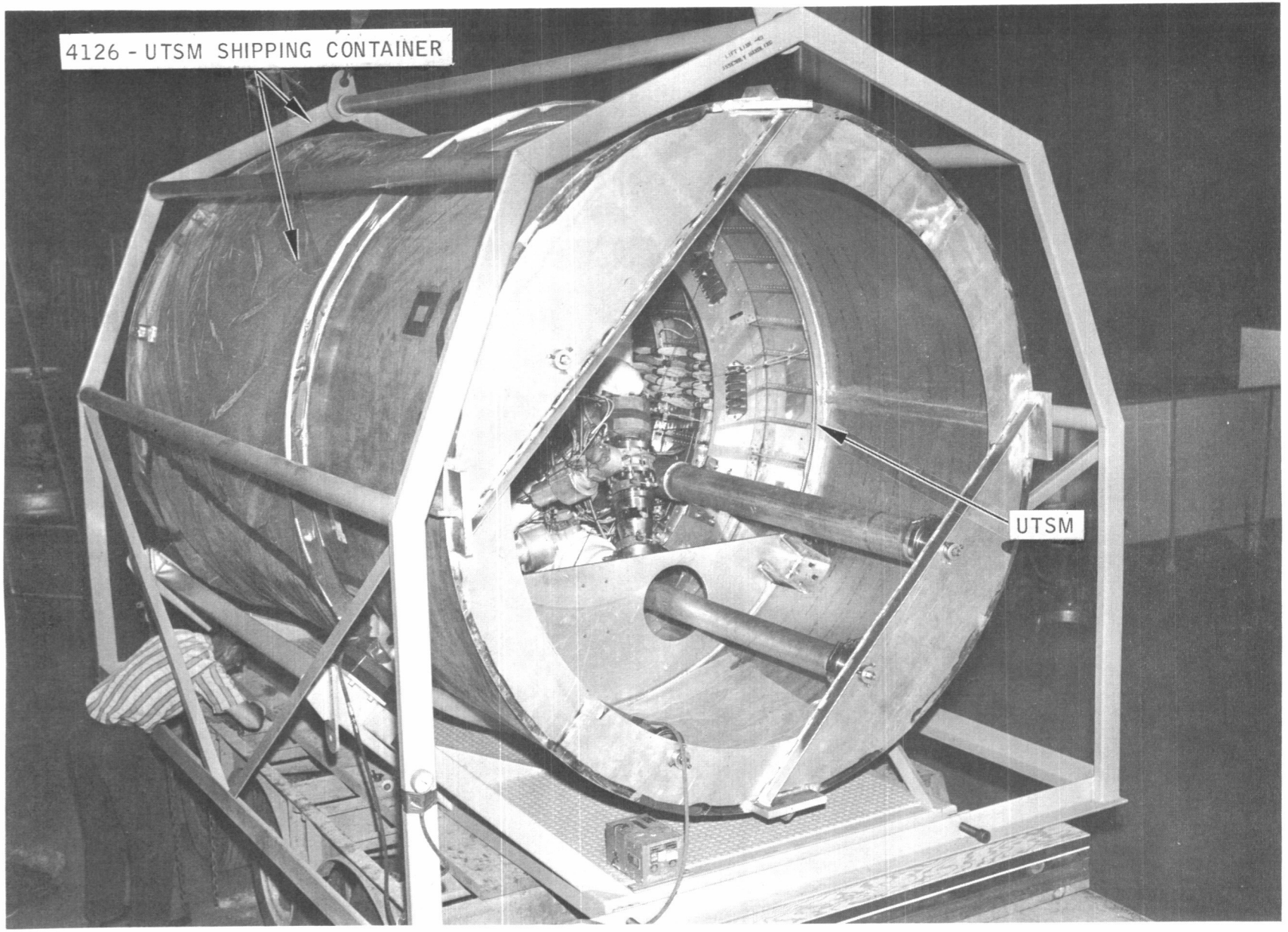


Figure 57 - Item 4126, UTSM in GSE



Figure 58 - Item 4126 in Transit, UTSM in GSE

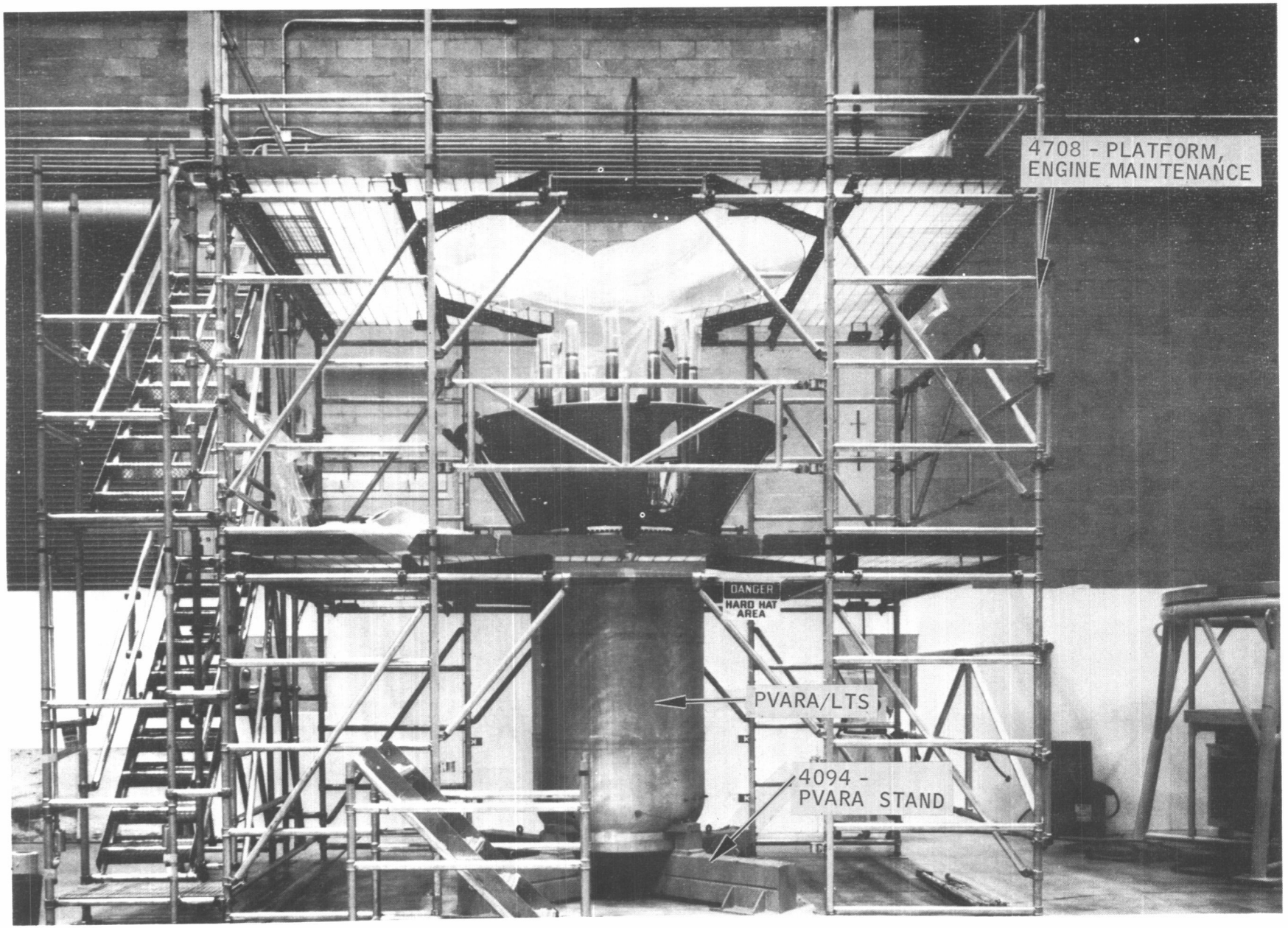


Figure 59 - Items 4094 and 4708, PVARA/LTS with GSE Items

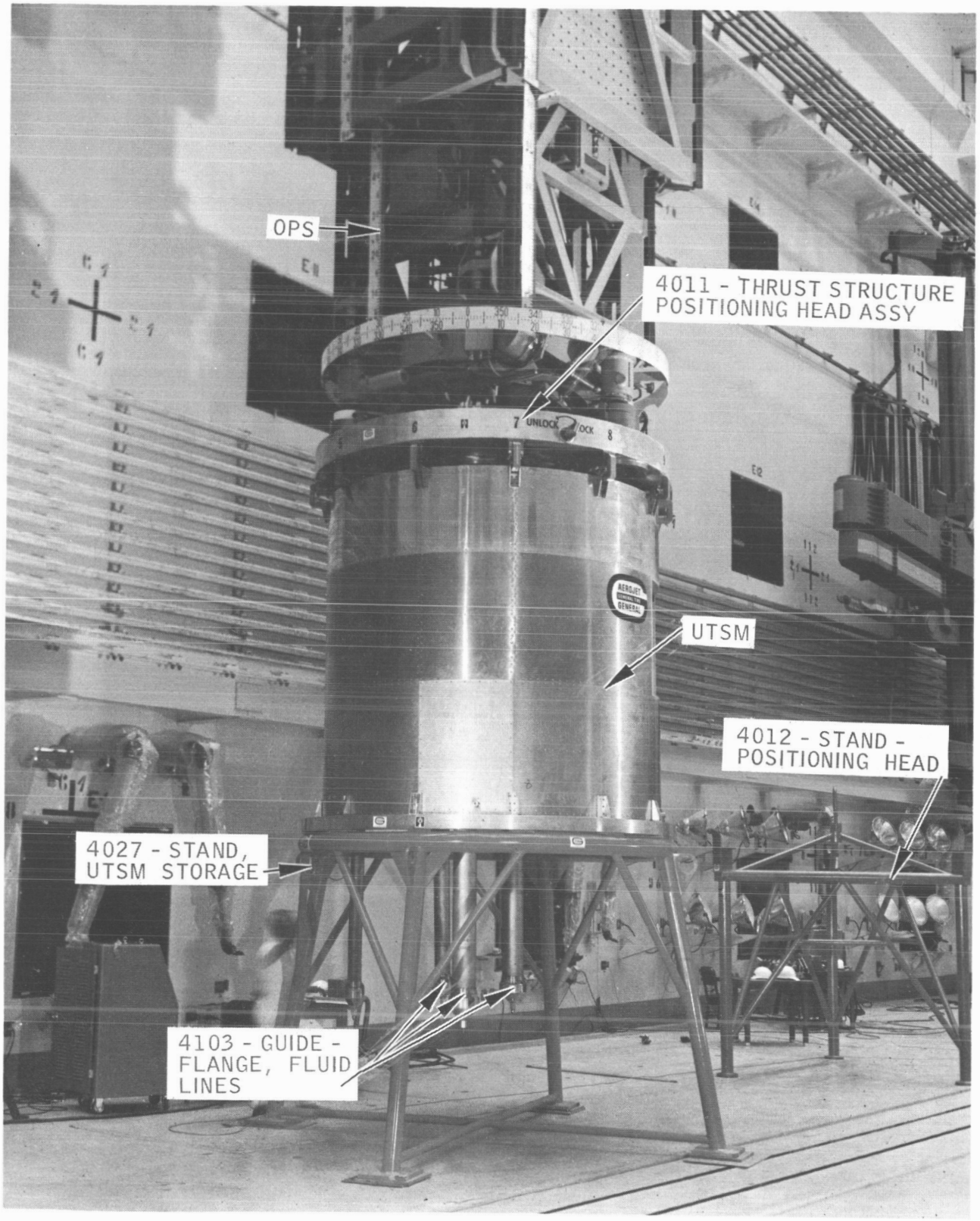


Figure 60 - Items 4011, 4012, 4027, and 4103, UTSM with GSE

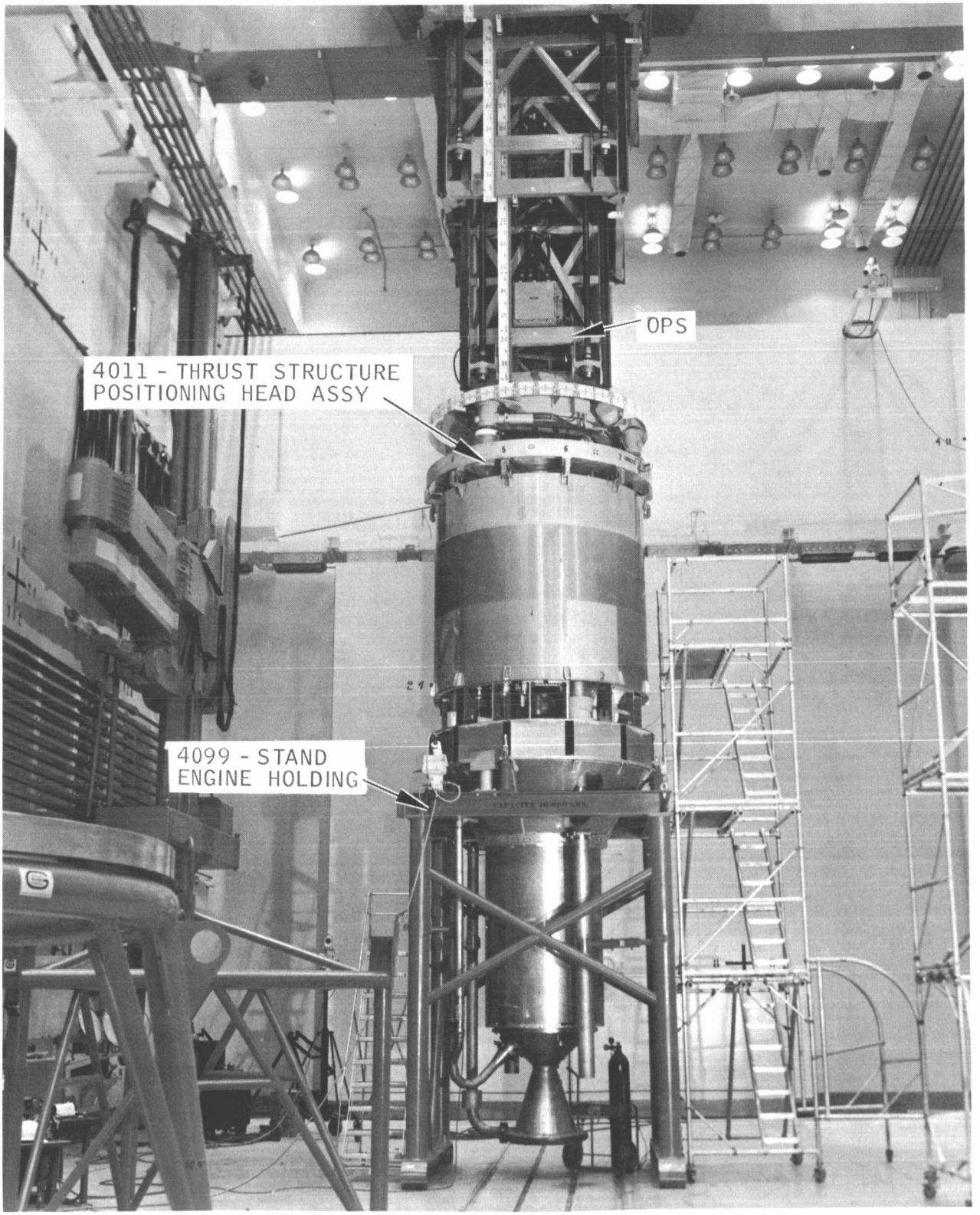


Figure 61 - Items 4011 and 4099, Engine with GSE

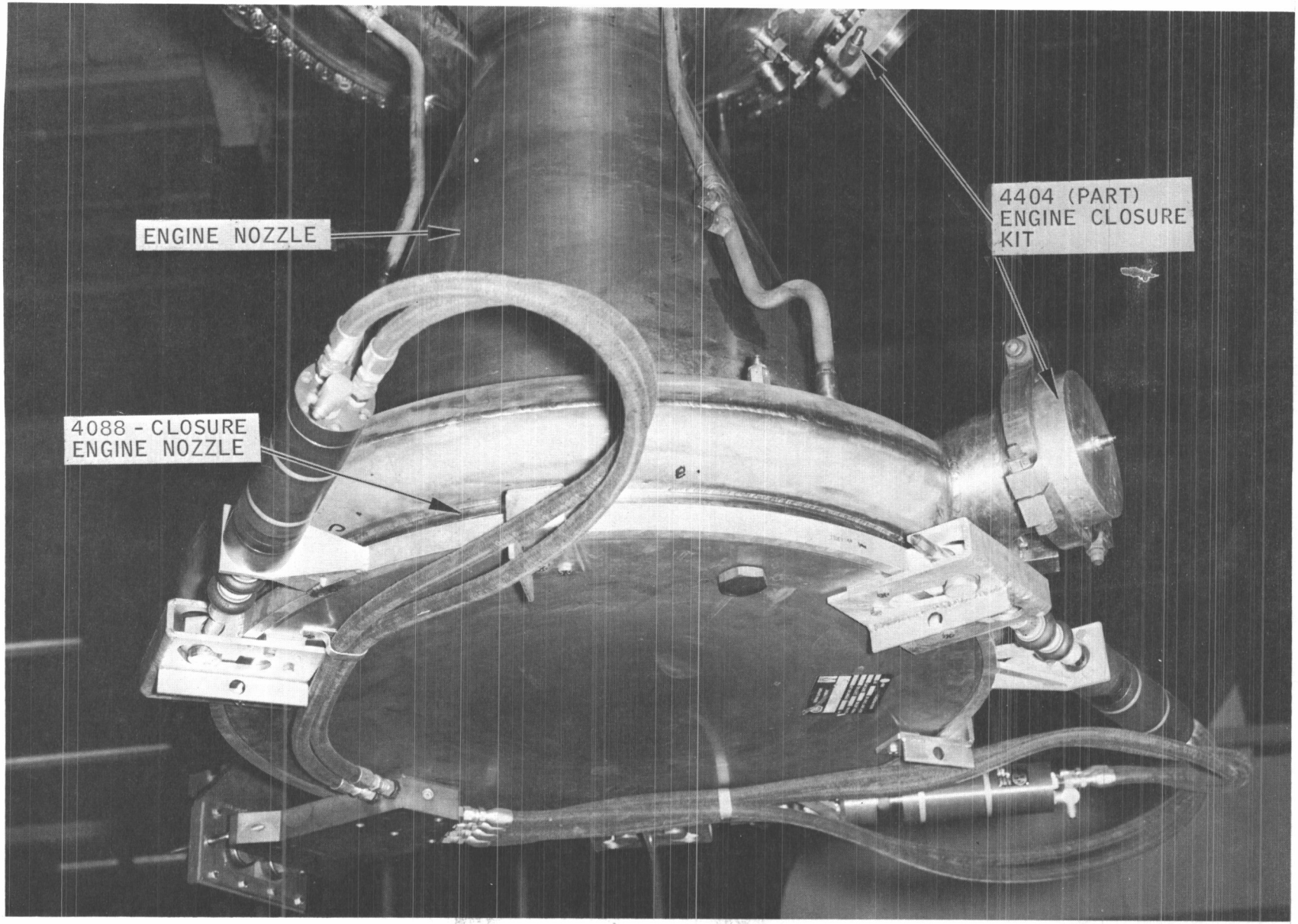


Figure 62 - Items 4088 and 4404, Engine Nozzle with GSE



Figure 63 - Item 4103, Guide Flange Fluid Lines

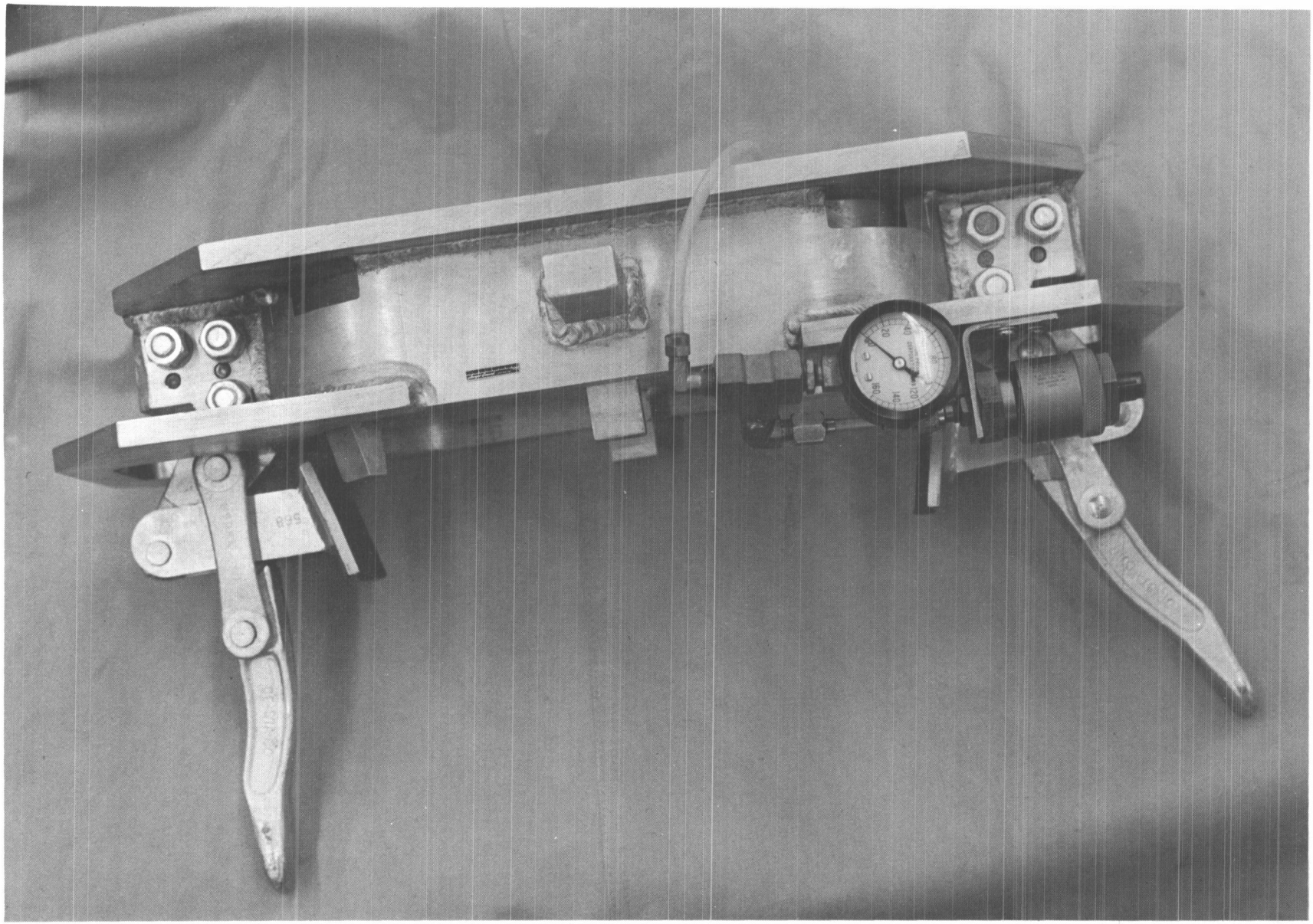


Figure 64 - Item 4108, Closure, Turning Exhaust Nozzle



Figure 65 - Item 4122, Engine in GSE

An operation and maintenance manual was prepared for P.L. Item 4708, Platform, Maintenance, Engine, and 4088, Closure, Engine Nozzle.

(c) MCC/EIV and E-MAD Equipment

Design effort was completed for the following modifications of the MCC/EIV:

A load readout system for the EIV to indicate engine load and insertion force when installing the XE into ETS-1.

A control system, including two 3-way solenoid valves mounted on the EIV, for controlling the air flow to and from the turbine exhaust nozzle closures.

Additional indicator lights to show positions of the EIV mounted engine dust cover and engine nozzle closure actuator.

A control system for actuating the solenoid-operated bleed valve mounted on the engine nozzle closure.

Modification of two of the engine support pads on the EIV to provide clearance for the larger brackets and longer bolts used to join the engine LTS to the engine external shield.

A new umbilical lock mechanism to be mounted on the EIV to assure that the umbilical can be unlocked and released from the EIV in am emergency situation.

Revisions to the MCC air conditioning system to provide more condenser cooling air capacity.

Addition of mirrors on the EIV to increase the direct-viewing capability of critical areas.

Additionally, design effort was expended in selecting new springs for the EIV to correct a shock transmittal problem encountered during transportation, shock, and vibration testing of the MCC/EIV at NRDS.

A conceptual design was completed of modifications required to enable the EIV to mate to the XE at ETS-1 with the S-2 side shield in position at the Engine Test Stand.

A review was conducted of the use of back-up tools (P.L. Items 4112 and 4121) to be used by the EIV manipulators in the event of a malfunction. This review showed that an EIV-mounted tool rack to support the tools was not required, and design of this item was cancelled.

Design was completed for revising the MCC/PM power transfer system to overcome problems noted during acceptance testing at NRDS.

Operation and maintenance instructions for the MCC and EIV were written and published.

The ATP was completed on the MCC/EIV/PM. The end item reports on the MCC and EIV are being finalized for review and approval.

Dispositions and corrective actions relative to the POCMTS discrepancies noted during acceptance testing were completed. The final POCMTS end item report was completed.

Checkout of the OPS floating head load range change modification was completed and revealed the need for a well filtered 28 vdc power supply. This problem was evaluated and the equipment modified as required.

(2) Fabrication

(a) NRX Program

Modification of NRX support equipment was to be performed by NTO/NRDS on P.L. Item 17, Remote Cooldown Nozzle Cover, and Item 137, Nozzle Examination Fixture.

Modification of P.L. Item 21, Remote .812 Bolt Removal Tool, and Item 923, Remote Thrust Chamber/Reactor Disassembly Fixture, will be accomplished in CY 1968.

(b) XE Program

Fabrication was completed on the following mechanical XE support equipment and all units were shipped to NRDS:

P.L. Item	Nomenclature	Figure
4021	Stand, Engine Assembly Supports the engine by engaging the external shield and provides engine end-for-end rotation through 360°.	53
4027	Stand, Upper Thrust Structure Module Storage For supporting the UTSM during standby, checkout, and storage.	60

P.L. Item	Nomenclature	Figure
4059	Platform, Maintenance, ETS-1 For personnel access to all levels of the engine and TSA after installation in ETS-1.	48
4095	Cover, Auxiliary Duct, ETS-1 A thin, aluminum honeycomb-sandwich disk to cover the ETS-1 exhaust duct top opening to prevent contaminants from falling into the duct.	-
4108	Turbine Exhaust Nozzle Closure A manually or remotely operated nozzle closure for sealing the turbine exhaust nozzles during engine leak test.	64
4112	Tool, UTS/TSA Nut Removal - Remote A remotely operated impact wrench for removal of the UTSM/TSA fastening nuts if they fail to disengage after testing.	66
4117	Coupling Device, 6.50 cc Hex For remotely coupling and uncoupling the clamp on the turbine inlet line at engine station 185.14.	49
4118	Coupling Device, 7.62 cc Hex For remotely coupling and uncoupling the clamp on the pump discharge line at Engine Station 185.14.	50

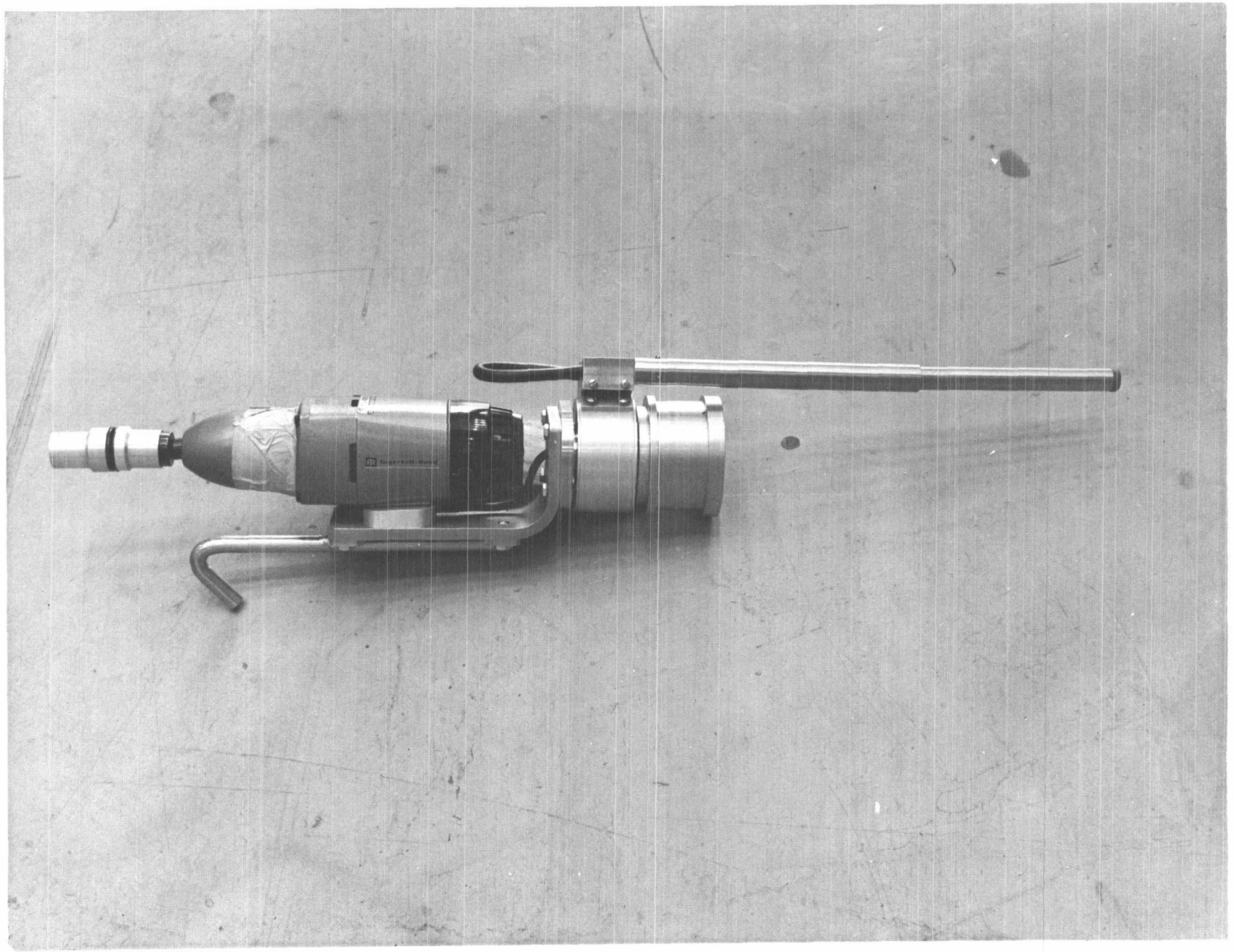


Figure 66 - Item 4112, Remote Tool, UTS/TSA Nut Removal

P.L. Item	Nomenclature	Figure
4119	Coupling Device, 9.00 cc Hex For remotely coupling and uncoupling the clamp on the turbine exhaust lines at Engine Station 185.14.	51
4120	Coupling Device, 7.75 cc Hex For remotely uncoupling the clamps on the actuator pedestal base at Engine Station 185.14.	52
4121	UTSM/TSA Coupling Device - Remote For remote operation of the fluid line remote couplings at Station 42.89 using a manipulator.	
4123	UTSM/Shield Nut Actuation Device For remote removal and installation of the 12 nuts that fasten the UTSM to the shield.	54
4124	Tools, Conoseal Installation - Remote For remotely replacing the propellant line seals during remote engine reassembly operations.	55
4125	Parallel Target Kit - Remote Three sliding plate indicators that are remotely equipositioned around the periphery of the shield and under the UTSM during assembly to indicate to the operator the parallelism of the UTSM to the shield prior to mating.	56

P.L. Item	Nomenclature	Figure
4126	UTSM Shipping Container Provides shock isolation, structural support, tie-down, and protective cover for UTSM during shipment and storage.	57, 58
4133	Crane Hook Adapter, Lifting Fixture For adapting the large lifting bale on P.L. 4009 and P.L. 4116 to a 15-ton crane hook and hydraset.	-
4135	Protector, Flange, Pressure Vessel Three interlocking ring segments, which when engaged to the PV flange, protect the Omega seal and flange from damage during reactor installation.	-
4708	Platform, Maintenance, Engine Envelopes the engine in the engine stand to provide personnel access to all portions of the engine.	53, 59
5007	Mount - Binocular Supports and provides smooth positioning, swiveling and locking of the binoculars at each viewing window in the E-MAD Building.	-

The following XE mechanical GSE items, which were completed in CY 1966 and which were tested and used at Aerojet-Sacramento, were shipped to NRDS in CY 1967:

P.L. Item	Nomenclature	Figure
4008	Stand, External Shield Supports the external shield (loaded or unloaded) during cold assembly and hot disassembly operations.	67
4009	Lifting Fixture - External Shield Lifts and positions the shield both manually or remotely when loaded or unloaded. It attaches to the shield lower surface.	67
4049	Cover, Fluid Line - Remote Simple closures to protect open lower line sections from contamination during remote replacement of the UTSM on the XE Engine.	-
4088	Closure, Engine Nozzle A nozzle exit plane closure plate, secured by a remotely operated Marman Clamp Ring, for engine leak test and inerting.	62
4094	Stand, PVARA Supports the PVARA in the nozzle-down position for storage or assembly or disassembly of the LTS and loaded shield.	59
4115	Guides, Control Drum Drive Shaft Housing Twelve pilot plugs of different lengths for guiding control drum shafts through the shield during mating of shield to the PVARA.	-

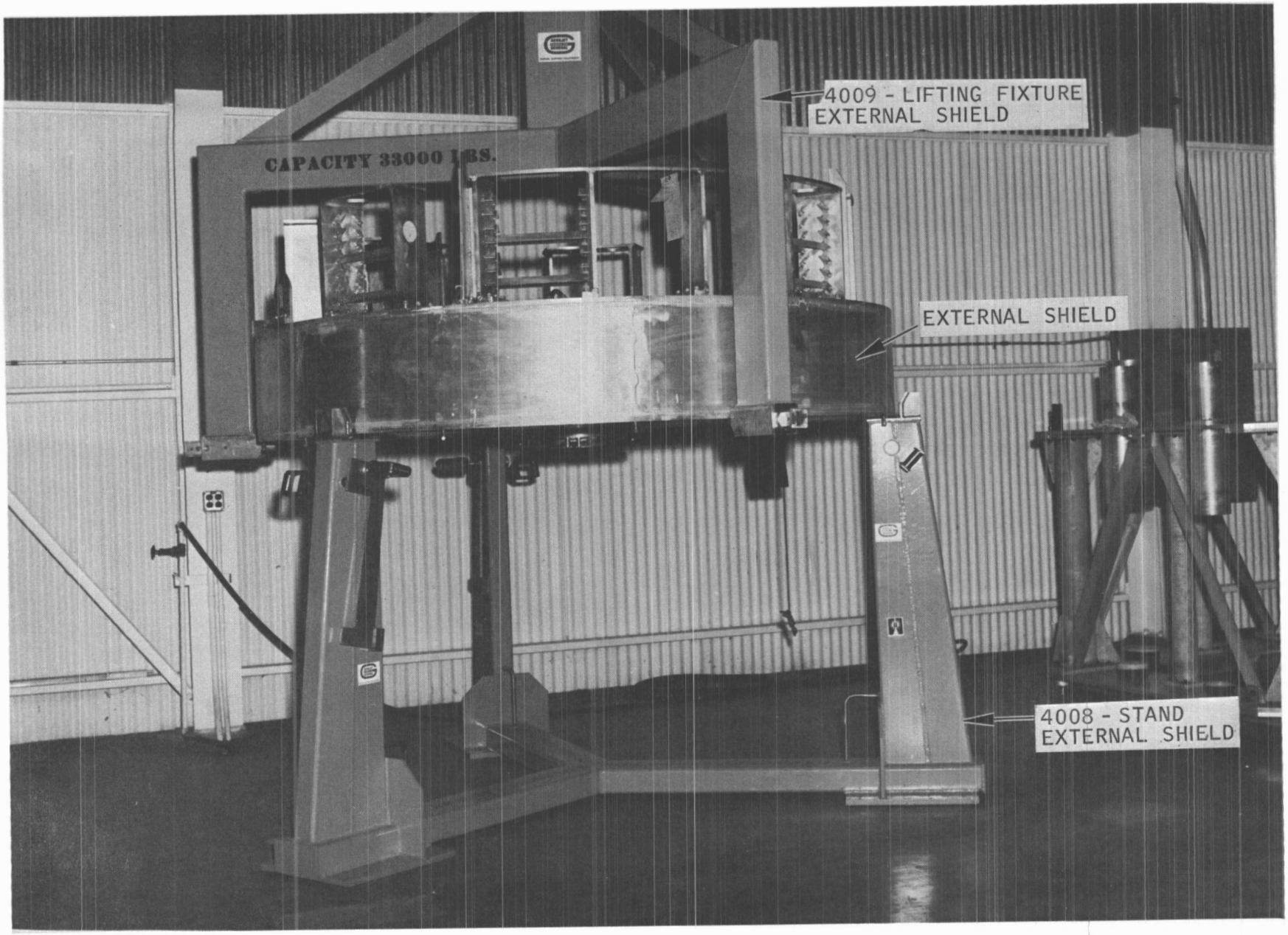


Figure 67 - Items 4008 and 4009, Exterior Shield with GSE

P.L. Item	Nomenclature	Figure
4116	Fixture, Lifting - XE Lower Module Engages to the shield to lift the lower engine module (PVARA, Nozzle, LTS and Shield) during cold assembly operations, and to the UMA to lift the complete engine.	53
4408	Fixture, Retention, Central Core Poison Wire A shaft with a rubber cap used with P.L. 4088 to fit in the engine nozzle to prevent the central poison wires from falling out during engine assembly and checkout in the E-MAD.	68, 69
4420	Simulated Engine Test Stand Dimensionally the same as ETS-1 including engine mounting, clearances, and railroad access, for development of engine handling procedures relative to ETS-1. Located near the E-MAD on an NRDS railroad spur.	70
4746	Sling, Test Stand Adapter A four-legged sling for lifting and positioning the TSA during checkout and for installation onto the EIV Carriage.	71

Fabrication of the following XE mechanical GSE items was completed in CY 1966 but the items were not delivered to NRDS until CY 1967:

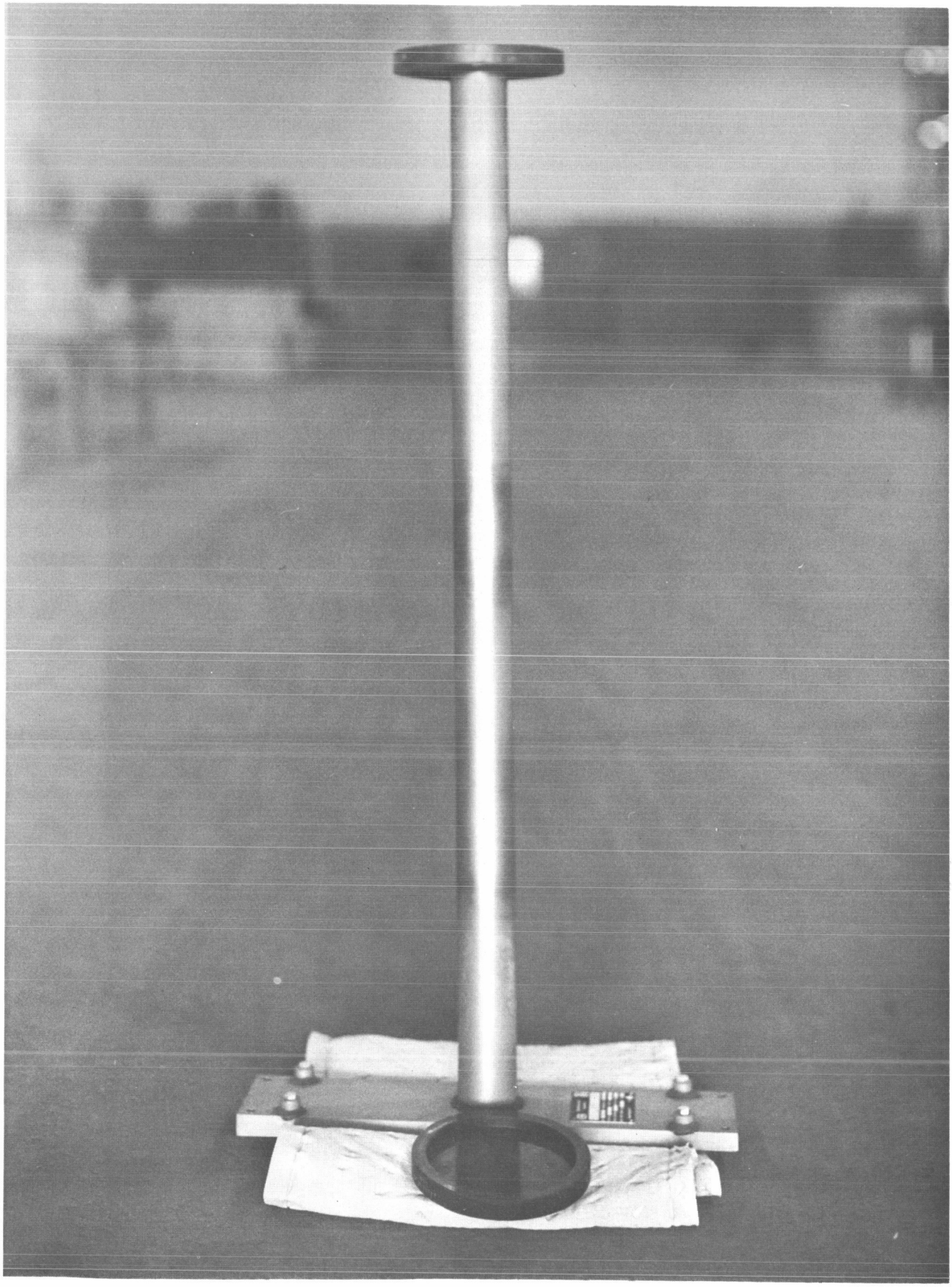


Figure 68 - Item 4408, Retention Fixture, Central Core Poison Wires

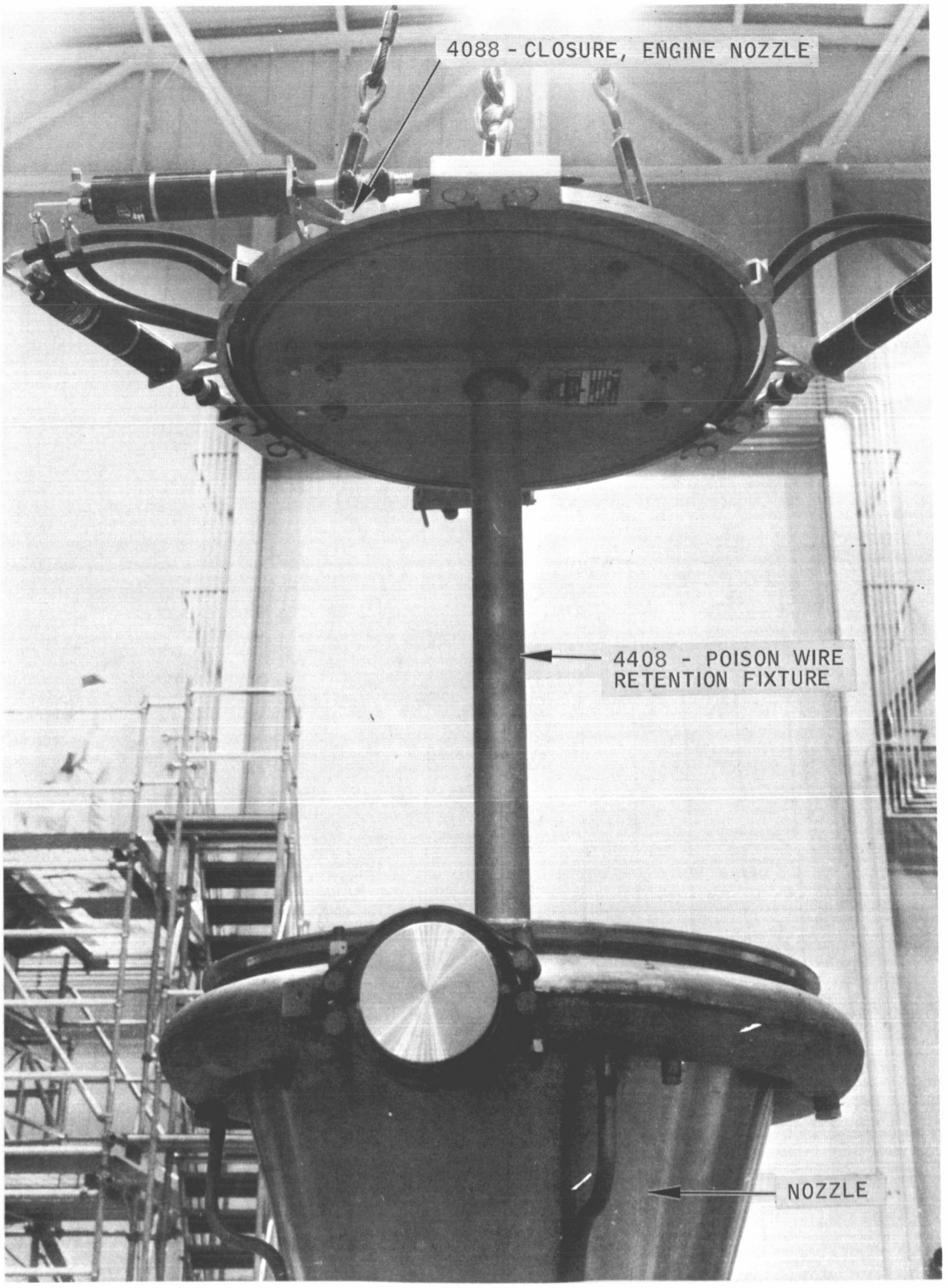


Figure 69 - Nozzle Closure with Item 4408 Being Installed in Nozzle

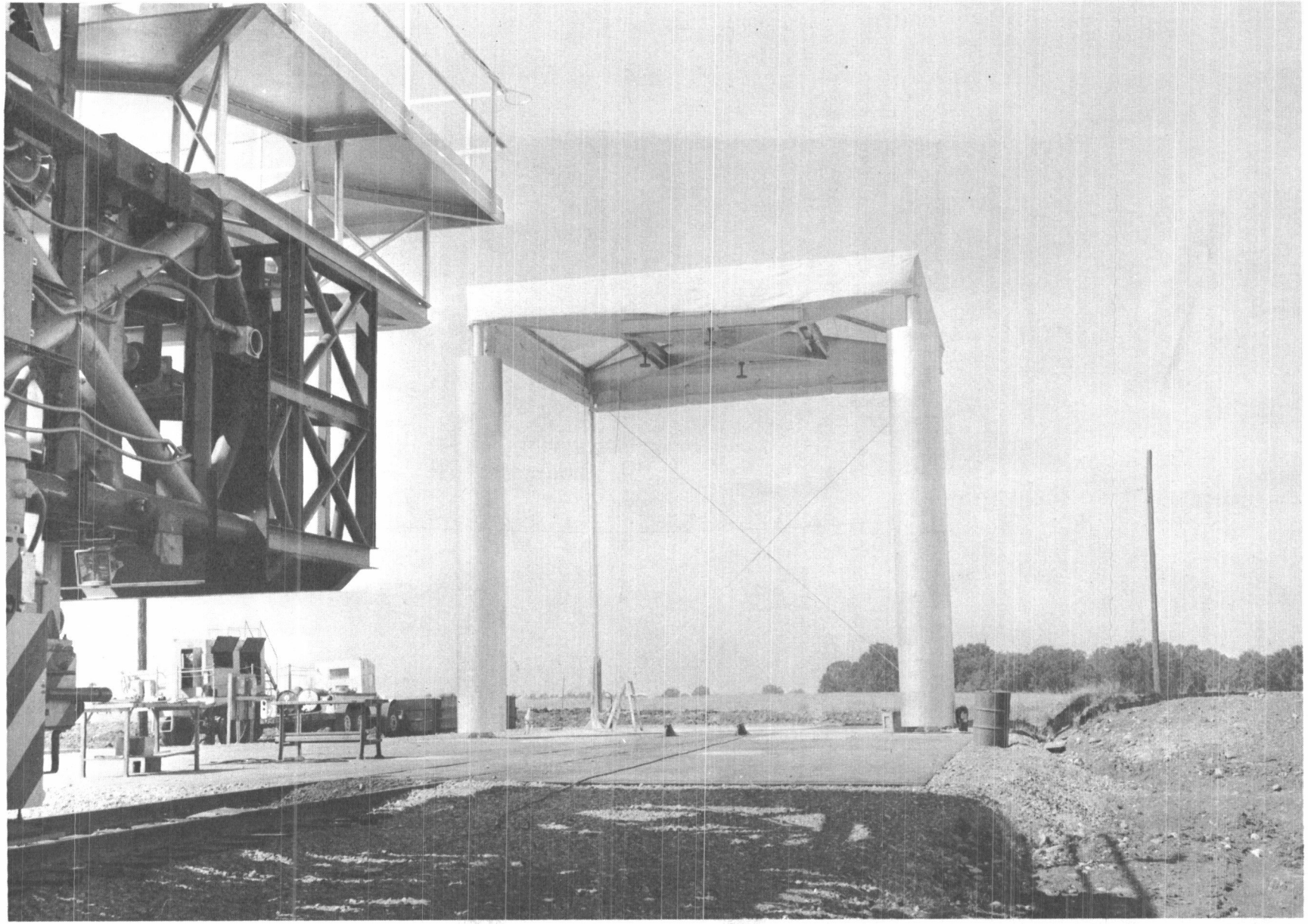


Figure 70 - Item 4420, Simulated Engine Test Stand

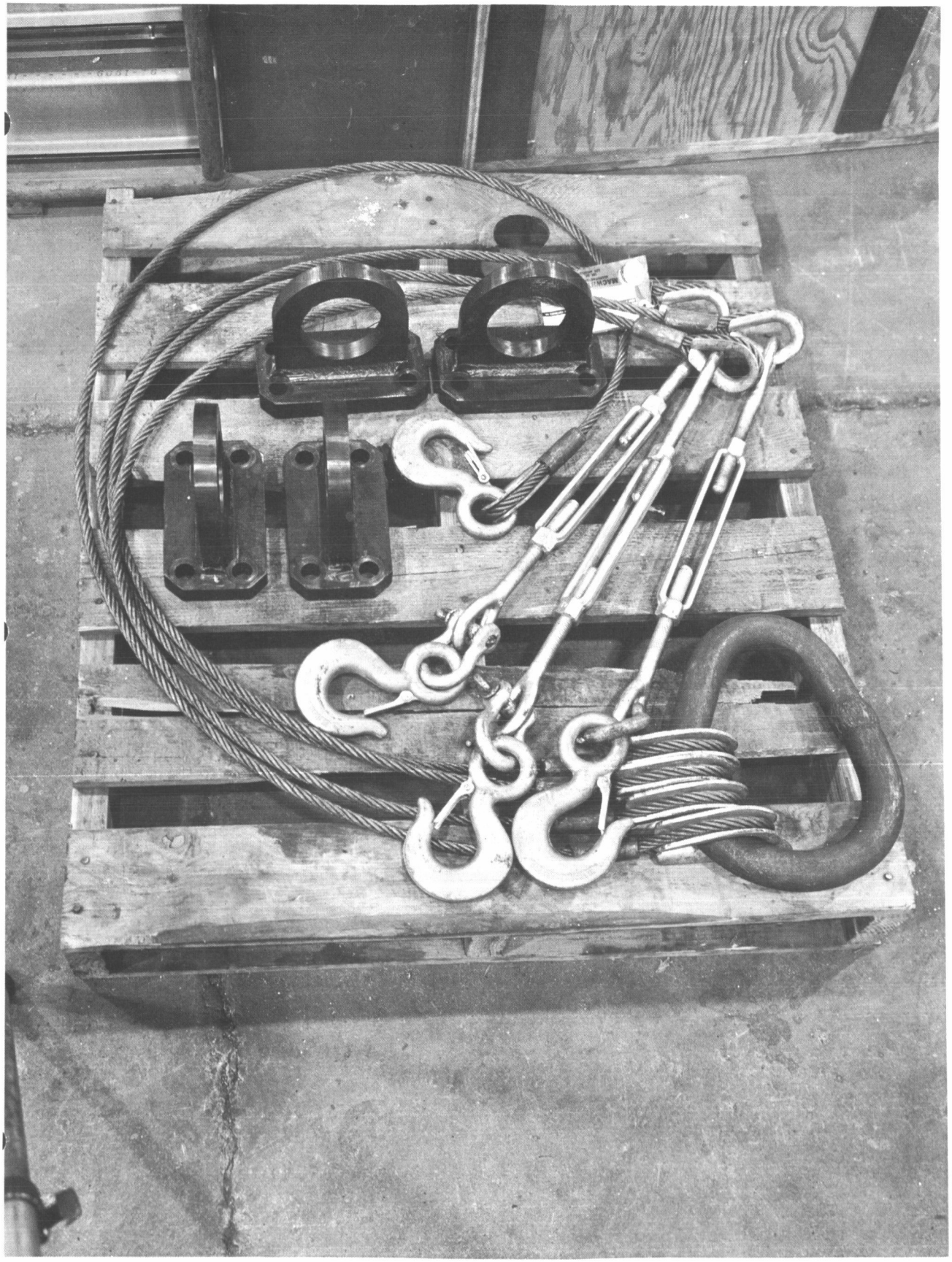


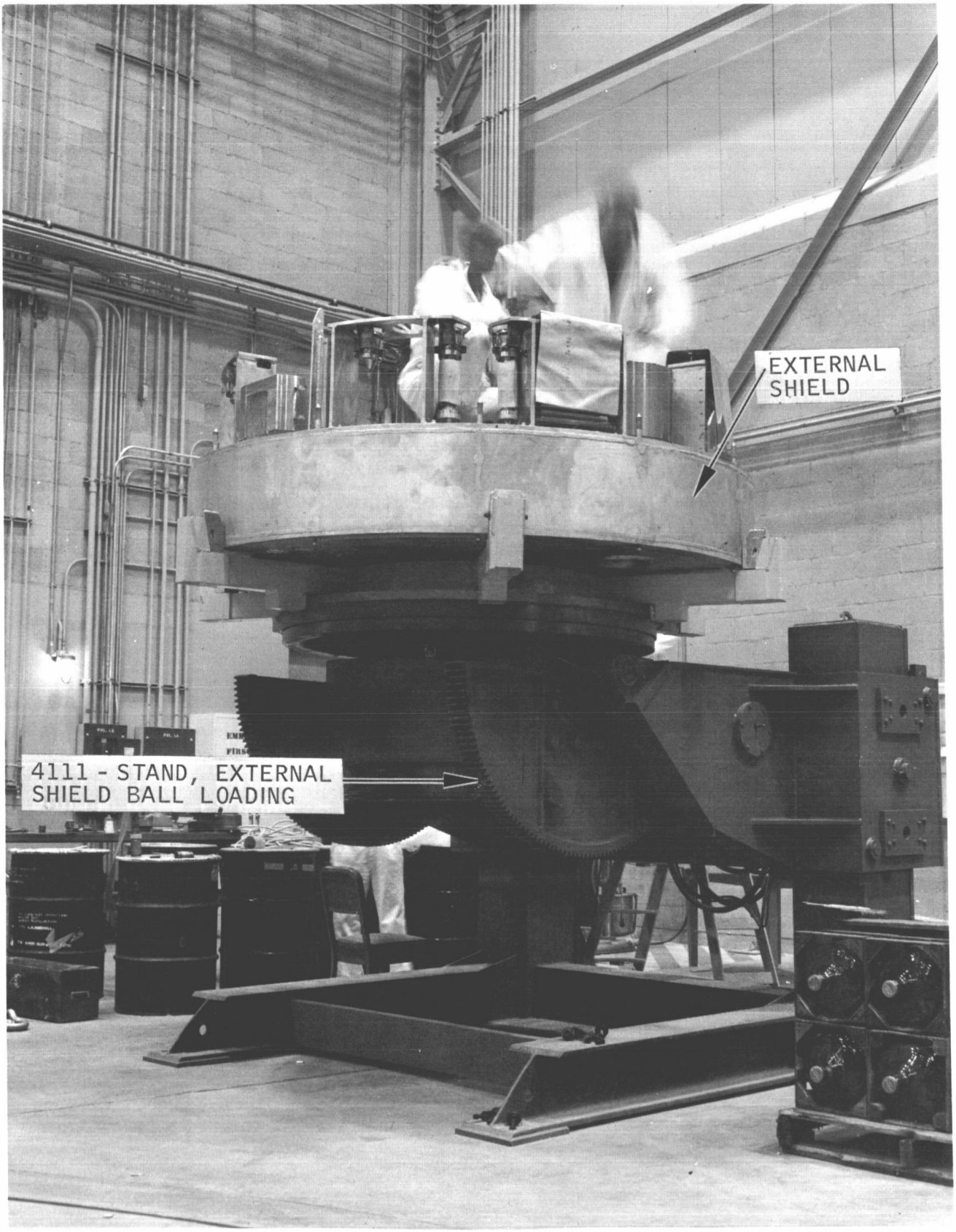
Figure 71 - Item 4746, Sling, Test Stand Adapter

P.L. Item	Nomenclature	Figure
4111	Stand, External Shield Ball Loading Supports, positions, and rotates the shield for loading the shielding balls into the 12 shield segments.	72
4749	Fixture, Fluid Line Handling - Remote A Class A parallel hand assembly modified for grasping, supporting, and handling the 3-in. to 6-1/2-in.-lines during remote disassembly of the XE engines.	73

Completion of fabrication for the following XE items of support equipment has been scheduled for CY 1968:

P.L. Item	Nomenclature	Figure
4102	Platform, Internal UTS Provides personnel access within the UTS to unlock control rod actuators after E-MAD checkout.	-
4134	Fixture, Lifting, Insulating Shield, XE For lifting the insulating shield during remote-disassembly operations in the E-MAD.	-

Fabrication modifications of the following XE items of support equipment were completed and the units were shipped to NRDS during CY 1967:



Fiuure 72 - Item 4111, External Shield with GSE

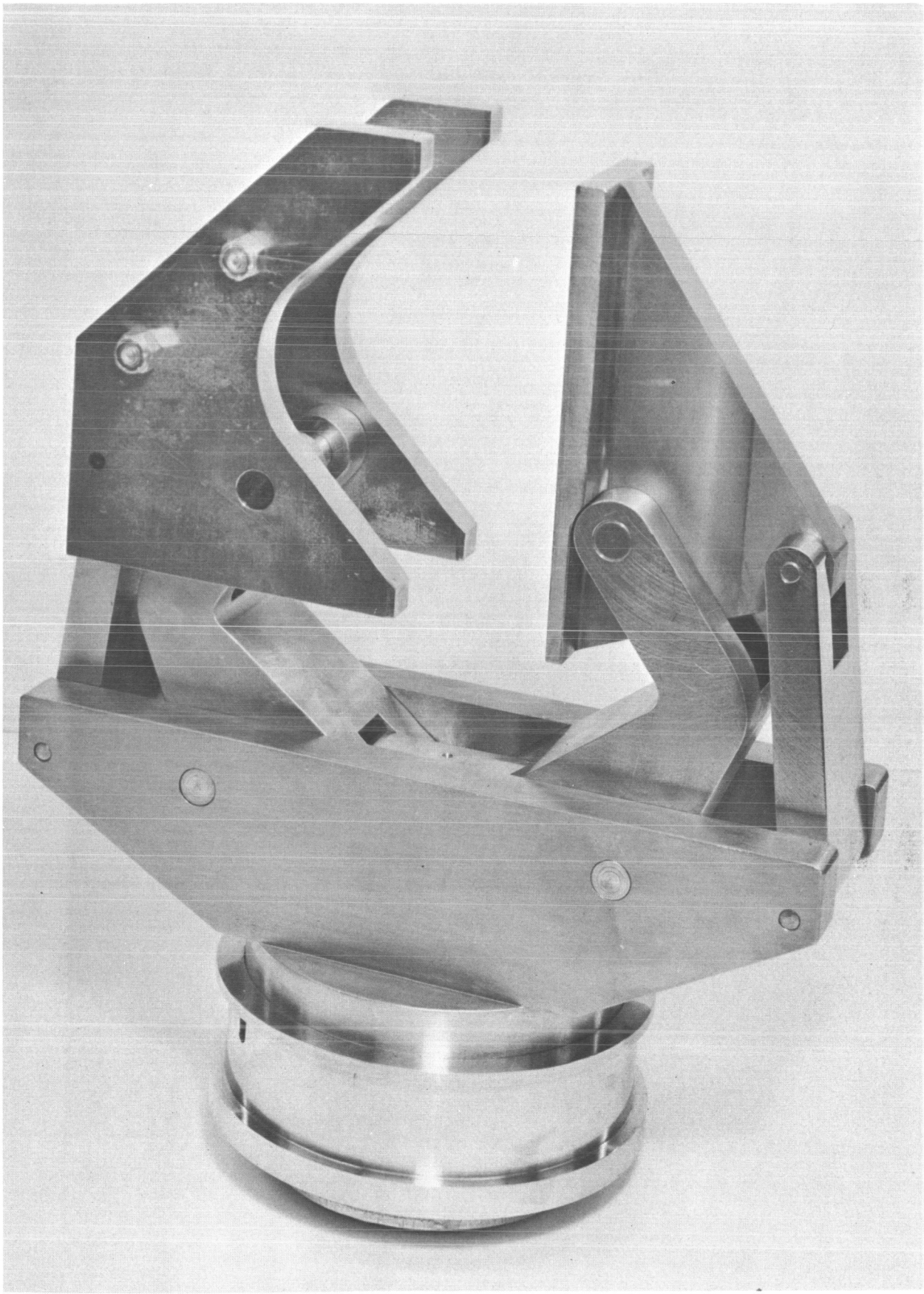


Figure 73 - Item 4749, Fixture, Fluid Line Handling Remote

P.L. Item	Nomenclature	Figure
4011	Positioning Head Assembly, Thrust Structure (OPS) Provides for lifting and positioning the UTSM LTS and complete XE engine by use of the OPS or 40-ton crane. The modification enables the positioning head to accommodate structural changes in the engine.	60, 61
4088	Closure, Engine Nozzle A nozzle exit plane closure plate, secured by a remotely operated Marman clamp ring for engine leak test and inerting. The modification relocates the remote electrical and air connection to clear the turbine exhaust nozzle closure, incorporates a remotely controlled engine vent valve, and adds handles for sling handling when required.	62, 67
4103	Guide - Flange, Fluid Line Remotely attaches to the flanges of the fluid lines of the UTSM to protect and guide them during insertion through the shield penetration liners during installation and removal of the UTSM to the LMA. The modification incorporated changes to allow installation and removal with only one manipulator.	60, 63

P.L. Item	Nomenclature	Figure
4122 (Reidentified from) 4099	Stand, Engine Assembly - Remote Supports the XE engine during remote removal and reassembly of the UTSM to the XE engine. The modification adds line support and aligning brackets to the stand for remote operations. This modification was incorporated into only one of the 4099 stands and that unit is reidentified as P.L. Item 4122.	65

Fabrication modifications of the following XE items of support equipment are scheduled for completion in CY 1968:

P.L. Item	Nomenclature	Figure
453	Closure Kit, Pressure Testing, Nozzle Throat A plug that closes and seals the nozzle throat during leak test operations. The modification provides an interim capability to retain the XE-1 central poison wires. This provides a backup poison wire retention system for XE-1 when P.L. 4088 is not available during assembly operations.	-
4108	Closure, Turbine Exhaust Nozzle (2) A manually or remotely operated nozzle closure for sealing the turbine exhaust nozzles during engine leak test. The modification provides a minimum envelope to eliminate interference with the engine nozzle closure and the pump discharge line bellows and clamp on the engine.	64

P.L. Item	Nomenclature	Figure
4142 (Reidentified from 1143)	Lifting Fixture, Forward Closure A fixture to remove the forward closure from the pressure vessel. This modification enables the use of the fixture to remotely handle the engine forward closure during disassembly operations. Prior to modification, the item was identified as P.L. Item 1143.	-

(c) MCC/EIV and E-MAD Equipment

Reassembly of the EIV was completed (Figure 74).

Procurement of hardware, fabrication, and installation of the following modifications to the MCC/EIV were completed: load readout system; indicator lights for the dust cover and nozzle closure actuator; control system for the turbine nozzle closures; control system for the nozzle closure bleed valve; direct viewing mirrors; additional blower for MCC air-conditioning system; two modified engine support pads; MCC/EIV umbilical unlock system; EIV front truck springs; and auxiliary power transfer system.

b. NERVA Mechanical GSE (2.1.1)

Proposal input data was prepared for the NERVA GSE based on the NR and NE specifications and data and available program guidelines. This included establishing preliminary sequence of events, and identification of the equipment to support the sequence. Provisioning sheets for the equipment, cost studies, schedules, and a program plan were prepared and utilized in the proposal input.

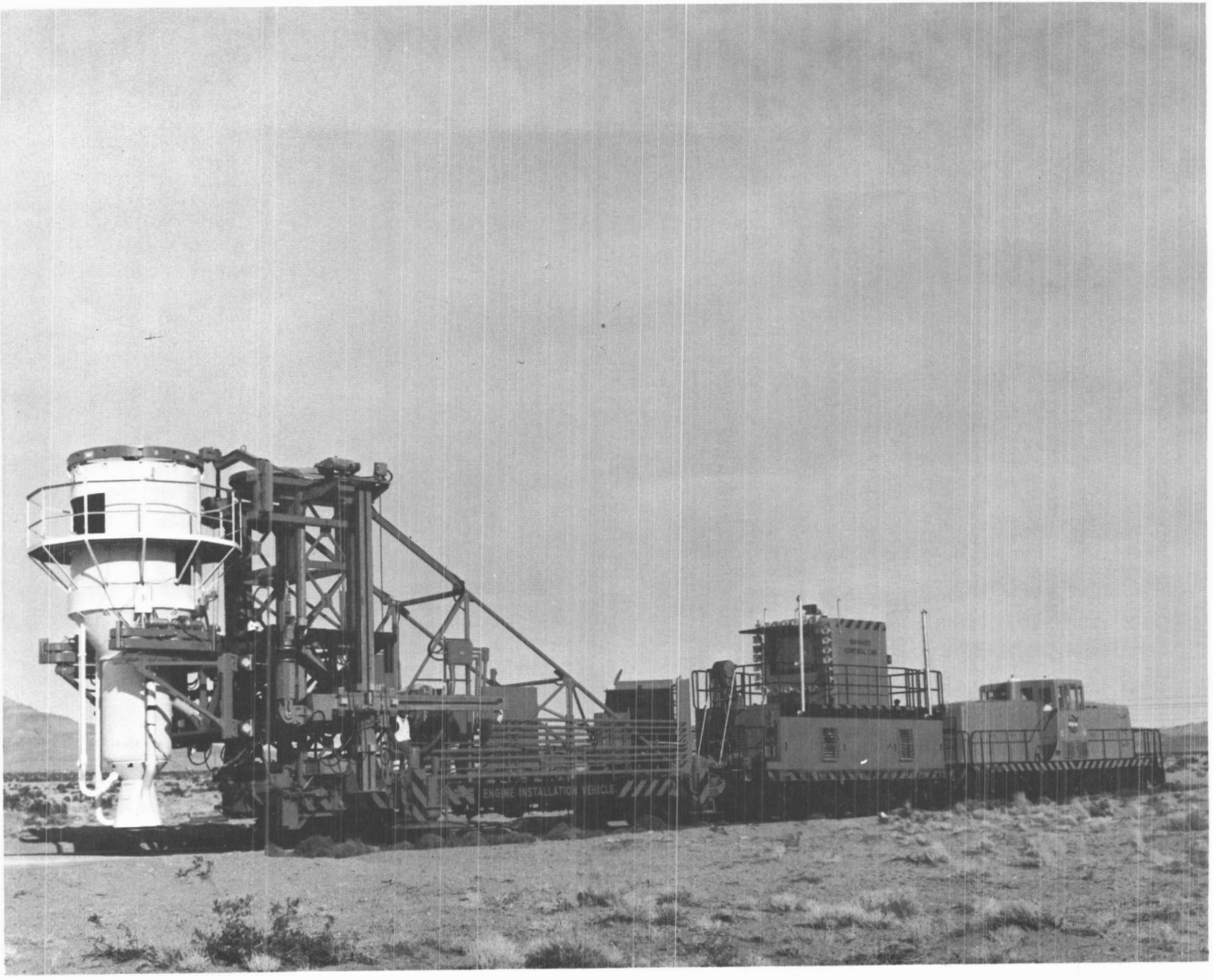


Figure 74 - MCC, EIV and Prime Mover with WEMU at NRDS

NE engine checkout requirements were compiled based on the current level of available data. These were integrated with an analysis of the preliminary engine assembly sequence or plan and the preliminary list of equipment as established in the proposal. Using the data the NERVA Checkout GSE Preliminary Design Plan was prepared. Copies of this plan, which projects a modular building block concept for the electrical-checkout equipment, were coordinated with SNPO-C and forwarded to WANL to provide direction for future planning.

Support was provided in analyzing E/STS 2-3 requirements and criteria in the area where the mechanical (EIV, etc.) and electrical GSE are affected.

Contacts were made with LASL and ACFI to assure maximum usage of Phoebus GSE on the NERVA Program.

2. Electrical Ground Support Equipment (2.2 and 2.2.0)

a. Engineering

Continuous coordination and review of applicable documents with the Nuclear Rocket Development Station (NRDS) and Westinghouse Astronuclear Laboratory (WANL) were conducted to ensure proper development and integration of NRX and XE electrical and checkout support equipment with the facilities and equipment at NRDS.

(1) NRX Program

No designs or modifications were required to support the NRX Program during this report period.

(2) XE Program

Report No. RN-TM-0402, Facility Gas Requirements for E-MAD, was prepared and issued to define the helium and nitrogen requirements at E-MAD for XE inspection and checkout during assembly.

A draft of a remote checkout verification plan was submitted to NTO for incorporation into the RADA Program.

Design criteria was completed, approved, and distributed for the P.L. 4409, Electrical Simulator.

Design was completed and drawings were released for the following electrical and checkout support equipment:

P.L. Item	Nomenclature	Figure
4043	Adapter Kit, Checkout, Remote	75, 76, 77, 78, 79
4400	Functional Valve and Leak Test Set	80, 81
4401	Electrical Test Set, Rocket Engine	82
4404	Kit, Closure, Engine Pressure Testing	62, 81
4409	Electrical Simulator	83
4412	Plug, Closure, Actuator Vent Line (Manual)	84

Design modification was completed and drawings were released for P.L. Item 4400, Functional Valve and Leak Test Set, to incorporate a TPCV test set as an accessory. Other modifications of 4400 included a meter change to improve TBV position readout and a change in meter selector switches to accommodate engine sensor-circuit changes.

Operation and maintenance manuals were prepared and issued for the following XE electrical and checkout support equipment:



Figure 75 - Item 4043 (Part) Pneumatic Control Box

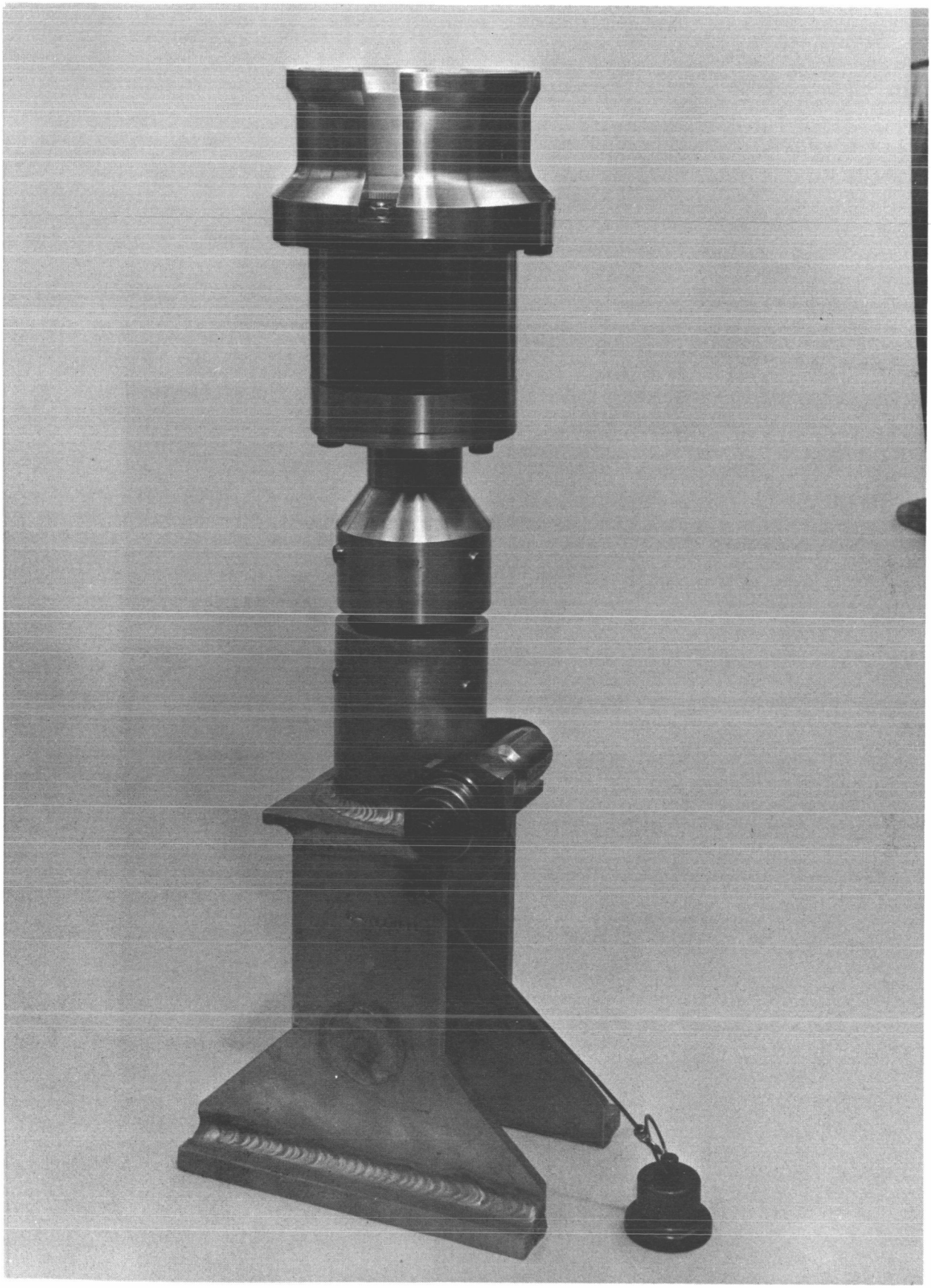


Figure 76 - Item 4043 (Part) Remote Pneumatic Coupling Figure (Inverted)

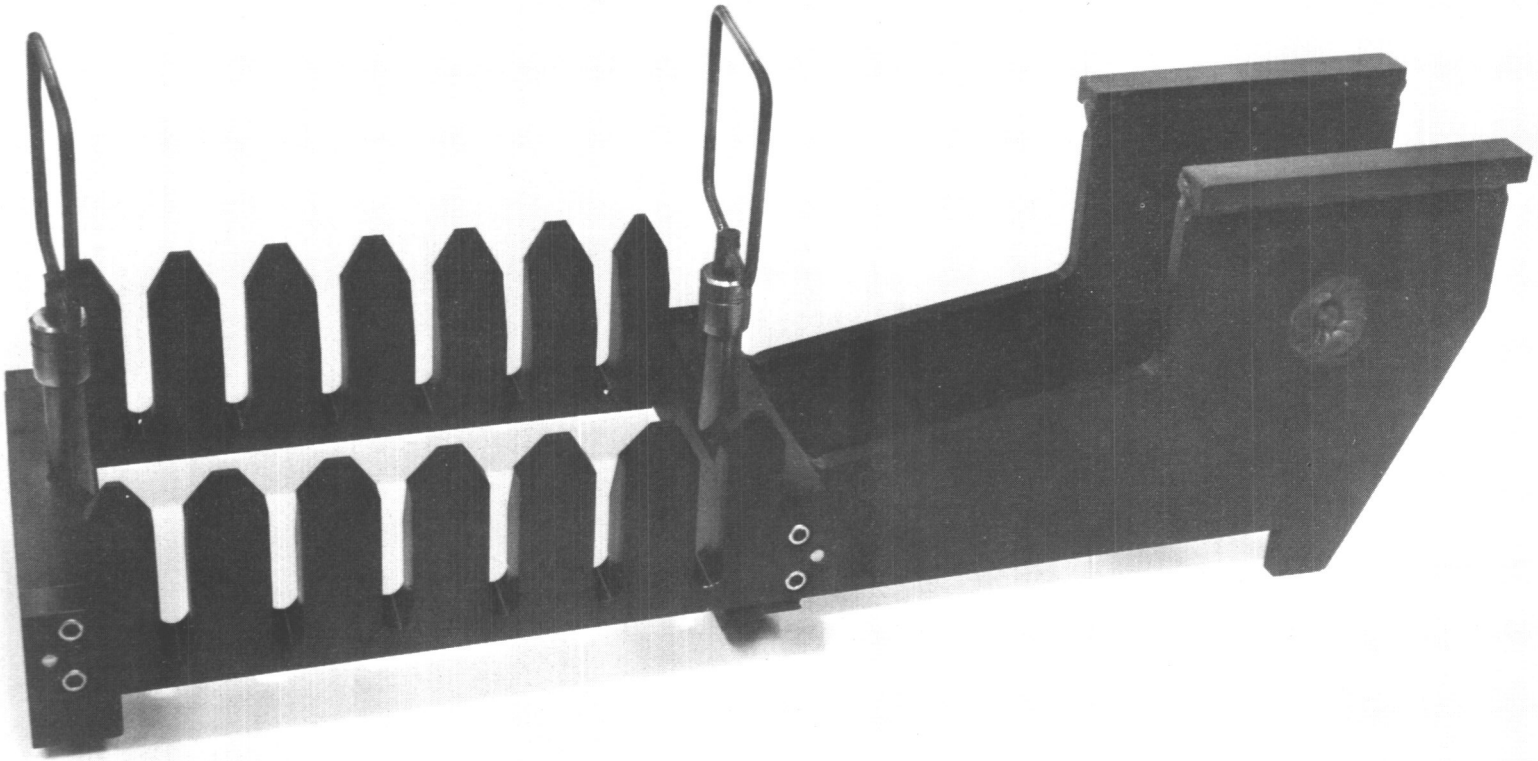


Figure 77 - Item 4043 (Part) Electrical Coupling Guide Assembly

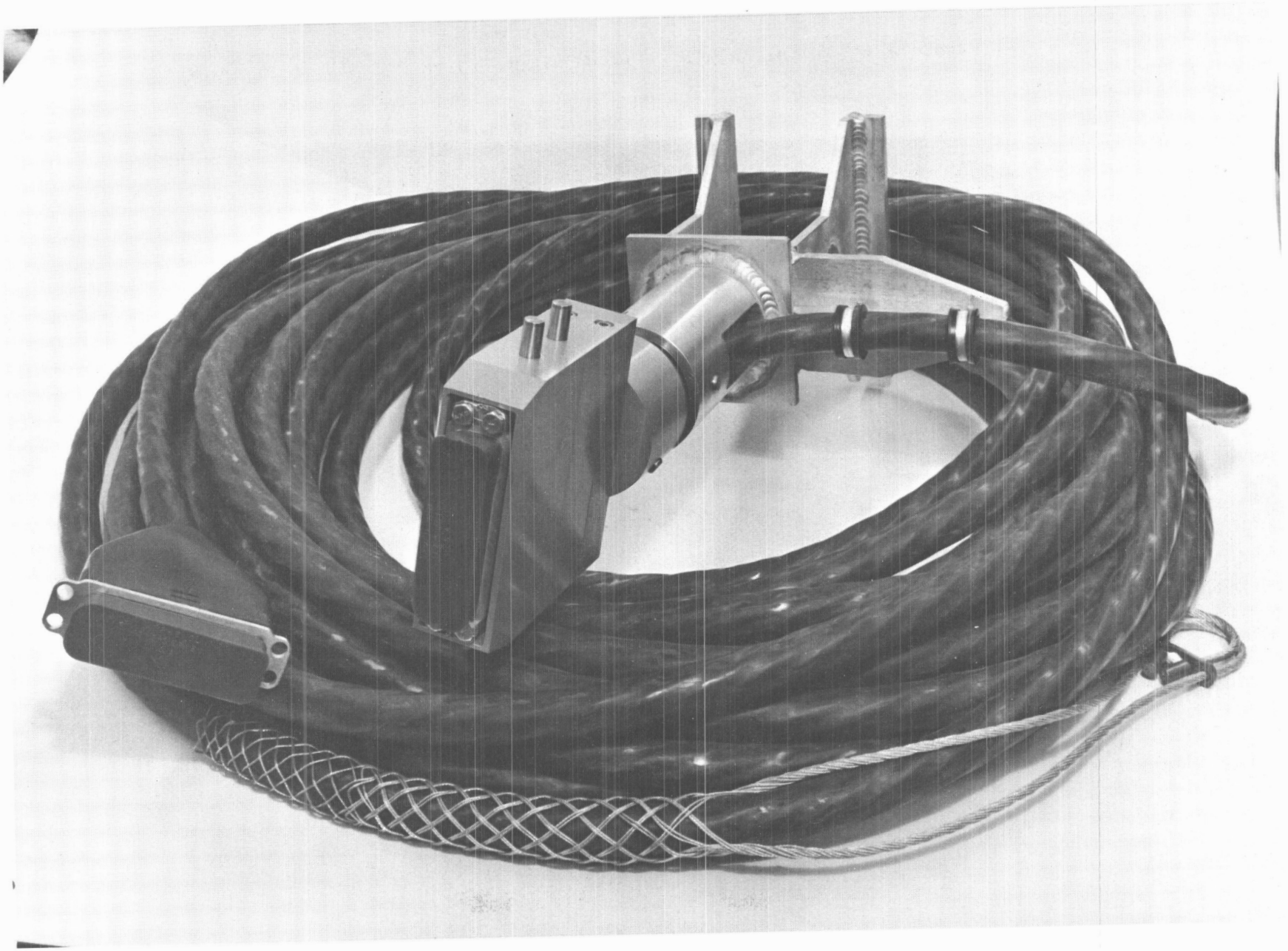


Figure 78 - Item 4043 (Part) Electrical Coupling and Cable Assembly

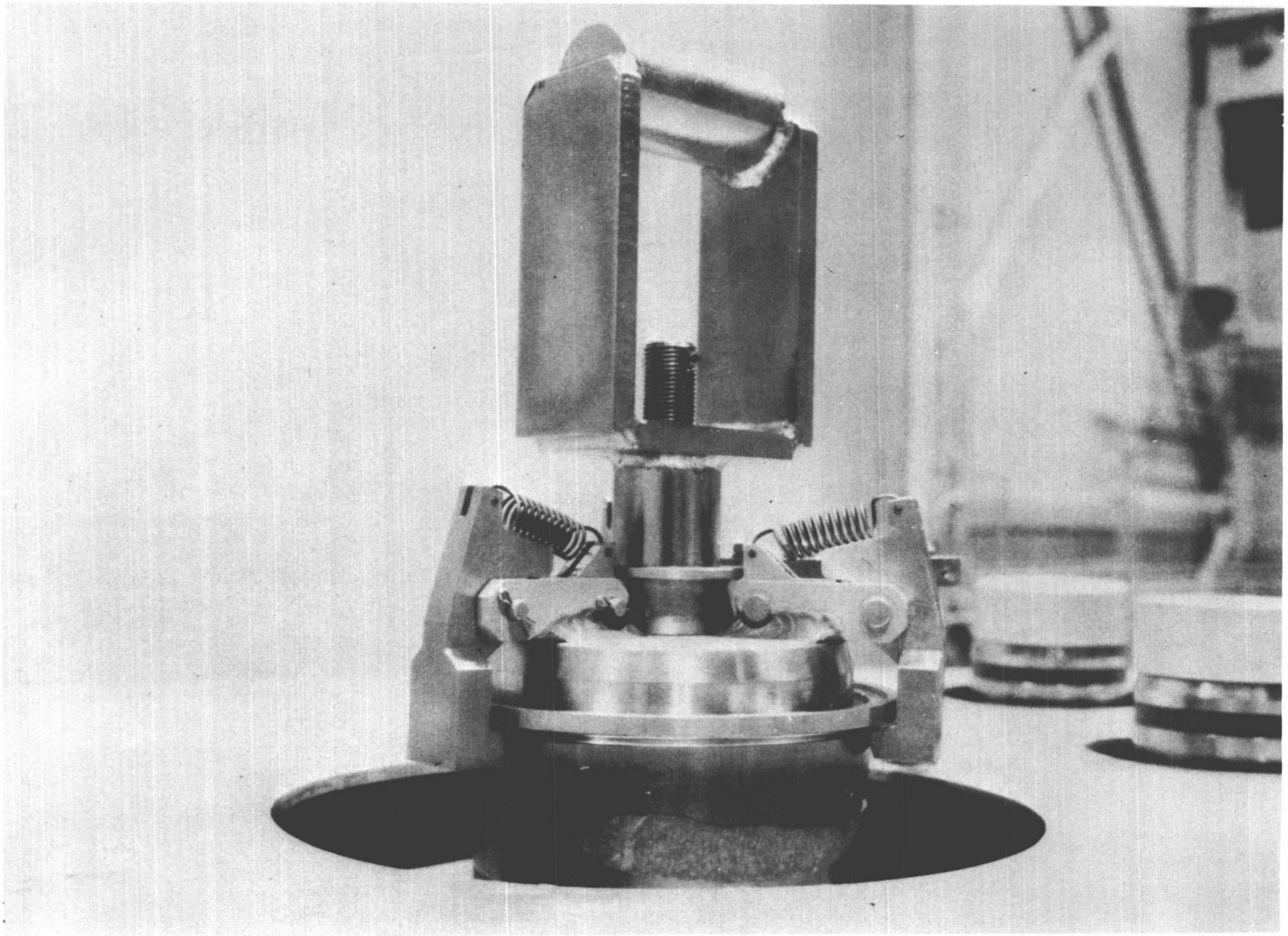


Figure 79 - Item 4043 (Part) Remote Live Closure Installed in UTSM

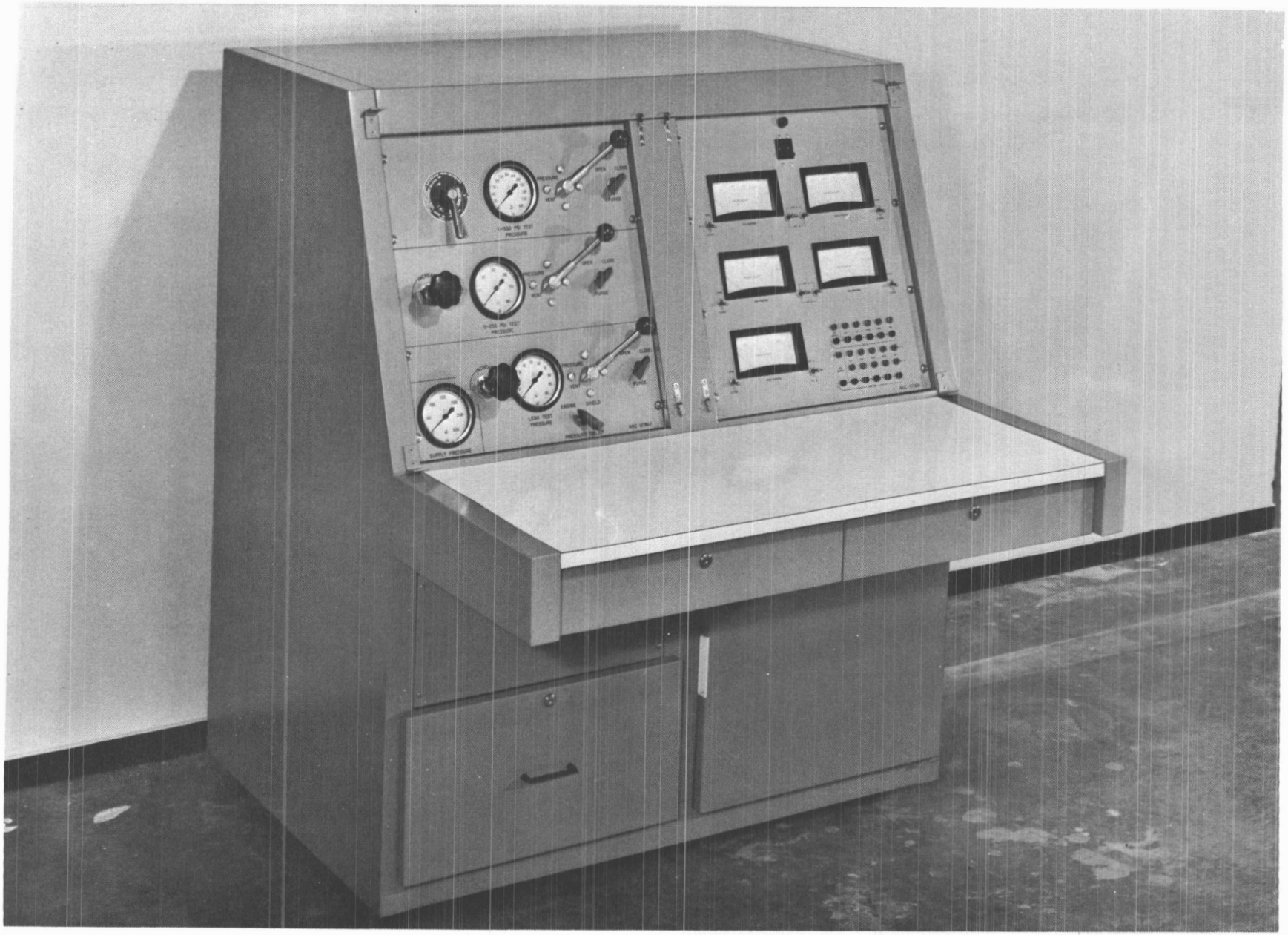


Figure 80 - Item 4400, Functional Valve and Leak Test Set (Console)

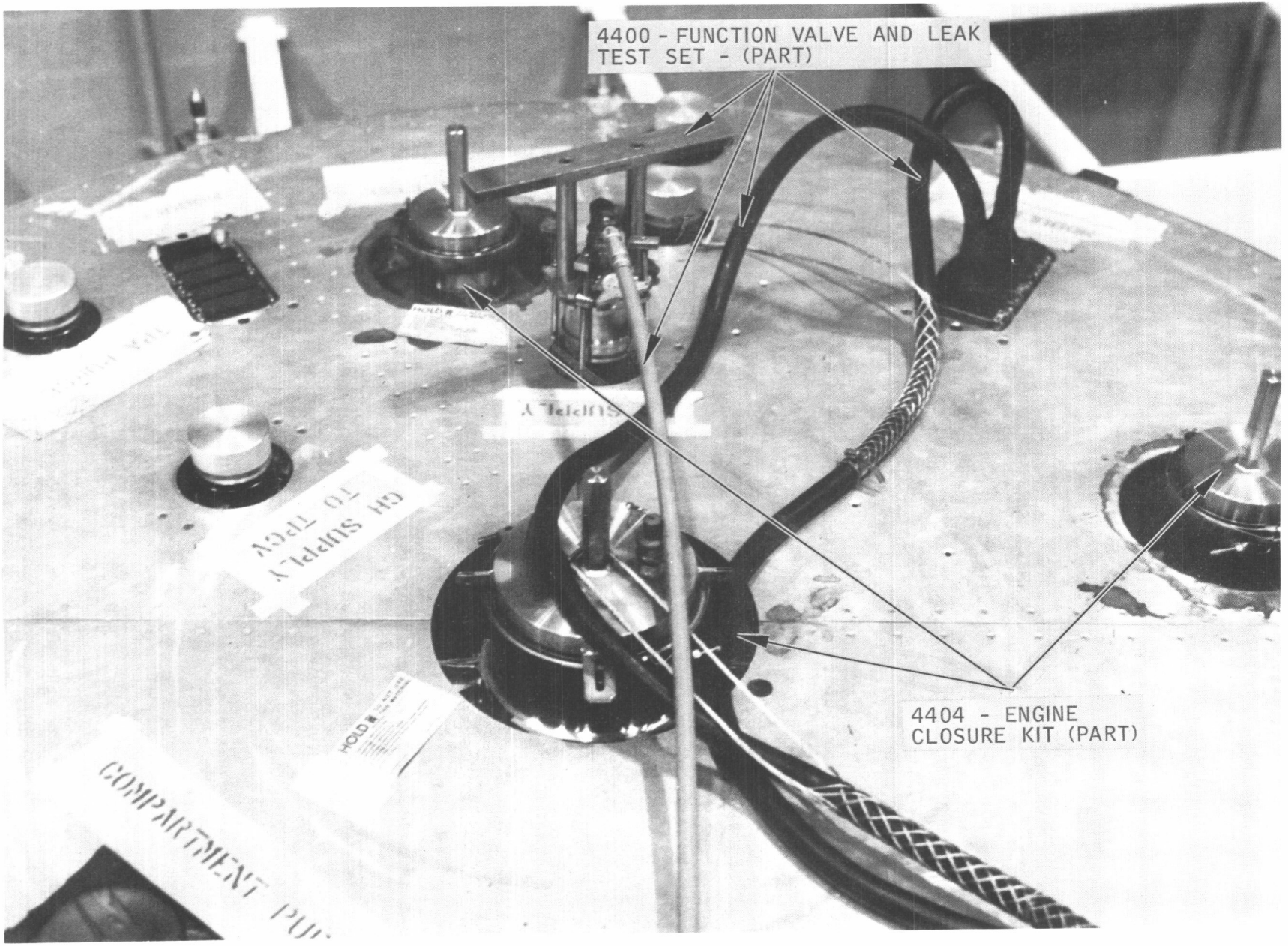


Figure 81 - Items 4400 (Part) and 4404 (Part) UTSM (Sta 42.89) with GSE

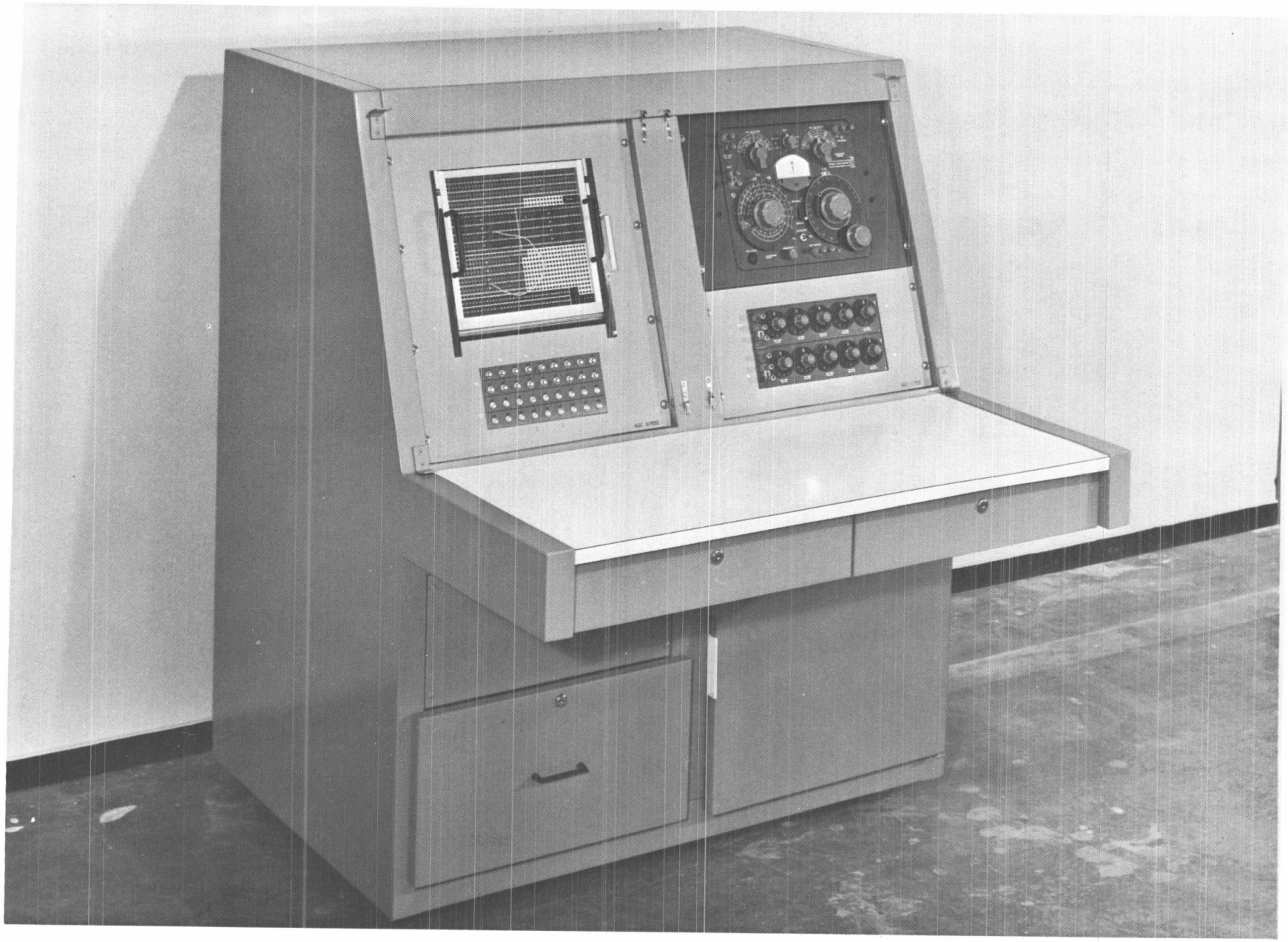


Figure 82 - Item 4401 Electrical Test Set



Figure 83 - Item 4409 Electrical Simulator

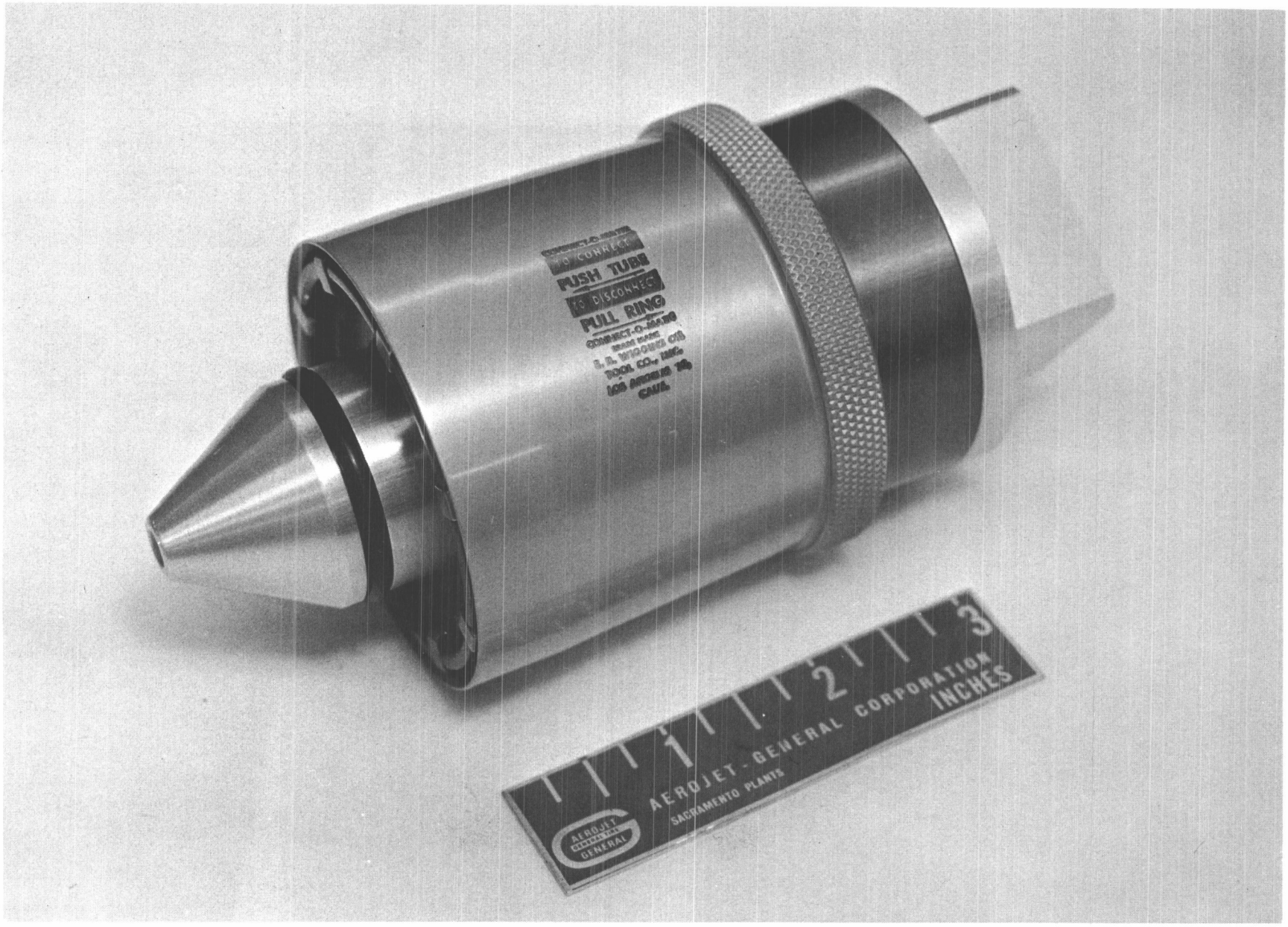


Figure 84 - Item 4412, Closure Plug, Actuator Vent Line (Manual)

P.L. Item	Nomenclature
4043	Adapter Kit, Checkout, Remote
4400	Functional Valve and Leak Test Set
4401	Electrical Test Set, Rocket Engine
4402	Helium Leak Detector Set - Remote
4404	Engine Leak Test Closure Kit
4409	Electrical Simulator

P.L. Item 4412, Pneumatic Vent Line Closure, fulfills a requirement established by the rerouting of the engine pneumatic actuator vent line to vent to the atmosphere in the area of the lower thrust structure. This pneumatic vent must be sealed off remotely in E-MAD for pressure testing and the closure will be remotely removed at ETS-1. The closure design is complete for manual use. The design modification for providing remote capability will be completed and the modified unit will be fabricated and delivered in CY 1968.

Engineering coverage was provided at NTO for the initial operation of the equipment. The WANL equipment was connected to the electrical test set and operated satisfactorily in all modes.

b. Fabrication

In the XE program fabrication was completed and the following items of XE electrical and checkout support equipment were shipped to NRDS.

P.L. Item	Nomenclature	Figure
4043	Adapter Kit, Checkout - Remote For hot-engine checkout used in conjunction with P.L. 4400, 4401 and 4402. Provides E-MAD wall feed-through terminations, a pneumatic (leak test) control box, remote pneumatic coupling and closures, an electrical connector guide block, and the necessary connecting pneumatic hoses and electrical cables with remote adapters.	75, 79
4400	Functional Valve and Leak Test Set A console unit containing electrical meters, switches, and a pneumatic control panel. It also includes an accessory TPCV test set, interconnecting cables, pneumatic hose assemblies, pneumatic coupling assemblies, etc. For leak test of the engine and functional test of engine sensors valves and actuators.	80, 81
4401	Electrical Test Set - Rocket Engine A console unit containing a patch board, signal generator, decade boxes, etc. with connecting cable assemblies for electrical checkout when used with selected WANL equipment for electrical checkout of the engine or subassemblies.	82

P.L. Item	Nomenclature	Figure
4402	Helium Leak Detector Set - Remote A Series-500 Uson unit with a remote sensor and manipulator adapter. The meter unit and power supply are used in the operator area connected through the E-MAD wall to the sensor by a 100-ft cable. It is used to remotely sense leakage at the remotely reconnected XE engine line joints.	-
4404	Kit, Closure, Engine Pressure Testing Pressure closures with clamps and seals for use during cold engine and subassembly leak test to close propellant system lines and ports and control actuator ports.	62, 81
4409	Electrical Simulator A portable unit for electrical checkout of GSE and connecting cables. Contains a patch board for properly connecting equivalent XE engine electrical parameters and circuits, and for readout of system electrical constants.	83
4412 (Manual)	Plug, Closure, Actuator Vent Line A Wiggins coupling with a special plug and o-ring seal to the engine actuator vent line adapter. Manually installed and removed for engine leak test operations.	84

Modification of P.L. Item 4400, Functional Valve and Leak Test Set, was completed and the unit was shipped to NRDS.

Modification of P.L. Item 4402, Helium Leak Detector Set - Remote, to provide a direct reading capability, is planned for completion early in CY 1968.

3. Instrumentation (2.4)

a. Instrumentation Components and Systems (2.4.2)

(1) Application

The performance of instrumentation installations on NRX-A5 was reported in RN-S-0330 and continued with analytical preparations for NRX-A6 and XE tests. A major effort was the development and upgrading of a computerized technique for predicting the effect of impulse lines on pressure-measuring systems. The technique was applied in sizing and analyzing impulse lines for the X-engine, and a detailed presentation of the theory and its practical applications is being prepared in Report No. RN-DR-0124. A follow-up to this study analyzed the effects of impulse-line bending on sensed pressure. This work will be documented in the next contract year.

A computer program was developed to automatically produce measurement system uncertainty data in the form of graphs for publication just prior to a test series. This program enables the latest circuit installation details to be included and provides uncertainty information in a timely manner. Additional studies of measurement uncertainty and error produced an analysis of temperature effects on cables and circuits for X-engine (Report No. RN-TM-0419), and an analysis of the effects of different types of cables on circuit performance. In addition, uncertainty-analysis

support was provided for subtask 1.9, which resulted in a modification of the thermal conductivity test fixture design and test procedure.

During preparations for the automatic reduction at Aerojet-Sacramento of data to be received from ETS-1, a time-code incompatibility was detected. Equipment has been designed and fabricated that resolved the problem.

Requirement specifications for a second-generation charge amplifier were formulated and hardware was procured for use at ETS-1. A calibrator chassis was designed and fabricated for use with the improved charge amplifiers and is being prepared for delivery to ETS-1.

Considerable effort was expended in planning for the Nuclear Ground Test Module (NGTM) and the Engine/Stage Test Stands 2 and 3 (E/STS-2/3). This included inputs to and review of the NGTM specification, detailed review of the Marshall Space Flight Center (MSFC) telemetry system, and technical inputs for the design of the instrumentation portion of the cryogenic and gas (C&G) system. Support in the design of the instrumentation and controls portion of E/STS-2/3 was given to Kaiser engineers. Additional support was given subtask 3.0 in monitoring ETS-1 instrumentation system checkout and performance. A thorough analysis of instrumentation systems for use in testing at ETS-1 has been initiated and is continuing. This effort resulted in the upgrading of both transducer selection and installation.

Assistance was given subtask 1.1 in the preparation of a measurement-requirements document (MRD) for the NERVA engine. This work, together with the planning of the instrumentation portion of the EPIC (Electrical Power, Instrumentation, and Controls) package of the NERVA engine, provided the foundation for electrical-interface discussions with the Astrionics Laboratory of MSFC. Work on the EPIC also provided background for discussions of the practicability and desirability of using advanced microcircuit technology for the EPIC fabrication.

Technical Memorandum RN-TM-0416 was released to evaluate various calorimeter designs that might be used in the determination of gamma-flux levels at any time during engine testing.

Continuous support was provided to sub-subtask 1.1.2 to review and issue program procedures, specifications, and other test documentations.

The following assignments were completed to assist in the resolution of several immediate problems affecting the current NRX and XE planning schedules. The design and testing of a sheathed-to-flexible cable splice that was required on XE-1 above station 137 was completed. The design was based on a concept previously reported in CY 66 under high-temperature thermocouple development. Splice assembly drawings AGC 1118618 and 1118634, process specification AGC 90162, and assembly aid drawing 1118754 were released. Flame spraying of a thermal conducting aluminum powder was found to be the most effective way to cool engine mounted cables in areas of high flux levels. A complete study and a series of tests were performed to qualify this concept. Two documents were published: RN-TM-0418, The Development of the Flame Sprayed Aluminum Concept for Conductive Cooling of XE Engine-Mounted Electrical Cables, and RN-TM-0301, XE Flame-Spray Capability Tests for Titanium, Hastelloy, 347 Stainless Steel, and 6061 T-6 Aluminum. Other associated documents released include: AGC 90159, material specification for the spherodized aluminum powder; AGC 90160, material specification for the nickel-aluminum wire used for the bond coat; and AGC 90161, process specification for the metal spraying process. Six dummy sheathed cables were successfully flame sprayed to the XECF engine pressure vessel at NTO. An additional test specification was written for the NRX-A6 flame-spray test.

(2) Installation

(a) NRX-A6

NRX-A6 instrumentation procurement and delivery was completed in CY 67. The basic kit consisted of the following transducers plus spares and supporting hardware.

11	Piezoelectric accelerometers
6	Strain gage accelerometers
7	Absolute pressure transducers
1	Differential pressure transducer
6	Strain gages
7	RTT's
41	Surface thermocouples
4	Tungsten-rhenium thermocouples

In addition to the basic kit, nine flush-mounted pressure transducers were delivered for transducer evaluation (discussed in Section 2.4.6).

An improved charge amplifier was selected late in CY 66 to support the piezoelectric accelerometer measurements. These amplifiers, which will also be used on the XE engines, were procured and delivered to NTO.

A flame-spray test will be incorporated on NRX-A6. All cables and tubes crossing the pressure vessel will be heat-sinked to the vessel by flame spraying a layer of aluminum over each cable or tube on the pressure vessel. The purpose of the heat sinking is to prevent possible melting and to keep conductor and insulation material temperatures at an acceptable level. This test, employing eight copper-constantan thermocouples, will measure: (a) conductor temperature in both a flame-sprayed

and an unsprayed cable; (b) sheath temperature of both a flame-sprayed and an unsprayed sheath; and (c) insulation resistance in a flame-sprayed and an unsprayed cable. In addition the test will determine the effect of flame spraying thermocouple tips, which should help improve thermocouple accuracy and response.

Five thrust-chamber thermocouples calibrated in August 1966 for NRX-A6 were recalibrated and found to be within ±1% of the August 1966 calibration. The thermocouples were recalibrated because a test of one of the reference junction transitions from sheathed cable-to-copper leads showed evidence of moisture penetration into the hydroscopic MgO insulation used in the sheathed cable. Since moisture may have an adverse effect on leakage resistance and form high steam pressure, it was decided to cut off all the cold junctions, to bake out the cables to remove any possible moisture, to remake the cold junctions with an improved epoxy bonding technique, to recalibrate the probes, and to compute new calibration curves. The ±1% agreement between the earlier calibration and the present calibration is similar to the short term repeatability of this transducer.

The moisture-penetration problem occurred because of poor bonding between the polycarbonate plastic end cap and the steel sheath of the cable. This bond had been made by applying a volatile solvent (methyl chloride) to the plastic to form a liquid plastic film that would stick to the steel. The bond was not as leak-tight over a long period as it had appeared to be in short-duration tests. The epoxy cement bond now used is resilient, adherent, and, according to the manufacturer's literature, completely impervious to moisture. Tests made at Aerojet to verify these claims showed no loss of insulation resistance on a transition junction made with this cement and submerged in water for 2 months.

(b) XECF

Procurement was completed for the basic instrumentation kit, modification kits, and the harness. All instruments and hardware were delivered to NTO. The basic kit consisted of the following transducers plus spares and supporting hardware.

- 3 Microphones
- 13 Piezoelectric accelerometers
- 6 Strain gage accelerometers
- 7 Strain gages
- 8 Differential pressure transducers
- 39 Psig, psis, psia pressure transducers
- 14 Surface copper-constantan thermocouples
- 10 Copper-constantan thermocouple probes
- 8 Chromel-alumel thermocouple probes
- 16 Resistance temperature transducers
- 1 PACE temperature reference junction

The modification kits included the following plus spares.

- 2 Differential pressure transducers
- 6 Surface copper-constantan thermocouples
- 2 Psis pressure transducers
- 1 Copper-constantan thermocouple probe
- 1 Differential pressure switch

In addition to the basic kit and modification kits, 11 WANL pressure transducers were mounted in Aerojet brackets.

Thirty-three TSA harnesses, thirty UTSM through harnesses, ten harnesses that feed into the UTSM, and five electrical

module assemblies for the LTSM were supplied, as well as all necessary connectors, splices and lead wire. These harnesses accommodate 134 channels in addition to the normal Aerojet diagnostic and control channels of the indicated instruments. These 134 channels include such functions as TPA bearing thermocouples, displacements, etc.

Instruments that NRO had not furnished previously included microphones, television cameras, a PACE temperature reference junction, and a differential pressure switch.

Brackets that required redesign because of a refinement of the UTSM environment definition were completed. A thermo-analysis of these brackets was also completed.

Engineering liaison was provided during the assembly of instrumentation and cable harnesses into the UTSM and TSA at Sacramento and during the assembly of instrumentation on the LTSM at NTO.

All XECF instrumentation and cable harness installation drawings were completed. These included four installation drawings and one modification kit drawing. Other modification kits were incorporated by letter changes to the applicable installation drawing.

An improved charge amplifier was selected late in CY 66. Forty-two amplifiers were purchased and delivered to NTO. These amplifiers will support Aerojet and WANL accelerometers and Aerojet microphones on XECF, XE-1, and XE-2.

(c) XE-1

Procurement was completed for the basic instrumentation kit, several mod kits, the harness, and an evaluation flush-mounted pressure transducer. All instruments and hardware were delivered to NTO.

The basic kit consisted of the following instruments plus spares.

1	Condenser microphone
2	Piezoelectric microphones
23	Piezoelectric accelerometers
16	Strain gages
3	Gamma detectors
9	Differential pressure transducers
41	Sealed gage pressure transducers
1	PACE temperature reference junction
11	Resistance temperature tranducers
42	Copper-constantan surface thermocouples
10	Copper-constantan thermocouple probes
8	Chromel-alumel thermocouple probes
6	Tungsten-rhenium thermocouple probes

The modification kits included:

8	Psis pressure transducers
2	Piezoelectric microphones
6	Copper-constantan surface thermocouples
2	Heat-rate sensors (calorimeters)
1	Pressure switch
1	Resistance temperature transducer
1	Copper-constantan thermocouple probe

In addition to the basic kit and the modification kits, 25 WANL pressure transducers were mounted in an Aerojet bracket and cable harnesses and connectors were furnished for all channels. These included 30 UTSM through harnesses, 10 harnesses that feed into the UTSM, and five electrical module assemblies for the LTSM. In addition to the

normal Aerojet diagnostic and control channels, cables were supplied for 263 other channels, such as switches, potentiometers, etc.

Instruments that NRO had not furnished before the XE-1 program included heat-rate sensors (calorimeters) and gamma rate detectors. These are in addition to those discussed under XECF, which will have their first radiation exposure on XE-1.

All instrumentation installation drawings were completed. In addition to those drawings common to both XECF and XE-1 (UTSM and TSA drawings), an LTSM instrumentation installation drawing and three modification kit drawings were completed. Other modification kits were incorporated by letter changes to the applicable installation drawing.

Engineering liaison was provided during the assembly of the UTSM instrumentation and harnesses at Sacramento.

An orientation class was conducted for the technicians and PAD personnel at NTO to familiarize them with the XE-1 instrumentation installation sequences and methods and with the special problems involved in installation and handling.

(d) XECF and XE-1 General

In addition to the basic kit and modification kit procurement, all the components were procured that were necessary to retrofit the XECF UTSM instrumentation to the XE-1 configuration. These components are being stored until needed. The retrofitted UTSM will be used on XE-1 in a later portion of the XE-1 test.

One interconnection drawing and 57 electrical schematics were made to augment the wiring termination schedule. These drawings will help insure the proper termination and grounding of all channels.

During the electrical checkout of the instrumentation installed in the XE-1 UTSM, two differential pressure transducers were found to have damaged pressure diaphragms. Damage consisted of a series of sharp impressions and dents that were probably caused by a sharp tool or by an object being forced against the diaphragm.

Because of the seriousness of this damage, it was decided to inspect all NRO-supplied differential pressure transducers and, in addition, the absolute or gage pressure transducers of similar construction that could have been subjected to similar damage.

These inspections were made at Aerojet-Sacramento on all XE-1, XE modification kit, and spare tranducers. Inspections at NRDS/NTO were completed on all transducers supplied for XECF and NRX-A6 or as spares.

A total of 16 differential and two absolute pressure transducers were found to be damaged. Those damaged units installed on XE-1 and XECF were removed and replaced with acceptable transducers.

The cause of damage was investigated, and a weakness was discovered in the transducer cleaning procedure that has been corrected by the publication of manufacturing process instructions. The results of the investigations were published in RN-DR-0125, Investigation of Damaged NRO Pressure Transducers.

(e) XE-2

XE-2 instrument selections have been completed and procurement has been started. Procurement has been initiated for the XE-2 electrical harnesses.

Bracket design has been started to accommodate those instruments on XE-2 that are different or that have been relocated.

(f) NES Duct Instrumentation

Engineering support and liaison were furnished during the NES duct instrumentation installation and checkout period at NTO. The permanent and temporary instrumentation kits were installed, routed, terminated, and functionally checked.

During the initial functional checks performed on the duct, an apparent vibration problem was detected in the operation of most of the Statham PM280 differential pressure transducers. These transducers are used to monitor water flow parameters on the duct. To investigate this problem, vibration tests were performed on similar PM280 transducers in the NRO Laboratory. The tests revealed vibration sensitivities of greater than 5.55% of full scale/g in the frequency range of 20 to 2000 Hz at acceleration levels of 1, 3, and 5g. Vibration isolator assemblies were designed and fabricated. These isolators reduced the sensitivity errors to 0.44% of full scale/g. As a result of this test, all PM280 tranducers on the duct were remounted using these vibration isolators and, in addition, orificed unions and flexible impulse lines.

As a result of the instrumentation inventory, a considerable number of pressure tranducers were determined to be unusable as engine hardware, but were otherwise acceptable. These surplus pressure transducers and cable assemblies were shipped to NTO for use on the duct and various facility installations.

b. Instrumentation Development (2.4.6)

Instrumentation development during CY 1967 was performed in accordance with the program plans approved by SNPO-C.

(1) Thrust-Chamber Temperature Probes

(a) Major Accomplishments During CY 67

1 Two prototype models of a probe for operation at 5000°R were built and tested.

2 The time constant of the standard probe was determined at partial engine power conditions in an arc plasma facility that can simulate various NRX firing conditions.

3 The extent of fission-fragment contamination of the standard probe in the NRX-A5 was investigated.

4 Detailed drawings were prepared for the Aerojet-built developmental thrust-chamber thermocouple and three of these probes were prepared for shipment to LASL for use on the forthcoming Phoebus 2 test.

5 The Aerojet high-temperature calibration capabilities were improved by fully qualifying a tungsten resistance furnace and an automatic optical pyrometer for calibration use.

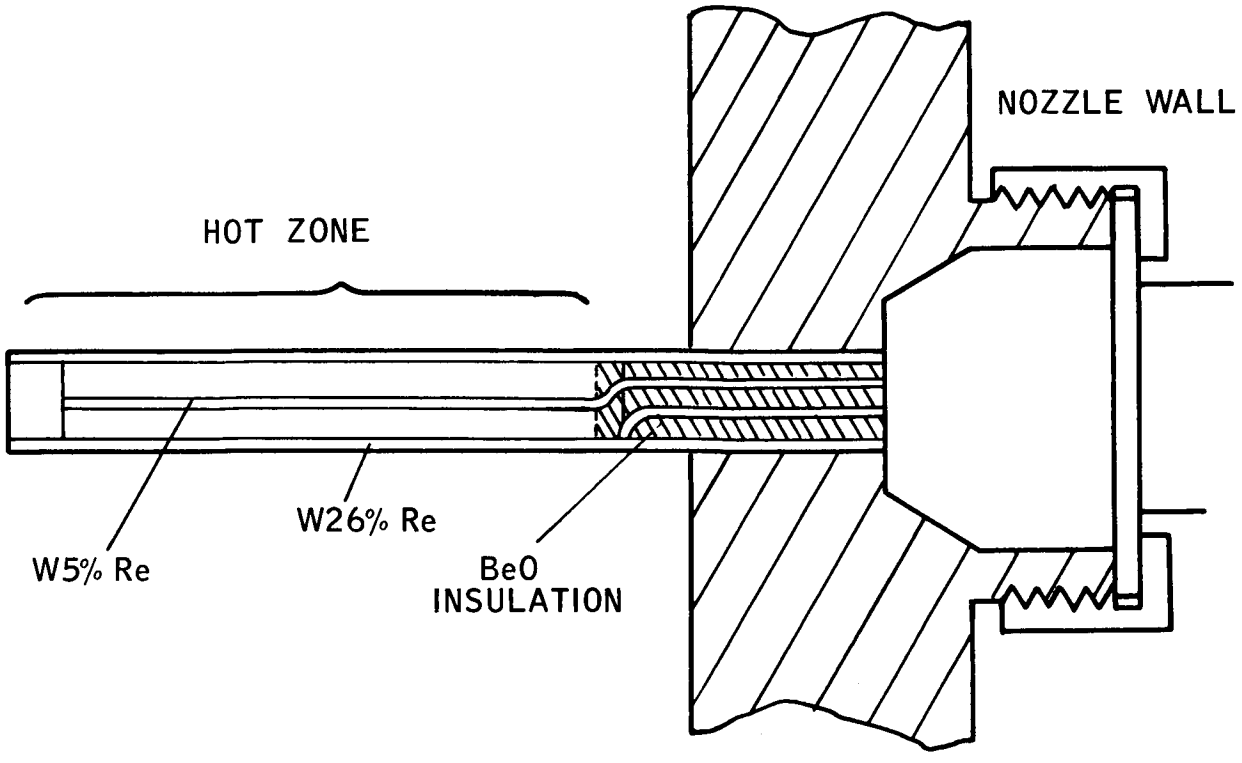
(b) Discussion

1 Prototype of 5000°R Probe

Figure 85 is a schematic diagram of the two 5000°R prototypes that were built and tested. For comparison, Figure 85 shows the standard 4000°R probe that has been used to date on the NRX tests. The two significant changes in the 5000°R probes are that no solid insulation is used in the hottest regions and that the circuitry changes from a two-wire sheathed thermocouple in the nozzle pass-through region to a single-wire coaxial thermocouple just inside the nozzle wall. This transition from one type to another enables the composite thermocouple to have many of the advantages of each type.

The single-wire coaxial portion uses the sheath as one leg of the thermocouple so that the remaining wire can have the maximum possible space for insulation. In the hottest region the insulation is helium plus hydrogen, which diffuses through the hot sheath wall. Both of these gases are chemically compatible with the materials being used and have very low electrical conductivity at 5000°R. Eliminating solid beryllia insulation from the hottest regions removes the source of beryllium metal that alloyed with the tungsten-rhenium sheath and caused melting in the previous attempt to operate at 5000°R. Removal of this solid insulation also improves the electrical insulation, since the electrical conductivity of beryllia at 5000°R is several orders of magnitude higher than that of hydrogen and helium.

Use of a two-wire sheathed portion in the nozzle pass-through eliminates the effect of secondary junctions, which is caused by the metal of the nozzle pass-through contacting the probe sheath in this region of large temperature gradient of the pass-through. In a two-wire sheathed thermocouple, voltages generated in the sheath are not in the thermocouple ciruit.



STANDARD TWO-CONDUCTOR SHEATHED PROBE

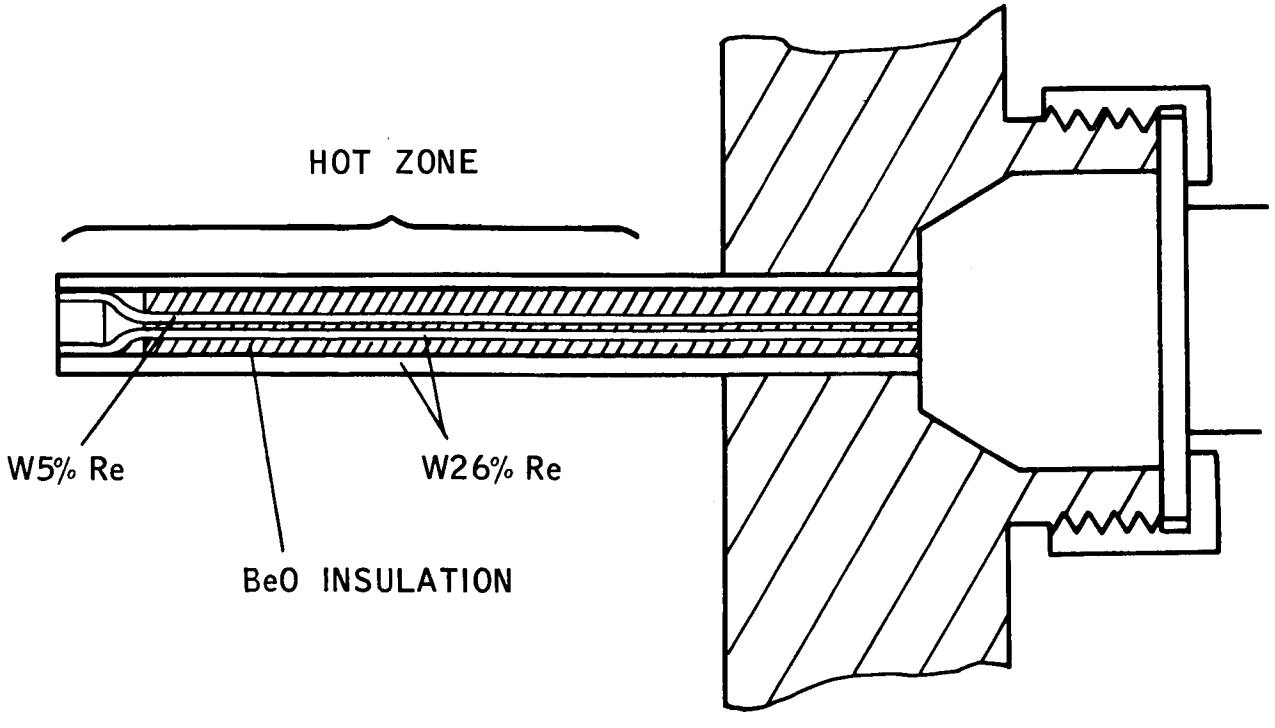


Figure 85 - Schematic Comparison of Two 5000°R Prototype Probes

gas to transport heat to the probe surface. This transport lag is a function of the gas conditions and is largely independent of the probe assuming no changes in external dimensions. On this basis, the time constant of other similar probes at a particular gas heat-transfer coefficient is, to a first approximation, the lead-bath-determined time constant for the probe plus the time indicated on the scale at the right on Figure 86.

Figure 86 indicates that, for a probe having the maximum allowed 0.5 sec at full power (lead-bath time), the time constant at one-fourth power will be the maximum allowed 1-sec time response. These data indicate that work needs to be done to speed up the time response of the thrust-chamber thermocouples, especially at low-power conditions, if they are to be used as the primary control sensor from one-fourth to full power.

Further details are reported in RN-TM-0426, Time Response Tests of the Thrust-Chamber Thermocouple in a Simulated Rocket Firing.

3 Fission fragment studies

A white powder was found on the thrust-chamber thermocouples and on the pass-through bosses during disassembly of NRX-A5. A photograph of one of these thermocouples is shown in Figure 87. During disassembly some of this powder was collected in a vial for analysis, but the vial was lost. A second attempt to identify the powder involved moving the radioactive probes to the hot cell in E-MAD where they were wiped to obtain any remaining powder for a photospectrographic analysis. However, no powder was collected.

The probes were then placed in a beta spectrometer to detect and identify foreign particles. No particles were found in the areas where the white powder had been. Apparently the white

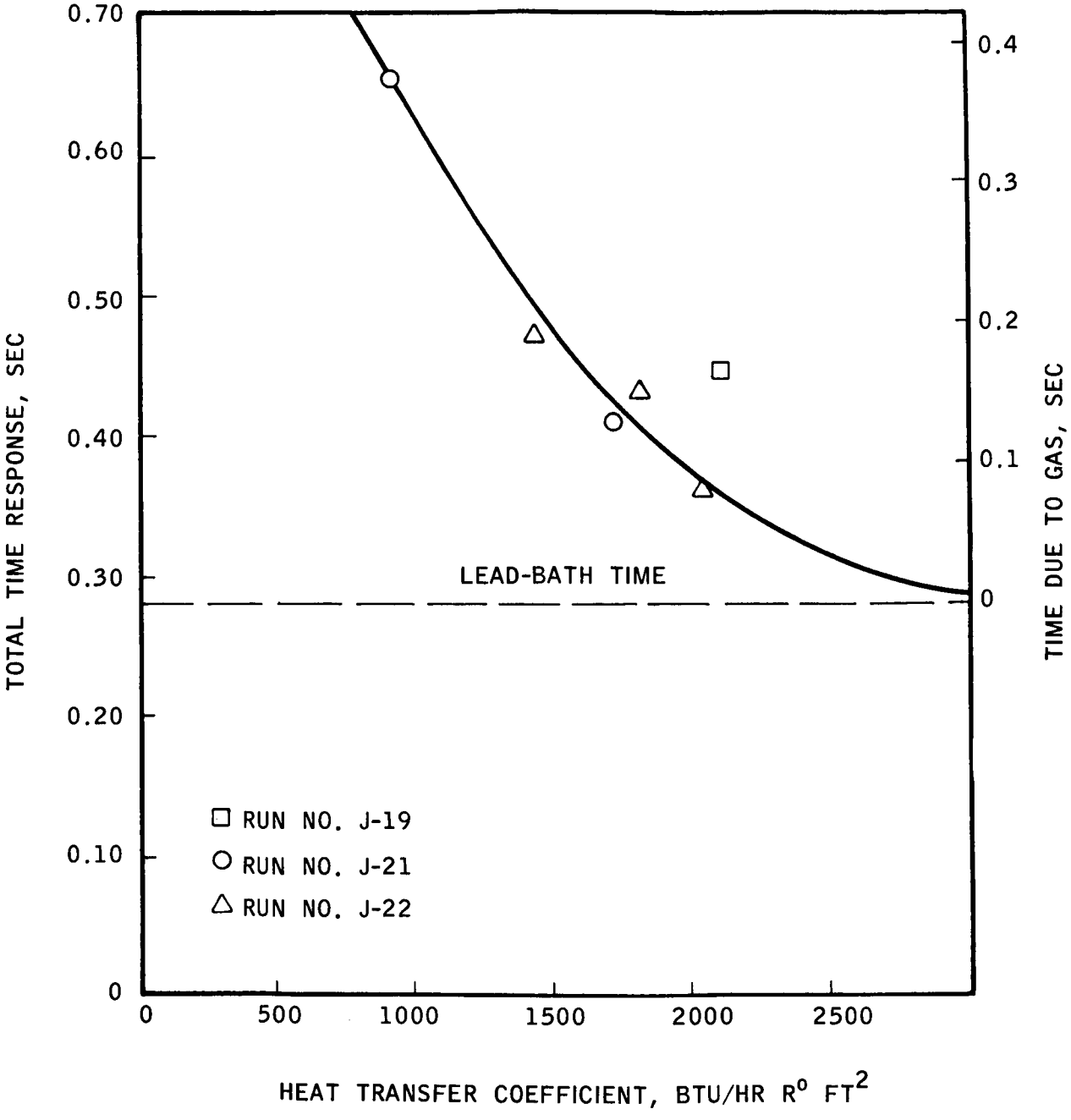


Figure 86 - Comparative Performance of Tungsten 5% Rhenium and Tungsten 26% Rhenium Thermocouples

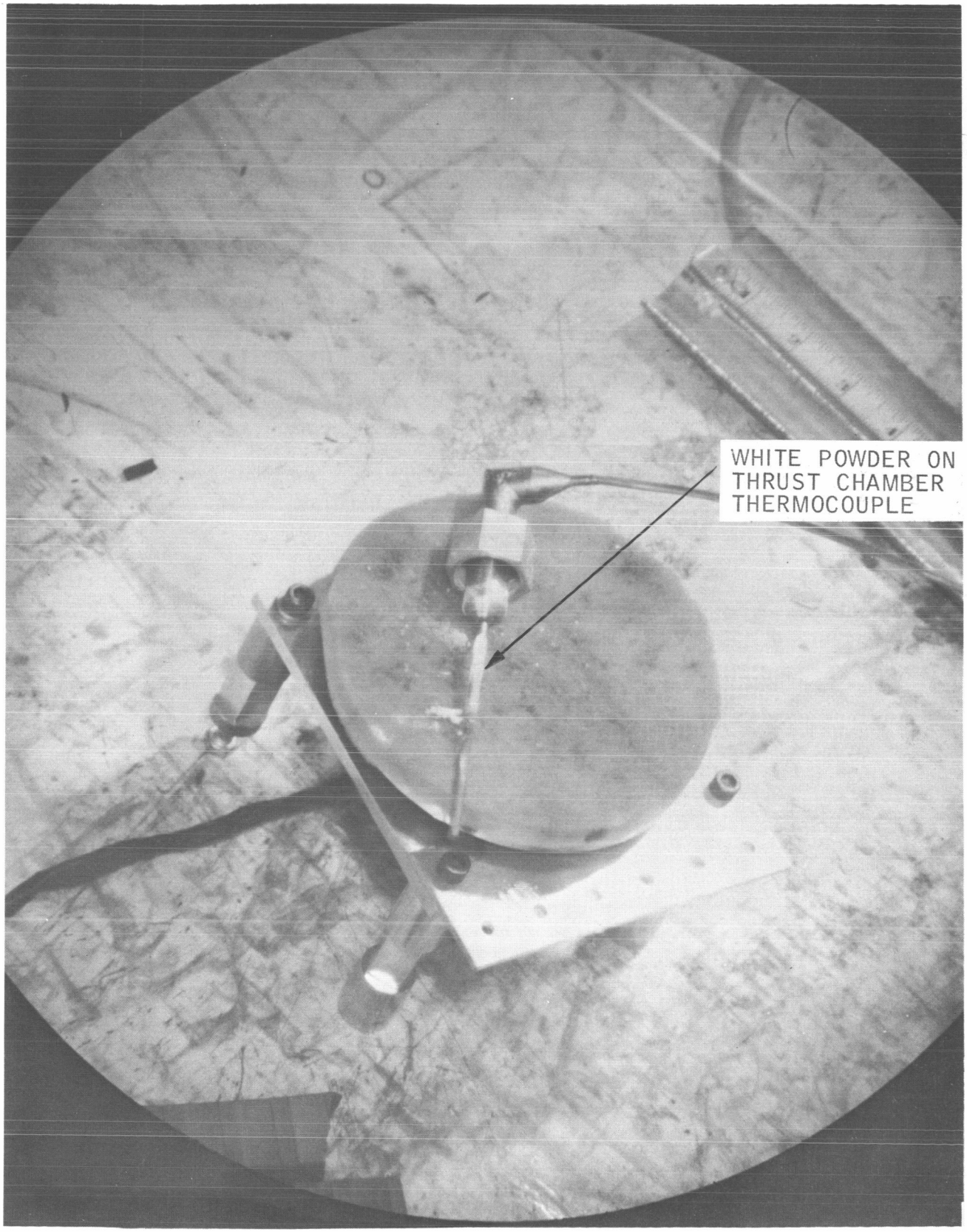


Figure 87 - Powder Deposit on Thrust Chamber Thermocouple

Tests of the two prototypes have not been entirely satisfactory. The first prototype was made of a vapor-deposited tungsten-rhenium sheath. Although this sheath had the same chemical composition as the wire, it did not have the same thermoelectric properties and it developed an error signal at the side transition. The second prototype was made with a sintered and wrought sheath that was electrically satisfactory but physically weak. Modifications are being made to increase the strength of the unit.

2 Time Response in Simulated Rocket Tests

In the summer of 1966, the thrust-chamber thermocouples were selected to be the primary engine-control sensor for NRX-A6 from approximately 2000°R to full power. Knowledge of the time response of these probes is of prime importance in determining the dynamic stability of the engine power-control loop. Probe-time response measurements had been made at full-power conditions, but none had been made at low and intermediate startup conditions where the probes are known to be somewhat slower because of the lower gas heat-transfer coefficients at reduced engine power. To measure how much slower the probes would be, the gas heat-transfer coefficients for various flow conditions were calculated and then duplicated in an Aerojet arc-plasma facility called the Hyperthermal Environment Simulator (HES). Step changes in gas temperature were made by a pneumatically operated shield that could uncover the probe in approximately 2 millisec.

The results of these tests are shown in Figure 86. This figure shows that the time constant decreases with increasing gas heat-transfer coefficient, probably approaching the 0.28 sec-limit time constant determined for full power for that probe by the lead bath test. This 0.28 sec limit is an internal lag for a particular probe and represents the time required for heat to flow by conduction from the surface of this probe through the sheath to the sensory junction inside. Durations longer than 0.28 sec obtained in the HES for this probe represent the time required for

powder is the remains of silicone grease that is to be applied as a light sealant film only on the copper gasket that forms the gas seal in the pass-through boss. It appears that some of this grease was applied to the probe stem to facilitate installation.

Although the beta spectrometer did not enable identification of the white powder, it showed that high radiation levels on that part of the probe exposed to the exhaust hydrogen. This radiation was caused by neutron activation of the tantalum carbide (TaC) protective layer and by fission-fragment plate-out.

A systematic beta test was made after the preliminary test to quantitatively determine the amount of the fission fragments and the depth of diffusion into the thermocouple probe sheath. Diffusion into the sheath is a potentially serious problem in the 5000°R coaxial development probe because the sheath is one leg of the thermocouple in the hot region. Diffusion of foreign materials into the sheath could alter its thermoelectric properties and thereby shift the output. The beta tests indicated that the fission fragments were virtually all within 1/2-mil of the surface, which would be expected if the fragments were only embedded in the semiporous TaC protective layer. The results of this beta activity test are shown in Figure 88. The curves indicate that fission-fragment diffusion into the probe sheath should not be a problem.

(2) Vibration Transducers

A detailed evaluation of data obtained from five experimental accelerometers during the NRX-A5 test series was completed. These transducers were Electra Scientific Corp P/N AXB-6070: a temperature-compensated piezoelectric accelerometer that has an integral, steel sheathed cable, is internally electrically isolated, is fabricated entirely of metals and ceramics, and is designed to dispose of radiation-generated heat by direct transfer from the transducer base to the mount. Post-irradiation tests indicated that no permanent damage resulted from irradiation during the entire

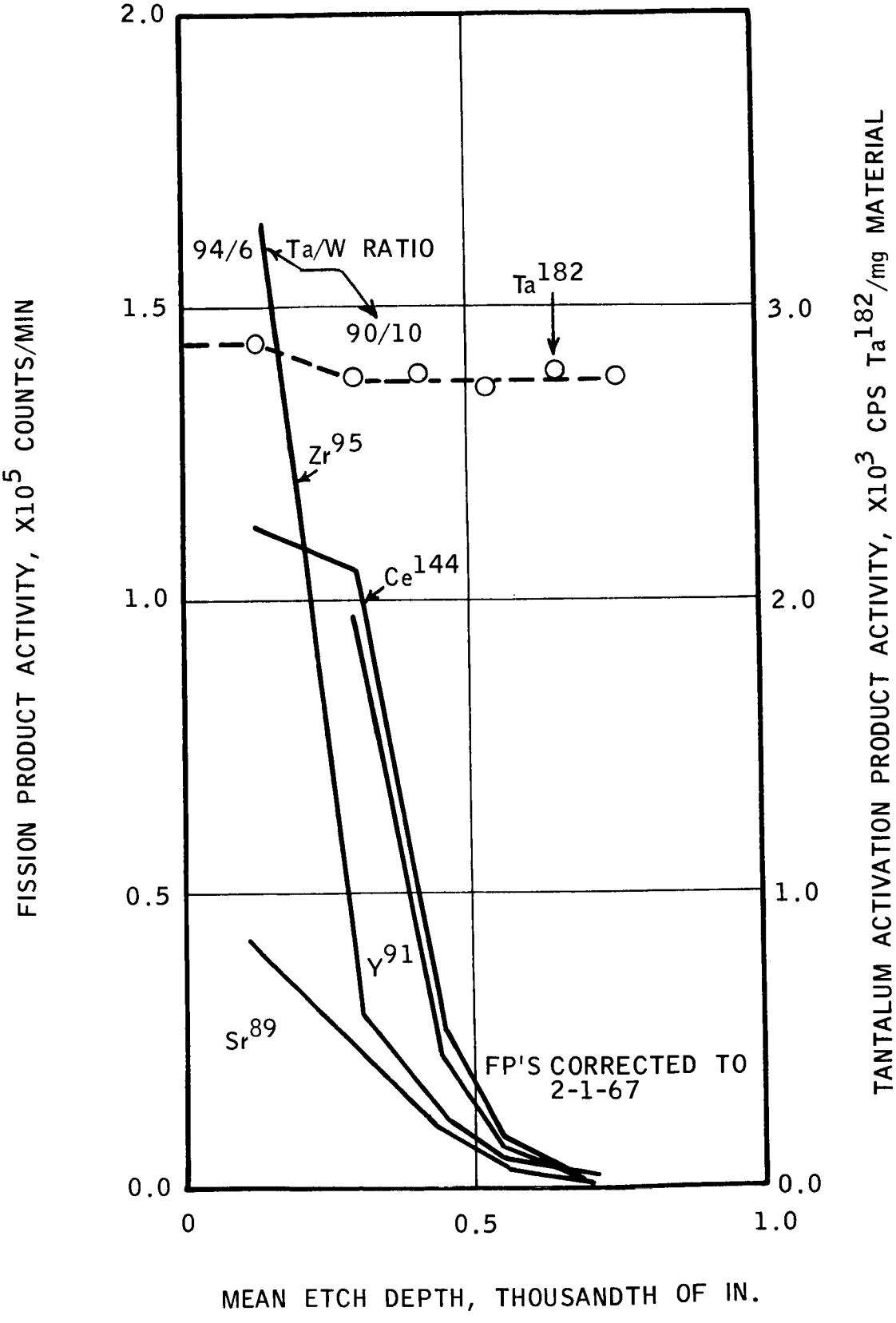


Figure 88 - Fission Product Count

test series. Data provided by these transducers during irradiation were comparable to those taken from strain-gage accelerometers measuring similar parameters in the immediate vicinity and are valid, qualitative representations of the acceleration levels that occurred during the test. It was concluded that this design is a promising candidate for development for NERVA and that it may be used to gather qualitative data from subsequent technology engines in environments similar to or less severe than those encountered during the NRX-A5 test. The detailed results of this test are documented in NRO Technical Memorandum RN-TM-0550, Posttest Results of NRX-A5 Evaluation Accelerometers, Electra Scientific Corp. Model No. AXB-6070.

Evaluation tests of the first transducers built to AGC 1117421 disclosed that excessive 60-Hz common mode noise was coupled into the output signal. After analyses and experiments were conducted, the integral cable design was changed and the arrangement of elements and compensators was altered to reduce the common mode signal to an insignificant level.

A preliminary radiation-effects test program using controlled vibration stimulus in a controlled environment was defined. The purposes of this program are to arrive at a quantitative determination of transducer accuracy during irradiation, to determine the presence and extent of radiation environment rate effect, and to extend the upper levels of exposure to neutron and gamma radiations.

In accordance with the directed readjustment of sub-subtask 2.4.6 funding for the remainder of CY 67, all development work was discontinued in March 1967.

(3) Control Pressure Transducer

(a) Major Accomplishments During CY 67

1 The NRX-A5 Statham vapor-deposited film strain-gage engine-mounted pressure transducer test results were written and published in RN-S-0369, NRX-A5 Qualification Report of Engine-Mounted Pressure Transducers.

2 As a result of the NRX-A5 test, the vapor-deposited film strain-gage control pressure transducer candidates were redesigned, calibrated over the temperature range of 360° to 960°R, and were provided for the NRX-A6, ASTR 23/R512A, and XE-1 instrumentation kits.

3 Two Statham vapor-deposited film strain-gage pressure transducers were internally instrumented in the NRO Research Laboratory for the ASTR 23/R512A test.

4 The ASTR 23/R512A dose-rate test was conducted successfully at Fort Worth, Texas.

5 High-temperature tests were made of the Statham thin-film strain-gage pressure transducers to extend the maximum temperature limit of operation.

(b) Discussion

1 NRX-A5 Qualification Test Report

The transducers, located in their intended nozzle location, were subjected to temperatures exceeding 1060°R at their diaphragms during full-power conditions, which resulted in permanent zero shifts. The diaphragm temperature is of major concern and should not

exceed 1060°R to maintain the transducer within operating specifications. Cable-connector insulation-resistance values were low because of high temperatures created by the NRX-A5 gamma heating rate of approximately 1.26 w/gm(C) hr and the absence of a heat sink for the cable in the vicinity of the test transducers. Unsymmetrical shunting by extremely low insulation-resistance values caused unbalanced bridge conditions to appear as large zero shifts and sensitivity changes, which resulted in off-scale drift for all four test transducers.

Because the dummy bosses used with the test transducers were twice the length of the live boss used for P-150, they had considerably more mass, which resulted in higher boss and transducer temperatures. A thermal analysis indicated that the temperatures for the test transducers were approximately 500°R higher than corresponding P-150 temperatures.

Post NRX-A5 tests indicated that the test transducers did not change sensitivity and that the electrical insulation resistances withstood the tests and returned to pretest values. The transducers showed no adverse physical or electrical effects and functioned as pressure transducers with only a permanent zero shift.

2 Redesigned Transducers

On the basis of the NRX-A5 test results, the transducers were redesigned to have integral stainless-steel-sheathed, magnesium-oxide (MgO)-insulated cables, and the dummy bosses for NRX-A6 were shortened to half their NRX-A5 length. These design changes eliminated the transducer connector, reduced the length and mass of the transducer, and will reduce the transducer maximum temperatures significantly when the transducers operate in comparable NRX-A5 gamma heating fields. On the basis of the redesign, two thermal analyses for the NRX-A6 transducers show that they should operate reliably at 1.26 w/gm(C)-hr and 1.73 w/gm(C)-hr (conservative case)

for the NRX-A6 and XE-1 tests, respectively. The redesigned transducers will be tested on NRX-A6 to verify the adequacy of the design changes. The redesigned transducers were calibrated at temperatures ranging from 320° to 960°R and were supplied for the NRX-A6, ASTR 23/R512A, and XE-1 kits.

3 Internally Instrumented Pressure Transducers

Two PA812 Statham pressure transducer diaphragms were instrumented with Chromel-Alumel thermocouples for the ASTR 23/R512A test. One transducer was instrumented at the center of the thin-film diaphragm for maximum diaphragm temperature, and the other was instrumented with two thermocouples to obtain a gradient measurement across the diaphragm. These measurements will be used to correlate thermal analysis predictions vs gamma heating rates and to see if the gradients produce any noticeable zero offsets.

4 ASTR 23/R512A

The ASTR 23/R512A test was conducted at Fort Worth, Texas, on 21 August 1967. Four Statham transducers, PN 50390-1 (redesigns of the NRX-A5 test transducers), and two instrumented Statham transducers were the test items. The transducers successfully passed the test at a maximum limit of 2.7 watts/gm(C)-hr and received an integrated fast flux of approximately 6×10^{17} nvt. All test objectives were met with the exception of the 400 and 500°F temperature runs that were curtailed because of the ASTR reactor imposed limitation of 40 Mw-hr.

5 High-Temperature Tests

High-temperature tests were conducted on Statham PN 50390-1, SN 58, at 500°, 600°, 700°, and 800°F. Room-temperature input/output bridge resistances were 675 ohms. After the 500° and 600°F runs the transducer was allowed to cool to room temperature; the input/output

resistance was still 675 ohms, which is consistent with the past history on this type of transducer. At 700°F the zero unbalance changed polarity from -1.04 mv at 600°F to 2.84 mv. At 800°F the zero unbalance was 64.17 Mv and tended to drift. The transducer was allowed to cool to room temperature and the input/output resistance was 758 ohms. At room temperature the transducer zero balance was 71.10 Mv, and the sensitivity was essentially unchanged. From this test it seems possible that the transducer limit may be extended from 600° to 700°F.

(4) Sheathed Cable-to-Transducer Attachment

Studies to define the problems associated with the use of metal-sheathed cable have been started. The use of triaxial and single conductor cable as opposed to multiconductor cable was investigated. Because of their concentric geometry, triaxial and single-conductor cables are advantageous when integrated in transducers, splices, and connectors. Hermetic sealing of cable assemblies is simplified and more easily controlled under adverse conditions. Other advantages include positive conductor identification, elimination of interface keying, smaller interfaces in areas of high-flux levels, and standardization of termination methods that enables reductions in time and cost.

The design of a coaxial to triaxial splice, to be used in conjunction with the XE engine-mounted accelerometers, was completed.

Emphasis was placed on the major problem of terminating sheathed cable. A sealing method was devised that will withstand extreme environmental conditions. This method permits assemblies to be integrated into transducers, connectors, splices, and control circuits without the need of additional components. Sheathed cable seal assembly drawing, AGC 1134533, was released and a purchase order was initiated for the procurement of 100 seal assemblies for evaluation and testing.

Other efforts included investigation of displacement transducers containing integral sheathed cable for use in the NERVA PSOV. Preliminary drawings and component specifications have been completed.

Evaluation tests were made of 54 sample metal-sheathed, ceramic-oxide-insulated electrical cables to determine if these units conform to Aerojet standards and specifications. Based on the results of these tests, AGC-STD-AS9702 and AGC Specification 90052 were revised to better define the standards for fabrication and quality-conformance testing of metal-sheathed electrical cable.

The test data are being analyzed and will be reported in RN-S-0392 Qualification/Evaluation Test Results of Metal-Sheathed, Ceramic-Insulated, Radiation-Resistant Electrical Cables.

(5) Cryogenic Temperature Transducers

The test data from the GTR-18 irradiation test, conducted in CY 66 to determine the effect of fast and thermal neutrons and protons on the operating characteristics of the Rosemount Model 134EB resistance transducer, were analyzed. The results have been reported in RN-S-0370, Fast- and Thermal-Neutron and Proton Effects on Platinum Resistance Transducers at Liquid Hydrogen Temperature.

The results indicated that the effects of thermal neutrons and protons are negligible at liquid hydrogen temperatures and that the errors noted are directly attributable to fast-neutron effects. The increase in error is proportional to the fast-neutron integrated fluence and is shown in Figure 89.

Completion of the GTR-18 irradiation test completes the development program for a high-accuracy platinum resistance transducer for liquid hydrogen use in a nuclear radiation environment. The limitation and

accuracies to be expected can now be defined for application to the NERVA engine for liquid hydrogen service.

A qualification test report was initiated to document current technology relative to the platinum resistance temperature transducer by summarizing the previous 5-year development effort.

Nonnuclear qualification/evaluation tests were performed on the redesigned Rosemount Model 134AJ resistance temperature transducer. This transducer is similar to the Model 134EB in all respects except that an integral sheathed cable is used instead of a connector. The redesigned model successfully passed the qualification/evaluation tests and the results are reported in RN-S-0439, Nonnuclear Qualification/Evaluation Test Results on Rosemount Model 134AJ Resistance Temperature Transducer.

(6) Gamma Heating-Rate Transducer

During CY 67, a device for measuring gamma heating rates during engine runs was conceived, designed, built, and tested. Two of these transducers (AGC 1134280) are now ready for installation on XE-1.

Prior to the development of this transducer, gamma heating rates were measured by silver glass and thermoluminescence dosimeters (TLD) that become activated by gamma exposure--the degree of activation being a function of the total integrated exposure. Knowing the activation and the reactor power at a particular time, the gamma heating rate can then be calculated after the test. A major drawback is that gamma heating rate information is not available during a test.

Instantaneous-reading gamma heating rate sensors have been used. In most cases, these sensors have been specially made by those desiring the measurement. None were commercially available that fulfilled the AGC requirements, hence the transducers had to be designed and built.

Figure 90 is a schematic diagram of this transducer. Basically, it consists of a copper sphere mounted on a constantan pedestal that is mounted on a copper base plate. A copper-constantan thermocouple is connected to the sphere and another copper-constantan thermocouple is connected to the copper base plate. The entire assembly is covered with a steel cap and evacuated. Figure 91 shows two views during fabrication.

This transducer measures gamma heating rates in the following way. Gamma absorption in the copper sphere generates heat at a rate proportional to the product of the gamma heating rate times the mass of the sphere. This heat production causes the temperature of the sphere to rise until the amount of heat flowing by conduction across the constantan pedestal to the copper base plate equals the amount of heat being generated in the sphere by gamma absorption. Knowing the mass of the sphere and the thermal resistance of the pedestal, the gamma heating rate can be calculated from the measured temperature difference across the pedestal. This temperature is indicated directly by the junction between the copper sphere and constantan pedestal and copper sphere acting as the other. The voltage developed by these two thermocouples in series is proportional to the temperature difference across the pedestal. This signal voltage is conducted from the transducer by the two copper leads of the thermocouples that attach to the sphere and to the base plate. The copper-constantan thermocouple connected to the sphere monitors the sphere temperature and provides a correction factor to compensate for the slight nonlinearity in the copper-constantan-voltage versus temperature curve.

Two of these gamma heating rate transducers are being installed on XE-1. Both will be mounted on the pressure vessel forward flange in an area predicted to have a 1/4 to 1/2 watt/gm gamma heating rate.

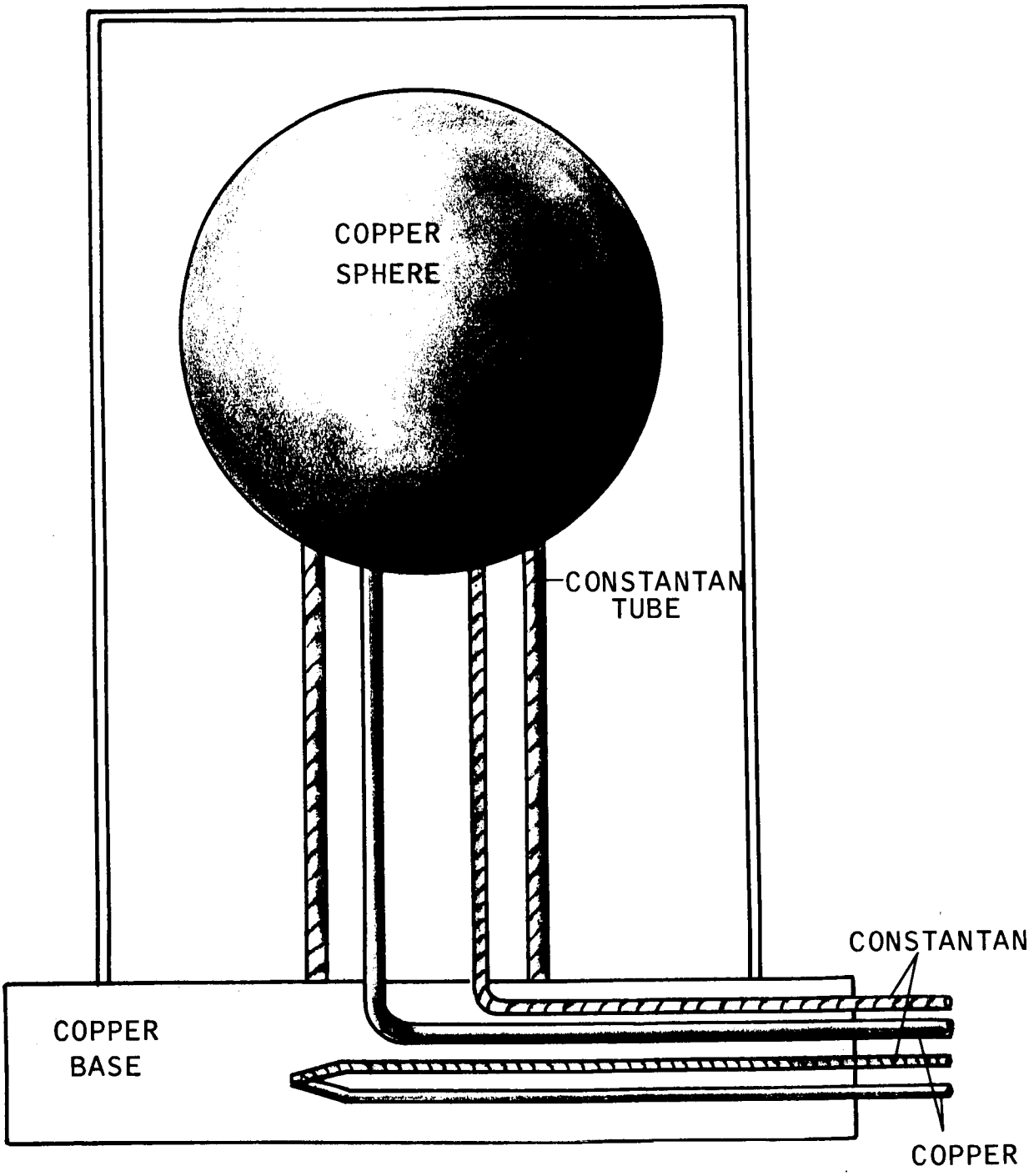


Figure 90 - Diagram of Gamma Heating Rate Transducer

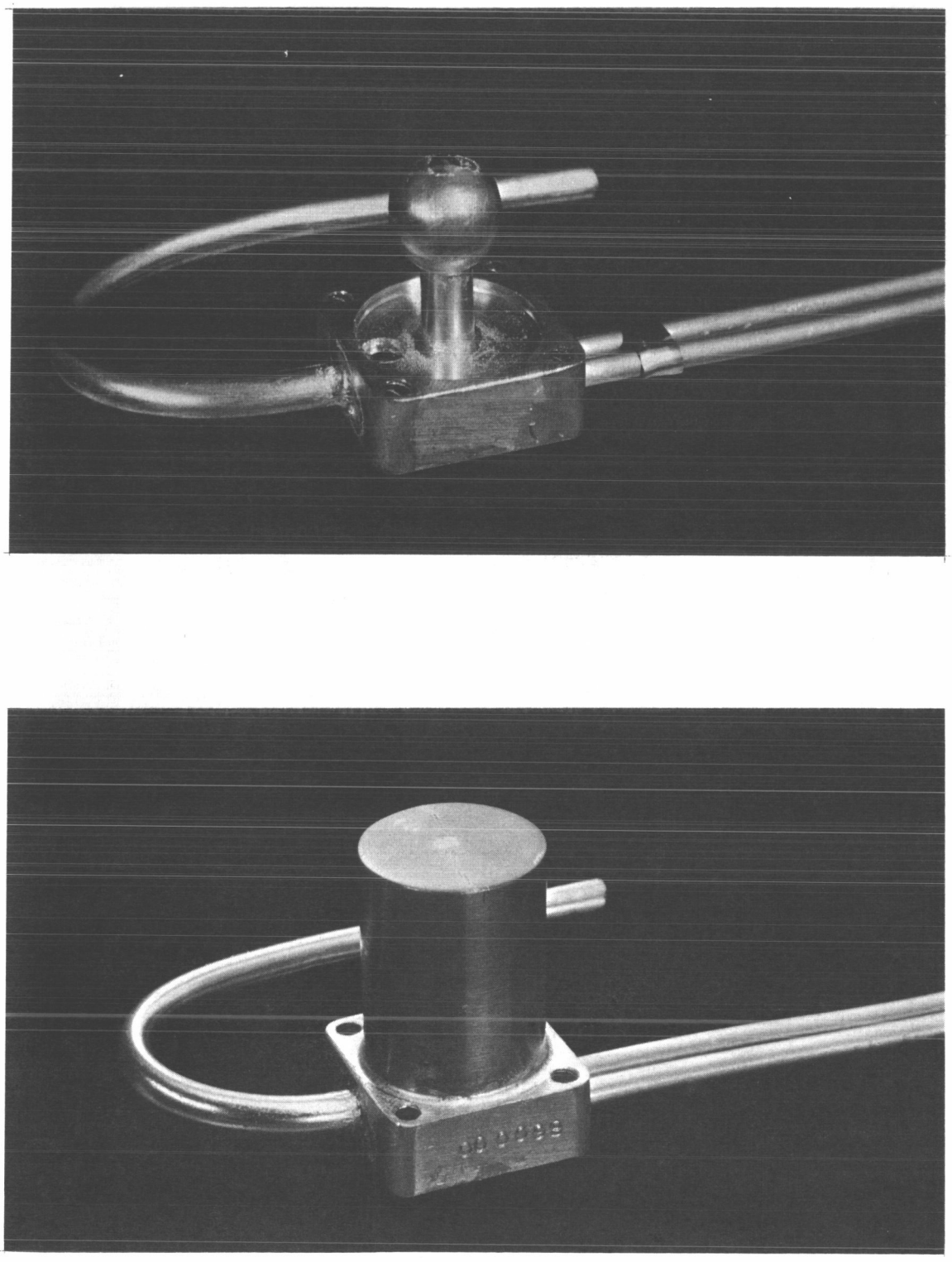


Figure 91 - Two Views of Gamma Heating Rate Transducer During Fabrication

(7) Development Reports

Instrumentation development progress reports were submitted to SNPO-C on a monthly basis in accordance with the CY 66 work statement.

(8) Instrumentation Reports

Instrumentation reports written during the calendar year are as listed.

Report	Title	Status
RN-S-0330	NRX-A5 Posttest Instrumentation Report	Released
RN-S-0369	NRX-A5 Qualification Report of Engine-Mounted Pressure Transducers	Released
RN-S-0370	Fast and Thermal Neutron and Proton Effects on Platinum Resistance Transducers at Liquid Hydrogen Temperature	Released
RN-S-0385	Qualification/Evaluation Test Specification for Flush-Mounted Pressure Transducer Test 23/R512	Written; Being Held for Additional Data
RN-S-0391	Minutes of CY 67 Instrumentation Development Review Meeting	Released
RN-S-0392	Qualification/Evaluation Test Results of Metal Sheathed, Ceramic Insulated Radiation Resistant Electrical Cables	Being Written
RN-S-0410	Instrumentation Calibration Data Log Book XECF	Released
RN-S-0417	Instrumentation Calibration Data Log Book NRX-A6	Released
RN-S-0419	Instrumentation Calibration Data Log Book XE-1	Released

Report	Title	Status
RN-S-0439	Nonnuclear Qualification/Evaluation Test Results on Rosemount Model 134AJ Resistance Temperature Transducer	Written; Being Reviewed
RN-TM-0301	XE Flame Spray Capability Tests for Titanium, Hastelloy, 347 Stainless Steel, and 6061 T-6 Aluminum	Released
RN-TM-0416	Design, Operation, and Selection Criteria for XE Calorimetric Nuclear Radiation Detectors	Released
RN-TM-0418	Development of the Flame-Sprayed Aluminum Concept for Conductive Cooling of XE Engine-Mounted Electrical Cables	Released
RN-TM-0419	Transmission Cable Temperature Effects	Released
RN-TM-0426	Time Response Test of Thrust Chamber Thermocouples in Simulated Rocket Firing	Released
RN-TM-0550	Posttest Results of NRX-A5 Evaluation Accelerometers Electra Scientific Corp. Model No. AXB-6070	In Publication
RN-TM-0554	Evaluation Test Results of Errors Caused by External Environmental Conditions on Surface Mounted Thermocouples	Released
RN-DR-0094	Assembly Procedure for the Experimental Engine Instrumentation Installation at AGC-Sacramento	Released
RN-DR-0124	Pneumatic Instrumentation Lines and Their use in Measuring Nuclear Rocket Nozzle Pressure	In Publication
RN-DR-0125	Investigation of Damaged NRO Pressure Transducers	Released

4. Ground Operations Safety (2.5)

a. Safety Analysis and Review (2.5.0)

Detailed safety evaluations of ETS-1 facility systems were accomplished. Several recommendations were made for facility modifications and procedural requirements to enhance personnel, facility, and test article safety. An ETS-1 Facility Safety Report was prepared. The purpose of this report is to show that the ETS-1 facility is operationally ready from a safety standpoint for engine tests. The final report, RN-S-0378, was issued in July 1967. Design criteria for several modifications to the ETS-1 facility were reviewed. The criteria reviewed included those for duct vault and pipe chase inerting, the NES scrubber system, and the test stand flange inerting and venting system. A large number of ECR's (Engineering Change Requests) for implementation of minor system modifications were reviewed. Test specifications, test descriptions, and operating procedures were reviewed for performance of NES tests, Facility Experimental Plans (FEP's) for flow tests, and XECF.

Safety evaluations of the E-MAD facility and facility subsystems were accomplished. Recommendations were made for facility modifications to improve personnel safety. An E-MAD Facility Safety Report was prepared. The purpose of this report is to show that the E-MAD facility will be operationally adequate to support engine test operations without compromising the safety of personnel, facility, or test article critical components. The final report, RN-S-0394, was issued in May 1967.

Safety aspects of the X-engine design, assembly, checkout and operation were evaluated. The XE Safety Analysis Report, NJD-9, was prepared jointly with WANL and issued in support of the XE test program. The Phase 1A Safety Evaluation Report and Operating Limits Document for XE-1 assembly operations were prepared jointly with WANL and issued. The assembly procedures were reviewed, and SNPO-C approvals for reactor shipment to NRDS

and engine assembly in E-MAD were obtained. The Safety Evaluation Report, the Operating Limits Document, and the assembly procedures for the NRX-A6 Phase I assembly operations were reviewed and SNPO-C approval of the operations was requested.

The safety audit program of operational facilities associated with NERVA was continued. A total of five safety audits of facilities at NTO and WANL were conducted during CY-1967. The Safety inspections of NRO operations at the Sacramento Plant were also maintained. These safety audits and inspections keep management informed of the NERVA program status in matters related to safety and provide a means for improving the overall safety of the NERVA program.

The WANEF Safety Report, WANL-TNR-099, and the Operating Limits Document, WANL-TME-1295, were revised by WANL in accordance with an Aerojet/SNPO request. These documents, together with a revised version of the WANEF Reactor Operations Manual, WANL-TME-267, were reviewed by the NRO Safety Division. On the basis of the review, approval was requested and obtained for the continued operation of the PAX and FCX reactors in accordance with the revised safety documentation. Additional minor modifications of the WANEF safety documents were reviewed and implementation was approved.

b. Ground Operations Safety-NRDS (2.5.1)

(1) General

The highest individual radiation exposure was 2.75 Rem.

The highest individual body burden to radioisotopes was 2% of the guide levels established by the Federal Radiation Council.

There were no Type A or Type B accidents or radiation exposures as defined in Chapter 0502 of the USAEC Manual.

The Health and Safety Manual, NTO-A-0022, was printed in a condensed version; 500 copies have been distributed to all members of NTO who had not previously received copies.

A total of 196 personnel received 12 hr of instruction in the "Fundamentals of Radiological Safety."

The NTO Criticality Control Manual was updated, revised, and reissued with specific emphasis on handling of fissionable materials in the E-MAD facility.

Corrective actions were recommended in response to the semiannual fire survey made by SNPO-N of NTO NRDS facilities.

Provisions were made with Los Alamos Scientific Laboratory to station a member of NTO Health and Safety in the LASL Technical Operations Building to perform liaison with and surveillance of Test Cell C activities performed by the Joint Test Operations.

There were two incidents during the year. One was a major leak of liquid hydrogen at ETS-1 (described in Report NTO-R-0109). The other involved inappropriate transfer of radioactive materials and is described in NTO-R-0117. In both cases, firm recommendations were made to preclude a recurrence and corrective actions were completed.

Physical examinations of NTO personnel were completed in accordance with Chapter 0528 of the USAEC Manual.

(2) E-MAD

The proof-load testing was witnessed for each personnel platform and turntable.

A minor fire in the MCC was investigated, and the loss was determined to be less than $50.

Health and Safety provided safety support to the checkout of the simulated engine-test-stand adapter and to the checkout of the MCC/EIV/PIC railroad transport system.

Proper inspection of chains in accordance with NTO-A-0022 was established at E-MAD.

The revision to the SS Materials Control Instruction Manual was prepared.

A safety audit of the off-loading of the XE-1 test article was made.

An emergency evacuation drill was conducted at the E-MAD through the sounding of the criticality alarm. The alarm was unannounced and the test was conducted to check the response of the people. In all, 174 personnel at E-MAD participated, and the results were very satisfactory. A critique of the drill is on file in the Health and Safety Office.

(3) ETS-1

The ETS-1 side-shield cables were reviewed. The cables were certified by the manufacturer at a 58,800-lb breaking strength, whereas only 12,000 lb tension is applied for the operation. The NTO ETS-1 Project Engineer agreed to provide protection to the cables for vehicle passage ways and restraints for the nonworking leg of each cable.

The following documents were distributed to all personnel (NTO, PAA, EG&G, and contractors) at ETS-1, plus key personnel elsewhere:

(a) "ETS-1 Emergency Plan" - NTO-A-0030, Section 018.

(b) "Area Surveillance and Warning System at ETS-1" - NTO-A-0030, Section 019.

Lectures on "ETS-1 Safety Systems and ETS-1 Emergency Procedures" were given in the training program for ETS-1 control-point operators.

Coordination was established with Pan Am on periodic maintenance of all respiratory protection equipment that will be kept in the ETS-1 tool crib in a ready condition.

Special training was provided in Scott Air Paks and emergency oxygen units to 60 NTO and EG&G personnel.

An audit was performed of NTO-I-0158, "Fill Operations for the Propane Tank". The operation was followed through the checklist for hookup and disconnect. No deviations were observed.

A program was initiated at ETS-1 to establish CGA standards for all fittings on K-bottles. SNPO-N is writing an SOP through PAA to establish site-wide CGA standards that will be compatible with ETS-1 installation.

Liaison was established with Pan AM rad safe personnel on required ETS-1 radiation services.

Deficiencies in the ETS-1 propane vaporizer were documented and sent to the Manager of ETS-1 Operations.

An accident that a Pan American employee had on a scaffold mounted for shield access was investigated, and a report was made.

Guidance was provided on interpretation of the NTO H&S Manual for leak checking of installed systems at ETS-1.

Criteria were provided for a scrubber to be used with XE-1 testing, and input criteria were provided for a system for safely collecting effluent from the XE-1 scrubber.

(4) Test Cell C

Communications between NTO H&S and the three safety engineers responsible for the LASL safety at Test Cell C have effectively kept NTO informed of facility safety changes and requirements.

Arrangements were completed to acquaint the NTO criticality engineer with the facility and to establish liaison with LASL.

An attempt at a full-power run of Phoebus 1B on 17 February 1967, was postponed because of weather and technical problems. On 23 February, the full-power run of Phoebus 1B was performed successfully.

In both cases, three personnel of NTO H&S supported the operation in the hazards control room. On 27 February, the critical restart of Phoebus 1B was conducted to verify critical drum position. NTO H&S support in the hazards control room was provided for this operation. Radiation exposure levels at Test Cell C were as anticipated before the run and were documented. Personnel control procedures were maintained to minimize exposures of NTO personnel at Test Cell C.

(5) R-MAD

An inspection team of two supervisors and four technicians was established by the Facility Manager to review operations and the facility once every two weeks.

Support was provided in the general decontamination of NRX-A5 hardware and fixtures for transfer to the 401 and R-MAD burial areas.

(6) Criticality

The reactor multiplication alarm monitor ("popper") purchased for NTO in 1964 was located by EG&G and placed in the E-MAD facility. It was installed, checked out, and used as an emergency backup monitor for the XE core.

Arrangements were made for film badges to be placed around the SSN vault at E-MAD for temporary use as criticality dosimeters.

The interaction between two NERVA reactors and the effect of the engine-assembly-stand gear-box oil on shutdown margins were evaluated.

The 1/M curves from NRX-A2, -A3, and A5 and EST were reviewed, and their significance was discussed with the WANL Safety Department.

A nuclear safety analysis was received from WANL/Large for E-MAD fuel-element transfer trays with Boral poisoning and was transmitted to MAD operations.

Supplement 1, "Minimum Separation Distances Between Two NERVA Reactors at E-MAD," to the NTO Criticality Control Manual, NTO-A-0029, was issued in final form on 14 August 1967.

The E-MAD facility criticality alarm system is being checked out by EG&G to determine cause of a false alarm on 13 September 1967.

Arrangements were made for the NRDS Fire Department to respond to the east instead of the north roadblock during E-MAD criticality alarms.

Five "poor boy" dosimeters were received from LASL and installed in the E-MAD assembly bay.

5. Product Assurance (2.6)

a. Product Assurance - Contractors' Plants (2.6.0)

A formal failure-mode analysis (FMA) policy and procedure was prepared and issued, as PD 1074. It organizes the technical efforts of design, project, safety, reliability and other engineering disciplines into a unified effort intended to eliminate potential design failures and to maintain reliability. The FMA also provides a means of controlling

failure risks that must be accepted. The FMA will be applied to technology and NERVA test article hardware and testing facilities. Failure-mode analyses will be initiated with the design effort and will be available for design reviews and test planning.

A comparative study was made of the reliability of a welded and of a seamless pressure vessel using Inconel 718. Examination of the modes of weld failure and a study of methods for controlling these conditions indicated that current Inconel 718 welding technology is sufficiently developed to ensure a reliable vessel.

The effect on nuclear propulsion system reliability of a zero-NPSP turbopump and of a positive-NPSP turbopump was evaluated. Despite the greater complexity of the zero-NPSP turbopump, which is theoretically less reliable (by the amount of 3 failures in 10,000), the overall propulsion system reliability with the zero-NPSP turbopump is slightly higher. This is due to the favorable trade-off in system simplification provided by elimination of the tank pressurization system which is required for the more reliable positive-NPSP turbopump.

An FMA was prepared for the Aerojet-Sacramento nozzle test facility on the basis of the modifications and extensive analog malfunction computer runs after the Phoebus nozzle incident (involving lack of coolant flow) in March. Reliability recommendations included separation of the control from diagnostic instrumentation, selection of the most direct circuit for chamber pressure (P_c), control of the nozzle cooling valve, and use of higher coolant flows prior to the initiation of hot gas through the nozzle. An FMA was also prepared for the redesigned film-cooled nozzle (having an increased film coolant capacity). This FMA was a key item in the critical experiment review meeting that authorized resumption of testing. Another FMA was prepared for the nuclear exhaust system engine test compartment for ETS-1. As a result of this effort, a series of modifications of the NES/ETC were recommended to provide additional system reliability.

Reliability engineering participated in a series of PSOV (propellant shut-off valve) design reviews. At the first preliminary design review meeting, reliability presented four FMA's covering PSOV's on NRX-EST and XE engines, plus Marshall Space Flight Center data relative to major cryogenic valve problems. Thereafter, reliability developed and submitted pertinent FARADA data together with IDEP test reports for cryogenic valves. After reviewing PSOV designs, reliability made recommendations relative to seal thickness, area, and hardness, and to forging characteristics and protective packaging. A preliminary FMA on the NERVA engine PSOV was prepared and coordinated prior to the second PSOV design review meeting. Subsequently, a series of reliability recommendations resulting from the FMA were reviewed with design personnel, and 10 of the 18 recommendations were accepted.

A revised draft of the XE-1 failure-mode analysis with 50 subsystem segments was completed in July. Essentially, this revision incorporated the reliability engineering analysis of pertinent failures and performance limitations. New or modified design features to improve reliability were listed, and prediction of frequency of occurrence of the failure-cause was added, together with the classification of the problem status. These extensive changes warranted a re-coordination of the FMA. Upon receipt and incorporation of Engineering's and NTO's review comments, the XE-1 FMA was revised and released for program coordination on 31 August 1967. In accordance with RN-PD-S-1074, the comments of the contributors will result in a program-approved document for use in preparing and testing the XE-1 engine.

Additional reliability efforts consisted of: (1) a review of the NERVA skirt development plan, resulting in submittal of some reliability recommendations and presentation of summarized test data pertinent to skirt design; (2) an analysis of the effect of space environment on materials, which included data obtained during Apollo X development; (3) providing assistance in developing an initial FMA on the NERVA engine pressure vessel, using pressure vessel data from both the Titan and NERVA programs.

Reliability participated in a flight-safety study concerned with the probability of sudden loss of coolant flow. The basis for the study was a 72-hr lunar transfer mission and two discrete time intervals during this mission. First, failure-mode analysis for the engine system was completed, which identified the components, their failure modes, and probability of occurrence. Design concept changes were recommended to eliminate or reduce the probability of component failures. The recommended changes were the use of: (1) fail-open valves; (2) redundant regulators; and (3) redundancy in the PTCV/TBV portion of the GH_2 subsystem. Subsequently, Reliability participated in the NERVA flight-safety presentation at SNPO-W on 19 July 1967. The presentation covered the engine-system failure modes that would result in a loss-of-coolant accident, including a probability estimate of the critical time period when an in-flight malfunction would result in a land impact during the suborbit phase of the 72-hour lunar transfer mission. Non-nuclear component temperature limitations were defined, and emergency cooling requirements and system concepts were also presented.

The engine system failure modes were defined as: (1) failure to start; (2) steady-state failure causing immediate abort; (3) steady-state failure causing mission failure but requiring no immediate abort action; and (4) failure to shut down.

The second system failure mode indicated above is a catastrophic-type failure and creates a flight-safety problem if it occurs during the 11-sec African-window portion of the lunar-type mission or during the second engine start or steady-state operating phases. By establishing the reliability of the various engine-system components for the applicable system failure modes, the reliability of the propulsion system and the probability of a catastrophic failure can be estimated.

The basic component failure-rate data used in this analysis were derived from more than 2400 rocket-engine test-stand firings for the Atlas, Thor, Jupiter, and H-1 engines. Titan static and flight-test

data and NERVA component test data were also considered in establishing basic component failure rates. The assumption made in using these data is that the NERVA program can develop engine components to a reliability level that will at least equal the level achieved by the preceding programs.

A reliability analysis revealed that by using a custom-designed valve and regulator system for the NERVA mission, the probability of sudden loss of coolant flow is directly proportional to the estimated failure rate of the TPA (0.0014). Without a custom-designed system, the probability of sudden loss of coolant flow during engine steady-state operation is estimated to be 0.0038.

For estimating the probability of sudden loss of coolant flow during the 11-sec African window, the total probability of failure was distributed linearly over the 600-sec time interval of steady-state operation. The African window probability of sudden loss of coolant flow was estimated to be 2.56 in 100,000 flight attempts with the custom-designed system and 6.75 in 100,000 attempts or flights if the custom-design concept is not applicable.

The estimated engine-system failure probabilities were distributed as functions of engine operating phase for the two cycles of operation required for the lunar-type mission. Two assumptions were made in establishing the engine-system mission-reliability profile. These are summarized as follows:

1. The failure distribution for the non-nuclear hardware is equal for the first and second cycles of engine operation.
2. The total failure rate for the reactor equaled the total failure rate for the non-nuclear hardware but distributed for a higher probability of failure during the second cycle of operation.

For the NERVA engine system, the estimate of mission reliability is considered to be the product of the reliabilities for two start, run and shutdown phases.

The first- and second-cycle probabilities of success were estimated to be 0.9873 and 0.9821, respectively. The mission probability of success for the NERVA engine system is estimated to be 0.9694.

An accurate assessment of nuclear engine system reliability is difficult to establish. The relatively limited amount of test hardware and data virtually precludes the use of a conventional statistical approach. However, a unique method of minimizing these assessment problems has been developed by NRO and WANL, and will be formalized in the near future.

The proposed approach, combining quantitative and qualitative assessments will:

1. Provide a detailed description and schedule of the test activity as it interfaces with the reliability assessment program
2. Show how the data generated in the test program will be used to support the analytical reliability evaluation process
3. Provide an accurate assessment of reliability
4. Satisfy the integrated test program and reliability assessment requirements of NPC 250-1

A new ultrasonic-inspection specification, AGC-STD-9014 (REON), was prepared and issued that combines the features of AGC-36163 and AGC-STD-9006, thereby providing for longitudinal and shear-wave inspections and criteria. Several innovations appear in this specification: a foreword that provides guidelines for the selection of quality level, definition of NRO requirements for preinspection planning, criteria for selection of equivalency of reference block material, and acceptance criteria for shear-wave inspection. This specification will be incorporated into all future applicable drawings.

X-ray and magnetic-particle inspection procedures were written for the NTO thrust ring, P/N 11134130, and were included in AGC 90175, the welding specification for this assembly.

Nondestructive test engineering also participated in the NDT symposium of AEC contractors held at Oak Ridge in April, and presented a paper relative to the Aerojet development of alcohol-penetrant inspection of graphite at the ASTM Symposium on NDT of Nuclear Graphite held in Boston in June.

A functional analysis on NRX-EST instrumentation as a joint effort between Instrumentation and PAD Quality Engineering was conducted. This effort disclosed the need to:

1. Establish more positive environmental criteria and tests for engine systems transducers, especially for vibration, gamma heating, and cryogenic tests.

2. Develop a heat-sink technique to reduce inducted electrical noise developed by radiation fields. Such a technique was subsequently developed and is being evaluated on NRX-A5 and XECF engines.

3. Conduct an intensive investigation of magnesium oxide, CRES-shielded instrumentation cable to develop realistic acceptance criteria. This investigation subsequently resulted in preparation of specification AGC 90052C.

The Aerojet and WANL subsystems of the engine control system of the TSCS were assembled at Aerojet-Sacramento into a functional system using the test-simulation system as a substitute for the XE-1 engine system. The functional characteristics of the engine, reactor, turbopump

and TPCV control parameters were checked out against approved acceptance test procedures. Certain workmanship deficiencies that were detected during the functional checkout were resolved.

The second revision of AGC-STD-9012 (NRO), Wiring, Routing and Termination of, was completed and issued. At the request of SNPO-C, this document will be used as the NERVA-program workmanship standard for all electrical and electronic assemblies used for test engines and associated controls. Another specification was issued this year (AGC-STD-9015) and covers the rework or modification of printed-circuit cards. This specification was coordinated with NRO divisions, WANL, NTO, and SNPO-C.

b. Quality Assurance (2.6.3, 2.6.4)

The NTO product assurance organization provided quality assurance and reliability services in connection with all major site activities and included: installation and testing of facility equipment, inspection of NRX-A6/T7 test car, installation of TSCS equipment, welding on the thrust ring, and inspection of the duct instrumentation. An example of the type of service rendered by this organization was the case of the V-5001 run tank. In the course of inspecting the run tank, the absence of some ladder bolts was detected. An investigation of the entire assembly was instituted, including an X-ray examination of inlet and outlet lines. As a result of the investigation, which disclosed the missing bolts in the outlet line and the presence of sand and chips in the expansion joints, inlet and outlet lines were disassembled and thoroughly cleaned, and all marginal welds were reworked to a radiographically acceptable condition.

6. Flight Malfunction Studies (2.7)

During the contract year, a joint Aerojet, WANL, and LMSC study was completed that established the safeness of nuclear rocket operation in the event of an in-flight malfunction during the suborbit phase of the 72-hour lunar transfer mission. On 19 July 1967, the results of this study were presented at SNPO-W. The Aerojet portion of the presentation material is contained in Report No. RN-DR-0132.

a. Mission Model

The mission model for this study was established by LMSC and was defined as a 72-hour, lunar-transfer mission having a suborbital start of a 5,000 Mw, NERVA-powered nuclear stage. An MLV Saturn V-3 launch vehicle will deliver the nuclear stage and payload to an altitude of approximately 90 NM. At this point, the nuclear engine is started and will operate to insert the stage and payload into a nominal 100 NM orbit. Following orbit injection, the nuclear stage and payload enter into an eccentric orbit. When launch window constraints have been satisfied, the nuclear engine will be restarted and will operate until lunar transfer velocity has been achieved.

To obtain maximum performance from the dual-burn parking orbit mission and to avoid overflight of heavily populated areas during suborbit operation, a launch azimuth of 100 degrees was used. This launch azimuth results in the minimum hazards to the population during suborbit flight.

The hazards from nuclear engine operation end when the stage reaches a point in the flight where the debris resulting from failure will remain in orbit long enough to enable the fission products to decay to an acceptable level prior to re-entry. In the reference case, the orbit lifetime is not reached until well into the second burn of the nuclear engine.

During the first nuclear operating cycle, there is a critical period of 11.0 sec when an in-flight failure will cause the nuclear stage to impact on the African Continent. Failures occurring during the first 6 to 7 minutes of nuclear engine operation result in a safe impact in the Atlantic Ocean.

b. Disposal Requirements

Post-failure disposal requirements assume that safe disposal can be achieved by directing the radioactive debris to a controlled deep-ocean impact or to a long-duration orbit until the radioactivity decays to an acceptable level. During suborbit operation, an ocean impact is the recommended disposal mode so that ΔV requirements can be reduced and the impact location can be more readily controlled.

For suborbit nuclear operation, the velocity requirements necessary to change the direction of motion vary significantly as a function of the failure time as shown in Figure 92. For early failures occurring during the critical African continent overflight time, the ΔV requirement to avoid land impact is 200 ft/sec. Using the option of boost or retro, the velocity requirement can be optimized at 100 ft/sec.

In estimating the potential radiation hazard to which an earth impact point will be exposed, especially for nuclear systems having radioactive fission products that build up and decay with time, it is desirable to delay the time of impact. Obviously, the longer that the impact time can be delayed, the less the potential hazard. Equally important is the coast time required for counter-measure application. Figure 93 shows the effect of time delay on ΔV application for a failure occurring after 409 sec of nuclear operation. For failures occurring after 409 sec, the curve shifts to the right so that for the same delay time less ΔV is required.

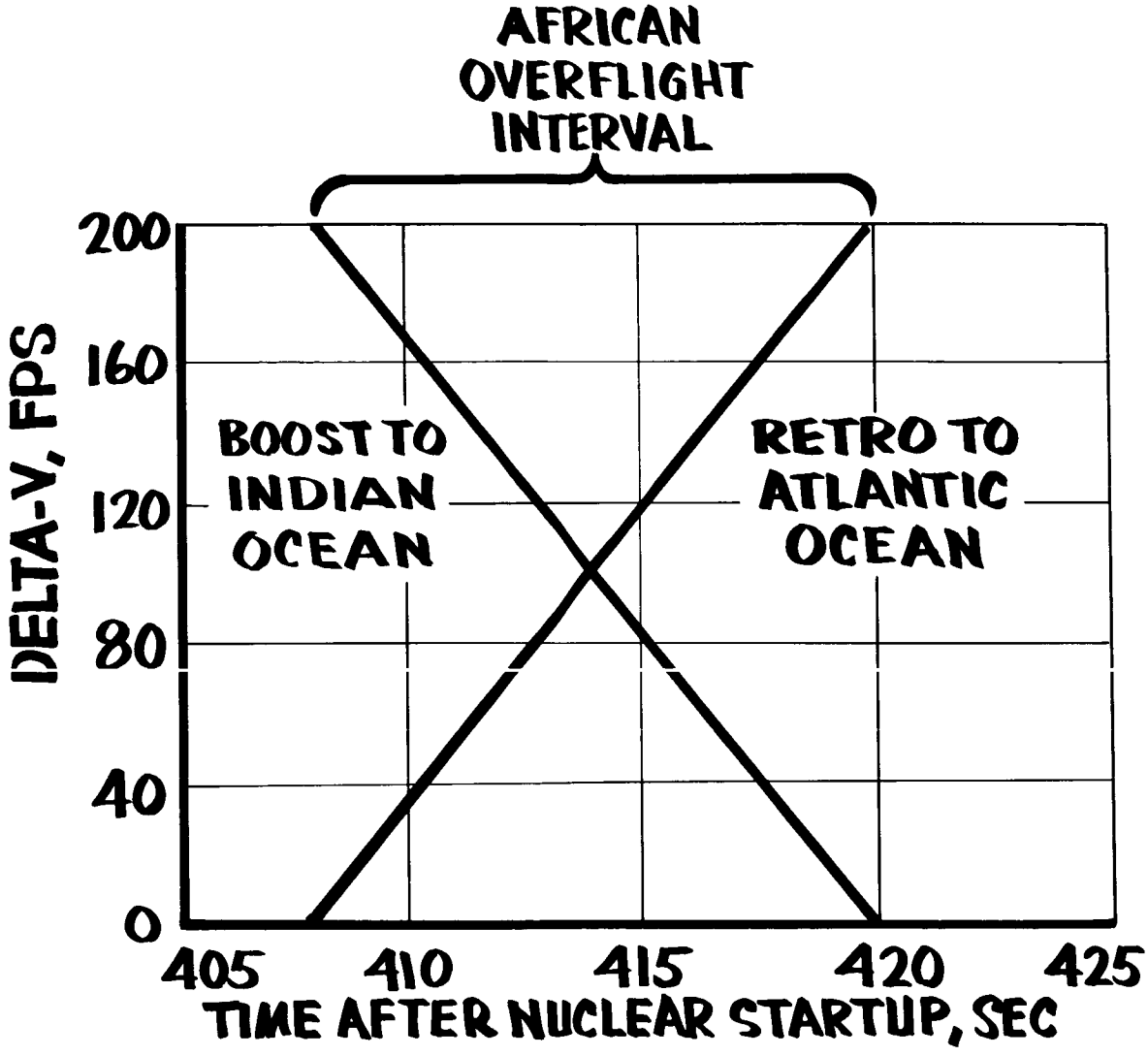


Figure 92 - Disposal, Delta-V Requirements, Suborbit Phase

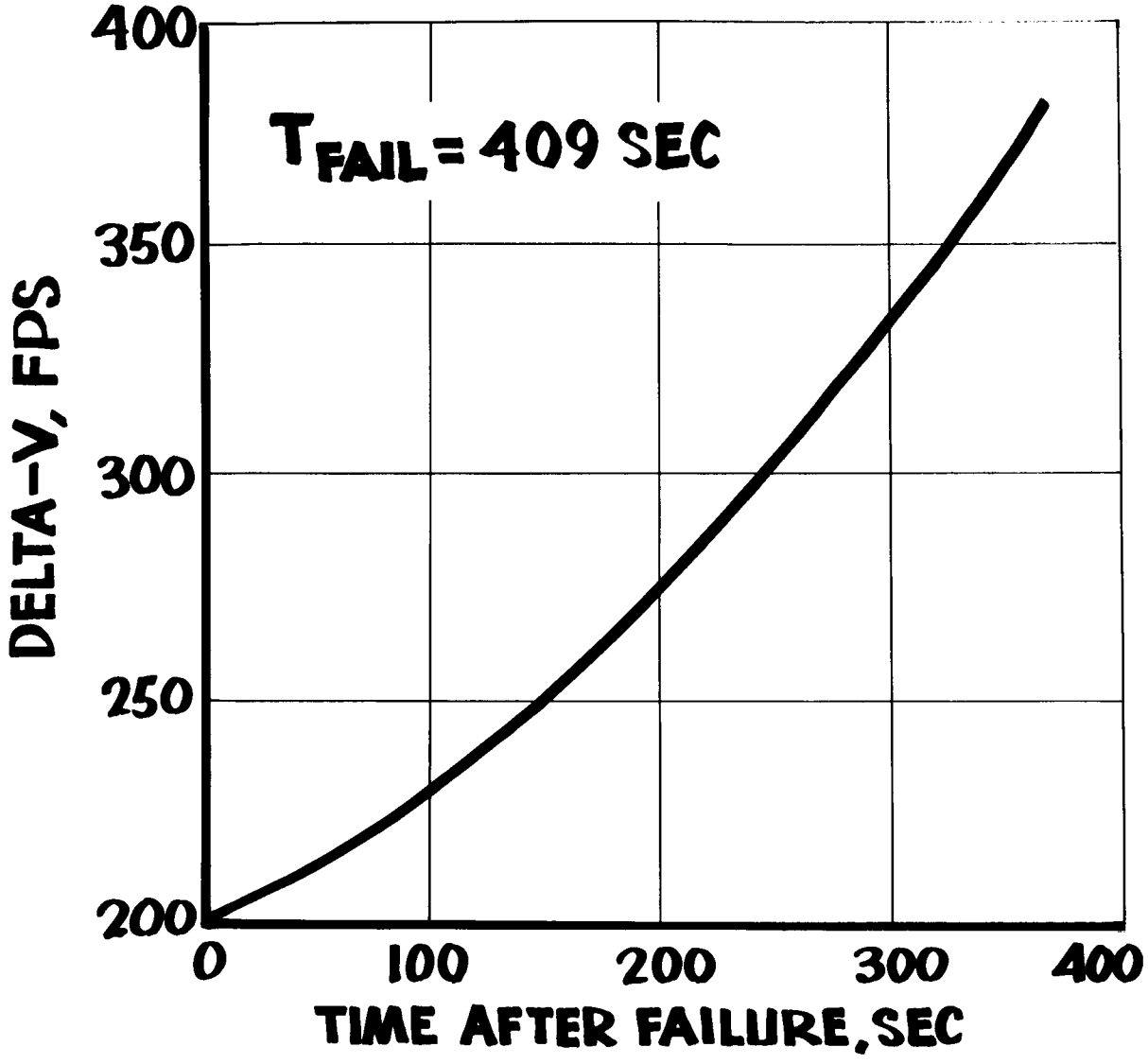


Figure 93 - Effect of Delay on Delta-V Requirements, Suborbit Phase

c. Accident Model Definition

The model selected to describe the most probable worst-case accident is based on a sudden loss-of-coolant to the engine system. It was assumed that the accident resulted from a failure attributable to a single cause; multiple simultaneous failure causes appear to be improbable. Also it was assumed that the module propellant tank and flow system remained intact. The accident described could occur, for instance, if the TPA bearing failed or the TPCV closed in 100 millisec. Both conditions would cause pump shaft speed to decrease to zero in 200 millisec. Flow rate would tail off in the normal pump shutdown fashion. Reactor scram would be initiated 50 millisec after the failure occurs. Figure 94 shows the time response for the first 120 millisec immediately after reactor scram. Beyond 200 millisec, engine flow rate would be supplied from the propellant tank at 35 psia. The major system parameters following a loss-of-coolant accident are shown in Figure 95. With insufficient coolant flow, the nuclear subsystem would be subject to an immediate and rapid temperature increase, resulting in eventual disassembly.

The nozzle's ability to operate at reduced flow rates without damage is determined by the ratio of flow between the hot and cold side as shown in Figure 96. During a rapid termination of flow to the engine, this ratio is well above the level where the nozzle would burn out: approximately 0.35. The ratio tends to stabilize beyond 120 millisec, so it can be concluded that nozzle integrity is maintained during pump-flow tail-off following a loss-of-coolant accident.

d. Failure Mode Analysis

The probability of a failure occurring in a given system varies as a function of its operating mode. For instance, the probability of failure in the nuclear propulsion system varies signficantly with the operational phases, as shown in Figure 97. Failure during steady-state operation

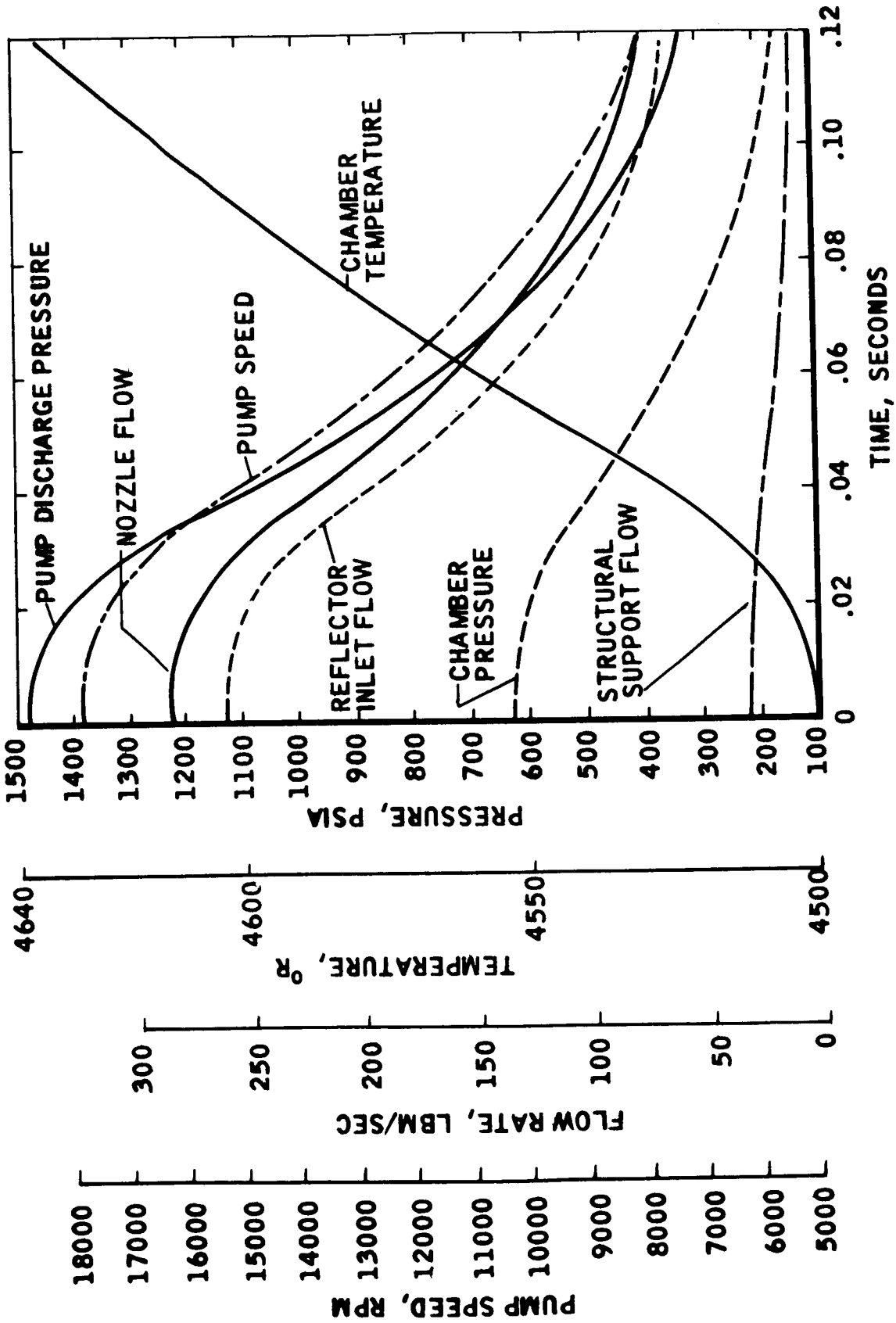


Figure 94 - NERVA Emergency Cooldown Engine Parameters Immediately After Scram

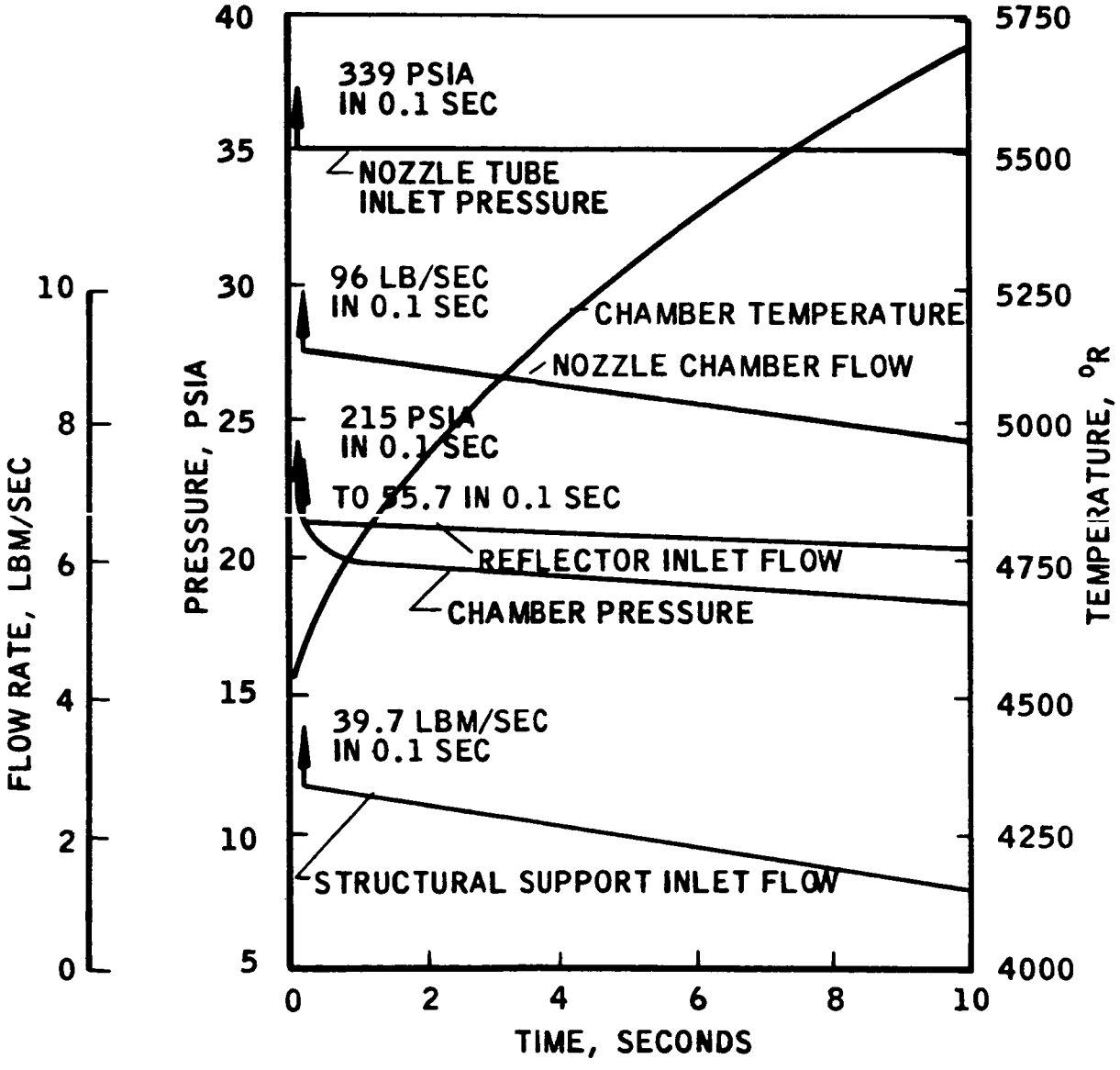


Figure 95 - Major System Parameters (0.0 to 10.0 Sec)
5000 Mw-T_c = 4500°R - P_T = 35 psia

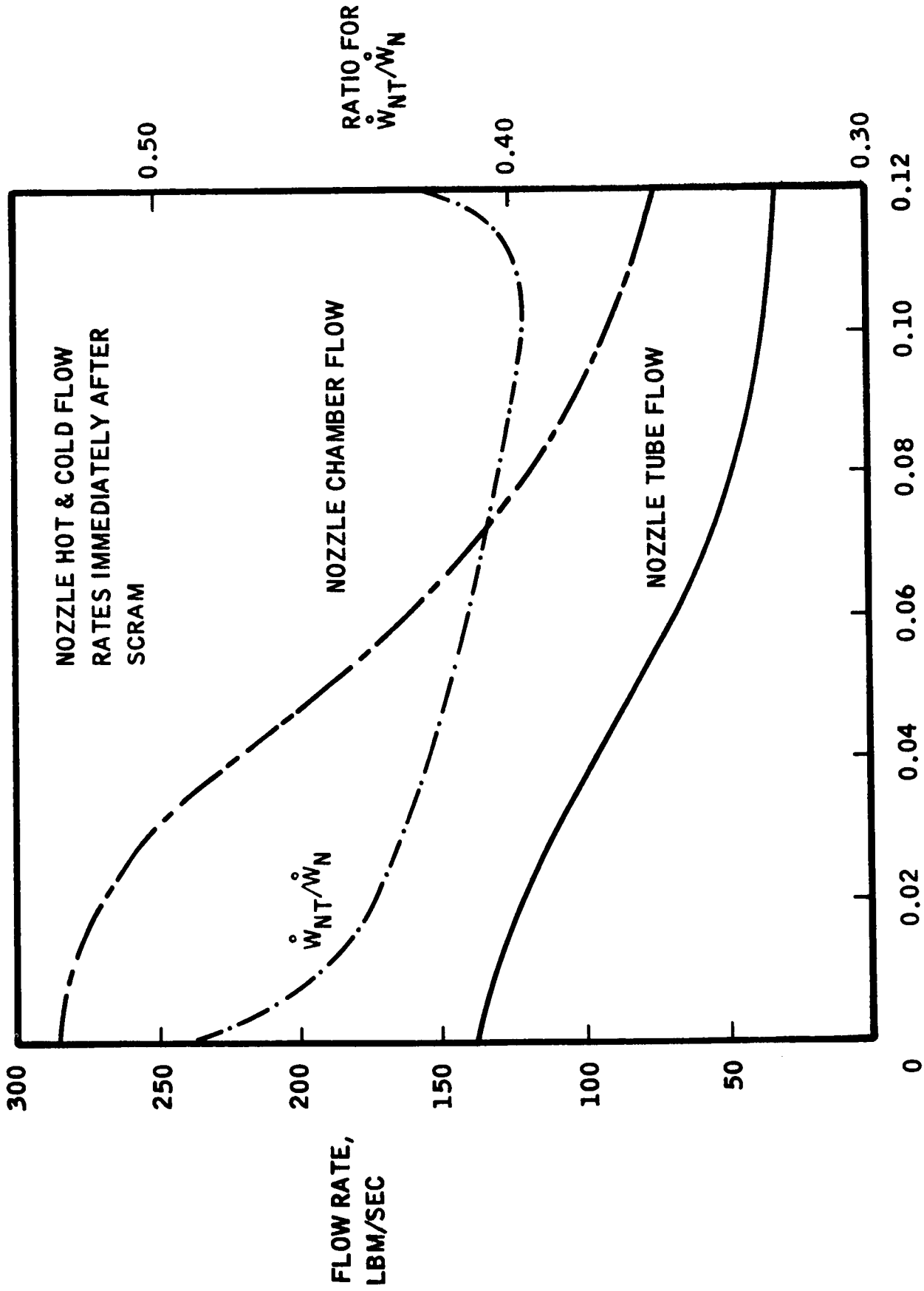


Figure 96 - Emergency Cooldown

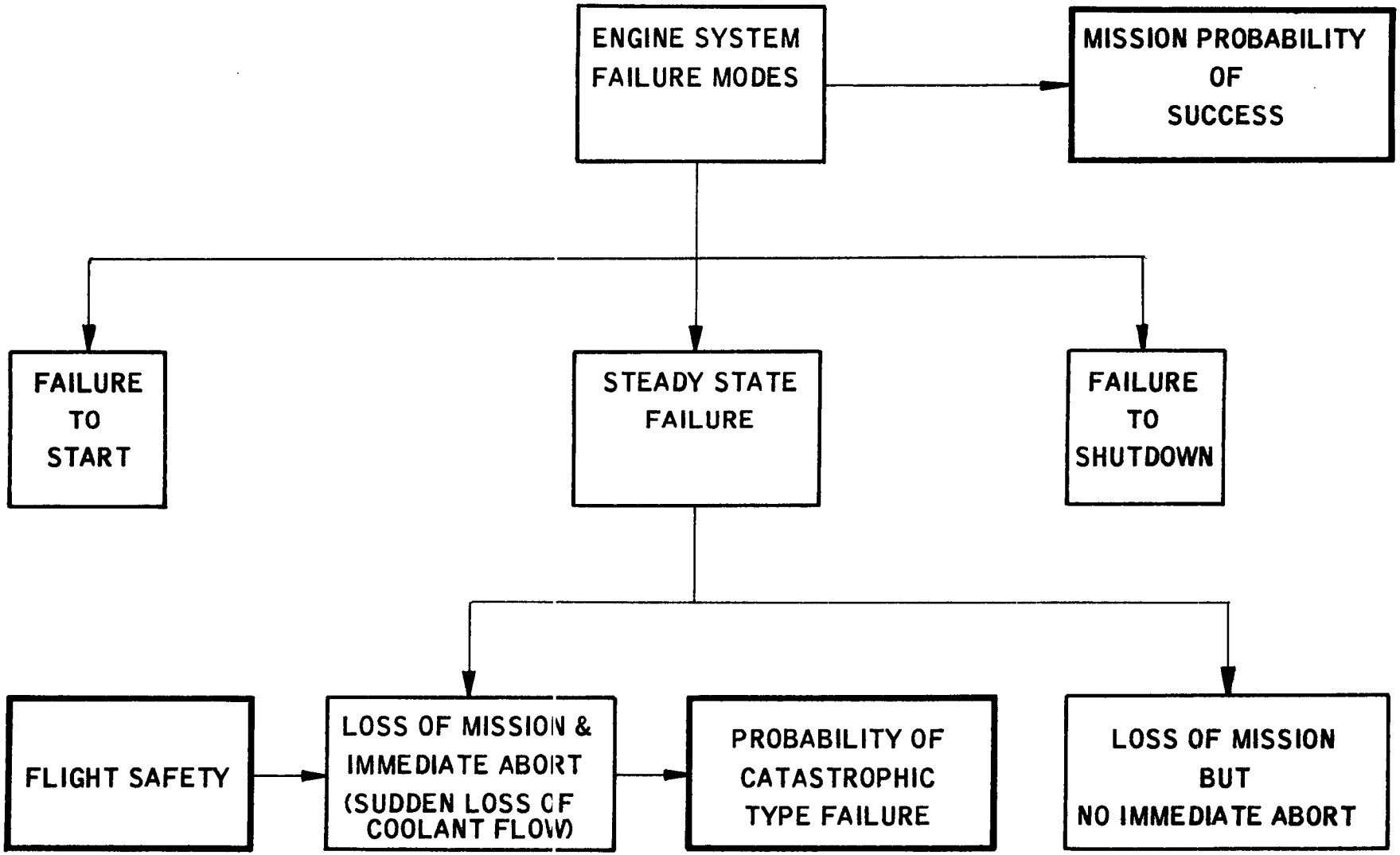


Figure 97 - Engine System Failure Modes

is a catastrophic-type failure and is hazardous to populated areas if it occurs during the 11-sec African continent overflight interval or during the second operating cycle of the engine.

The basic component failure-rate data used were derived from more than 2400 rocket engine test-stand firings during the Atlas, Thor, Jupiter, and H-1 engine development programs. Titan static and flight-test data and NERVA component test data were also considered in establishing the basic component failure rates. Figure 98 shows how the reliability data were apportioned according to the engine operating phase.

To assess the probability of a sudden loss-of-coolant accident during steady-state operation, it was necessary to determine which components are critical to this type of accident, their mode of failure, and the probability of a failure of this type, as shown in Figure 99. By using a fail-safe approach for valves and regulators, the probability of a loss-of-coolant during engine steady-state operation is directly proportional to the estimated failure rate of the TPA, 14 in 10,000.

For estimating the probability of a loss-of-coolant accident during the 11-sec African overflight, the total failure probability of 14 in 10,000 was distributed linearly over the 600 sec of steady-state operation (Figure 100). The probability of failure during this interval is estimated to be 2.56 in 100,000 flights. This estimate is based on the fail-safe concept for valves and regulators. If the concept is not applicable, the failure probability estimate is increased to 6.75 in 100,000 attempts.

In Figure 101, the estimated engine system failure-probability distribution is shown as a function of engine operating phase for two cycles of operation. During the first cycle, the non-nuclear components accounted for 62% of the total engine failure probability. In the second operating cycle, the nuclear subsystem accounted for 56% of the total engine-system probability.

COMPONENT	FAILURE MODE	OPERATING PHASE		
		START	RUN	SHUTDOWN
VALVES	FAIL OPEN	0.9996	0.9996	0.9996
1. PNEUMATICALLY OR HYDRAULICALLY ACTUATED	FAIL CLOSED	0.9996	0.9996	0.9996
2. SOLENOID ACTUATED	FAIL OPEN	0.9999	0.9999	0.9999
	FAIL CLOSED	0.9999	0.9999	0.9999
3. SPRING-LOADED VENT; RELIEF	FAIL OPEN	1.0000	0.9998	1.0000
	FAILED CLOSED	1.0000	0.9998	1.0000
4. CHECK	FAIL OPEN	0.9999	1.0000	0.9999
		0.9999	1.0000	0.9999
5. DISCONNECTS	FAIL OPEN	1.0000	0.9999	1.0000
a. FILL VALVE STANDARD b. QUICK	FAIL OPEN	0.9999	0.9999	1.0000
PRESSURE REGULATORS	FAIL OPEN	1.0000	0.9996	1.0000
	FAIL CLOSED	1.0000	0.9996	1.0000
TPA ASSEMBLY	FAILS	0.9990	0.9985	1.0000
LINES/BELLOWS	RUPTURE OR LEAK EXCESSIVELY	1.0000	0.9990	1.0000
NOZZLE/PRESSURE VESSEL	RUPTURE OR LEAK EXCESSIVELY	1.0000	1.0000	1.0000
EPIC	FAILS	0.9992	0.9994	0.9996

Figure 98 - Reliability Data Apportioned According to Engine Operating Phase

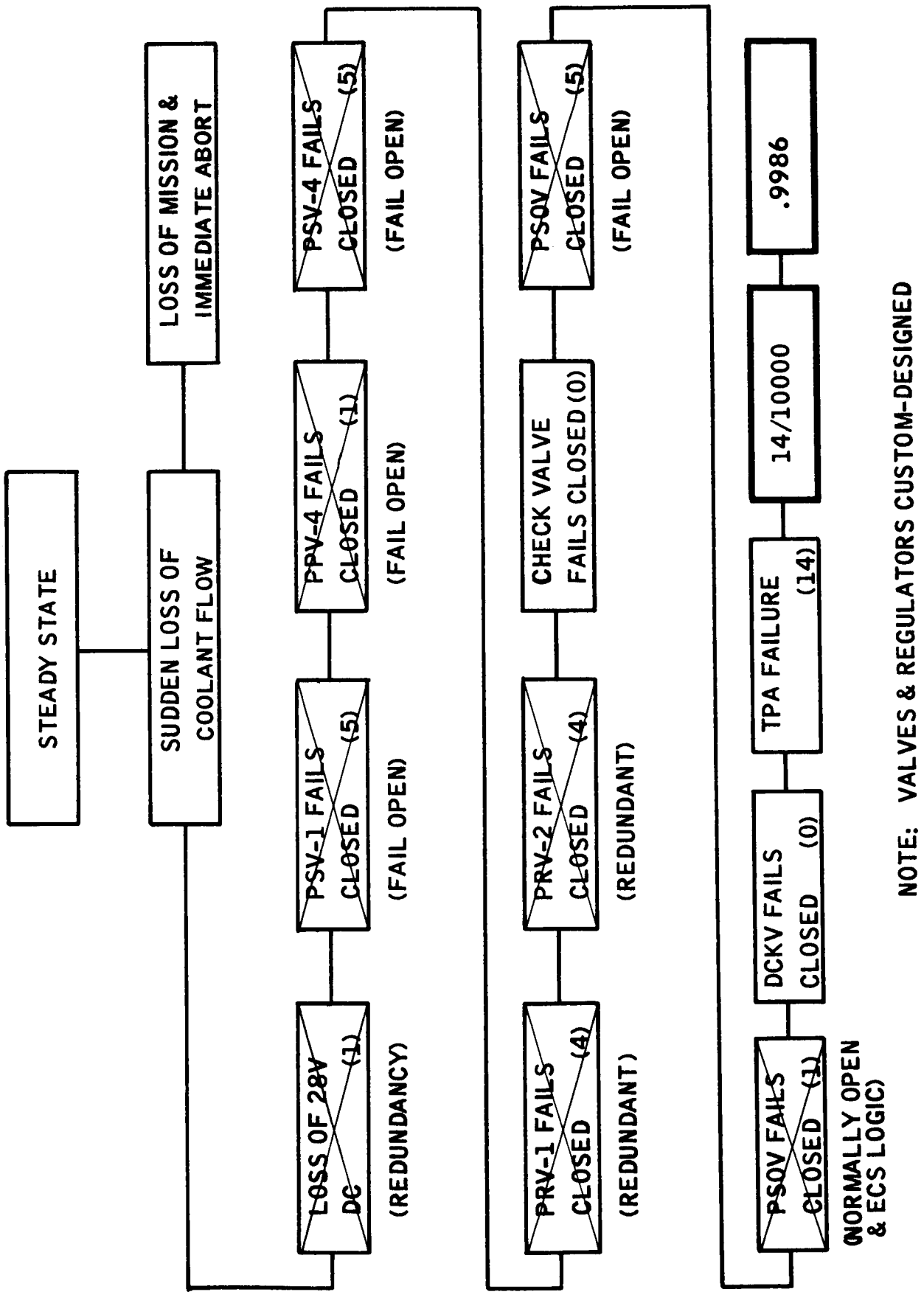


Figure 99 - Flight Safety Failure Mode Analysis

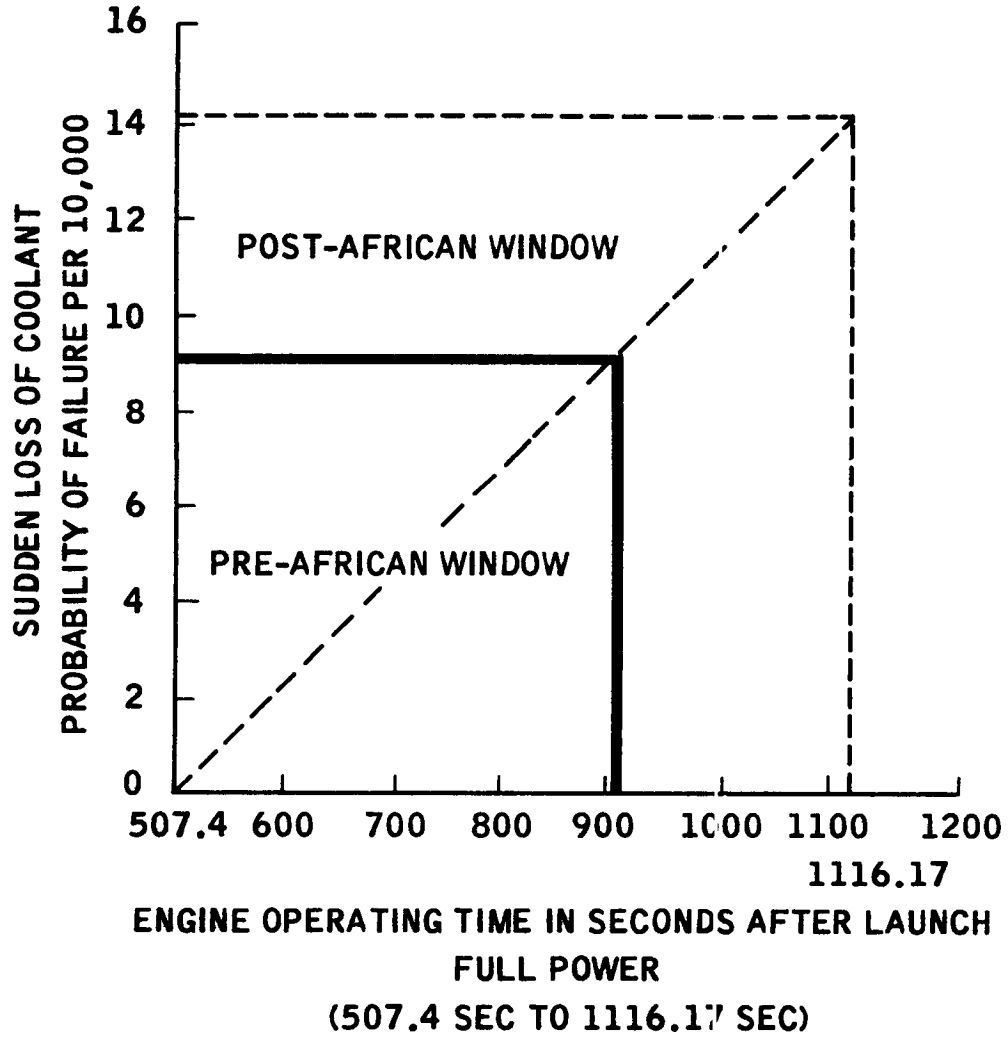


Figure 100 - Flight Safety Area of Interest (African Window)

ESTIMATE OF PROBABILITY OF SUDDEN LOSS OF COOLANT FLOW:

1. ASSUME 14 FAILURES ARE DISTRIBUTED EQUALLY OVER 600 SEC OF ENGINE STEADY STATE OPERATING TIME
2. $\frac{\text{FAILURES}}{10{,}000}$ PER SEC = 14/600

   $\frac{.0235}{10{,}000}\ \frac{\text{FAILURES/SECOND}}{}$
3. AFRICAN WINDOW PORTION OF FLIGHT EQUALS 11 SECONDS
4. PROBABILITY OF SUDDEN LOSS OF COOLANT FLOW DURING AFRICAN WINDOW PORTION OF FLIGHT EQUALS .0235 x 11 = 0.256 PER 10,000 OR 2.56 PER 100,000/11 SEC

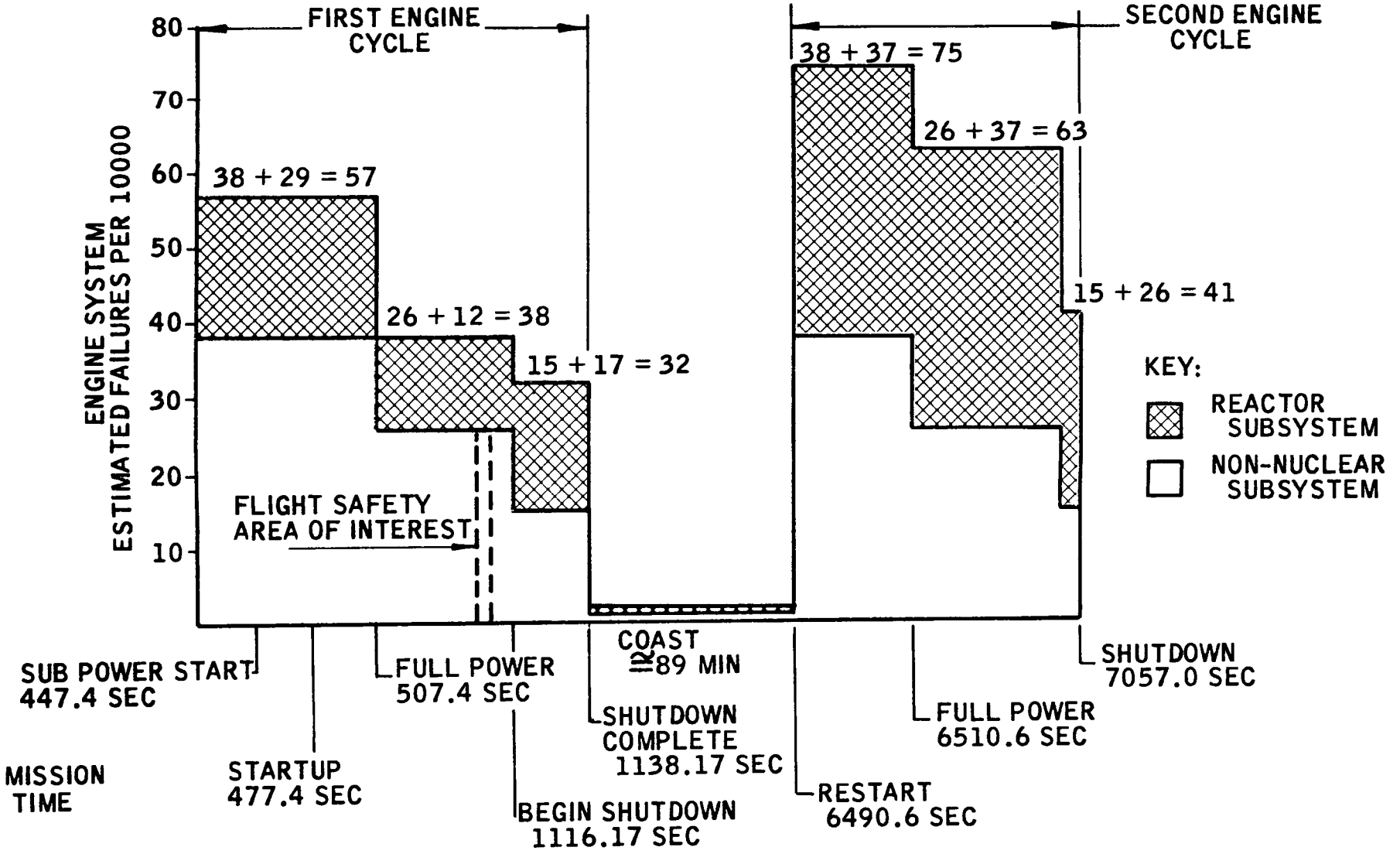


Figure 101 - Engine System Mission Reliability Profile

e. Emergency Cooling Requirements

With insufficient cooling, the nuclear subsystem will be subject to an immediate rapid increase in temperature, finally resulting in complete disassembly. In this case, initiation of the ATS cannot be delayed, which in some instances may significantly increase the ΔV requirements. To minimize these requirements, emergency cooling could be used to keep the nuclear subsystem intact until the ATS is activated, which could be delayed for as long as 3600 sec.

The emergency cooling requirements were established by WANL based on the nuclear subsystem normal cooldown-temperature limitations. Table 17 summarizes the requirements for 3600-sec cooling following a loss-of-coolant accident after 500 sec of nuclear operation. The coolant flow rate up to 130 sec after reactor scram is shown in Figure 102.

f. Emergency Auxiliary Cooling System

Within the basic NERVA design there are numerous alternatives for providing emergency auxiliary cooling to the nuclear subsystem. Since it was assumed that the flow system and module propellant tank remained intact following the reference accident, the normal flow path was selected as the emergency auxiliary cooling circuit. Logically, it would be expedient to use the on-board propellant for the duration of the cooldown operation; however, tank pressure is inadequate to cool the nuclear subsystem during the initial 80 sec of emergency cooling.

To meet the emergency auxiliary requirements, a high-pressure tank system was selected as the source of coolant during the initial 80 sec. Fluid from the high-pressure tank would enter the pump discharge line and would cool the nozzle, reflector, structural support, and core as in the normal flow sequence. Beyond 80 sec, the emergency cooling operation

TABLE 17

EMERGENCY AUXILIARY COOLING REQUIREMENTS

	High Pressure	Propellant Tank
Initial Cooldown	3050	940
Pulse Cooling		4440

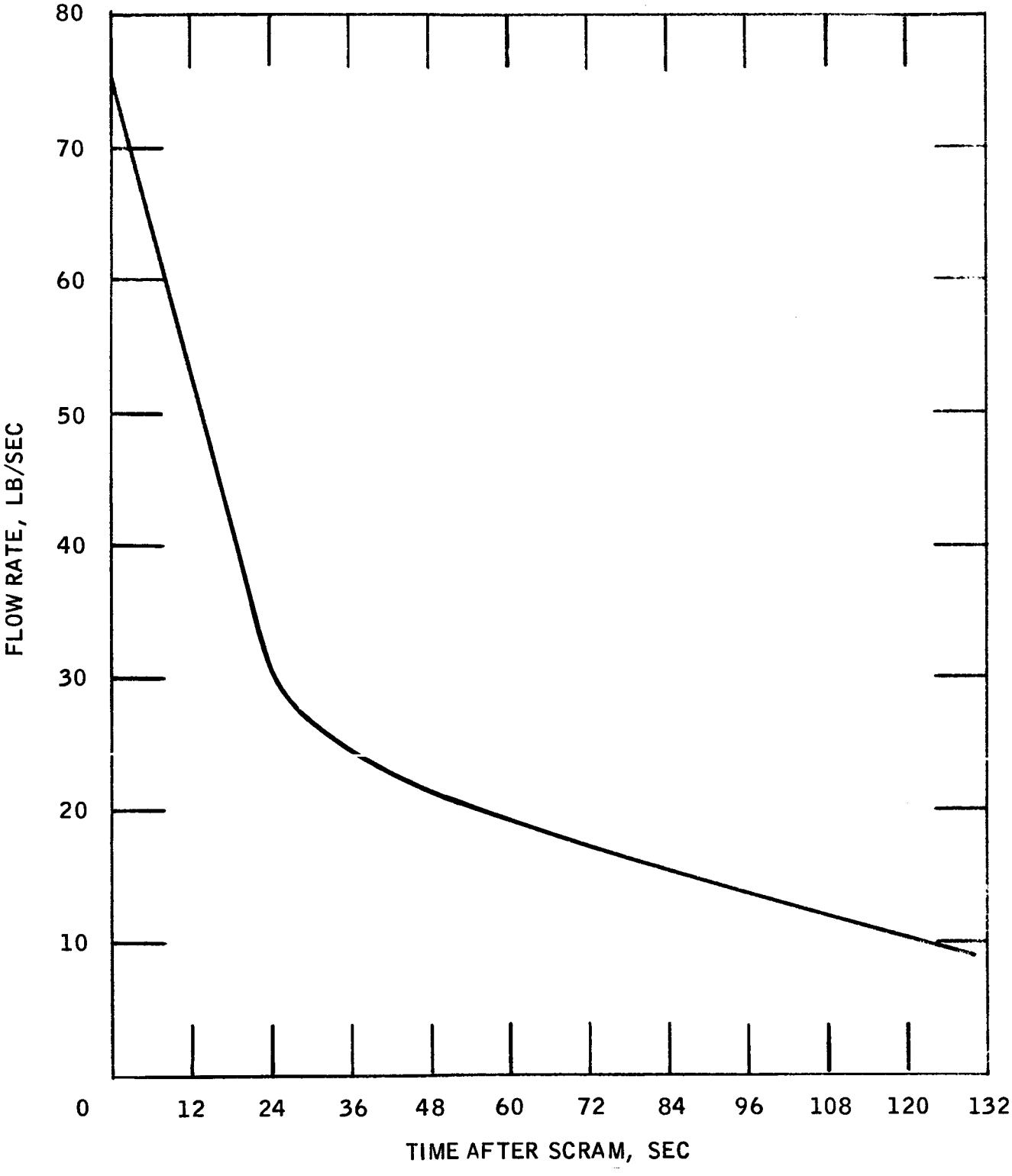


Figure 102 - Short-Term Emergency Auxiliary Cooling Requirements

would be transferred to the module propellant tank where fluid is supplied by tank pressure.

The system cooling requirements were matched to the flow ramp out of a blowdown system assuming various values of tank pressure and ullage. A selection was made, based on tank weight, to use a storage pressure of 350 psia and an ullage of 0.3. Figures 103, 104, and 105 show the system response up to 80 sec during emergency auxiliary cooling.

Figure 106 indicates that the system response is within acceptable limits during the time from 80 to 120 sec, where tank pressure is used to supply the coolant. At approximately 110 sec, pulse cooling can be initiated and continued for the duration of the cool-down cycle.

g. EACS Design Concepts

One version of the emergency auxiliary cooling system (EACS), shown in Figure 107, makes use of a single liquid hydrogen sphere located internally in the module propellant tank. Pressurization is accomplished by an ullage system comprised of a shutoff valve, check valve, and gaseous hydrogen storage sphere.

The liquid storage tank is sized for 3100 lb of liquid hydrogen stored at a pressure of 350 psia and a temperature of 41°R. The ullage sphere is sized for 30% of the liquid storage volume and weighs 734 lb. The total estimated weight of the system is 2900 lb, including 27 lb of ullage gas.

h. EACS Failure Mode Analysis

A failure mode analysis of the EACS was completed. The spectrum of failures was reviewed and an estimate of failure was prepared

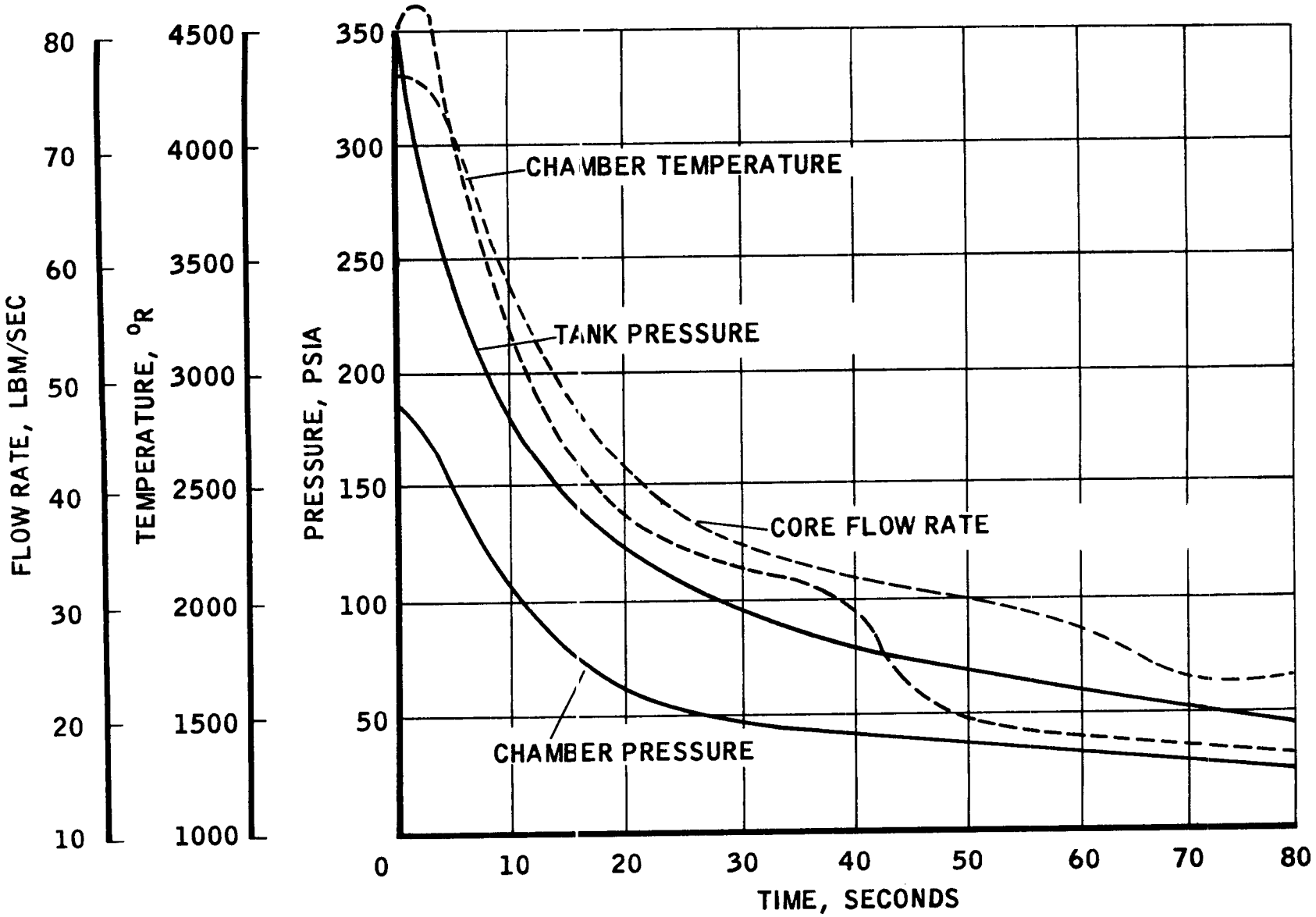


Figure 103 - NERVA Emergency Cooldown, Emergency Dewar Initial Pressure of 350 psi and Initial Ullage of 0.3

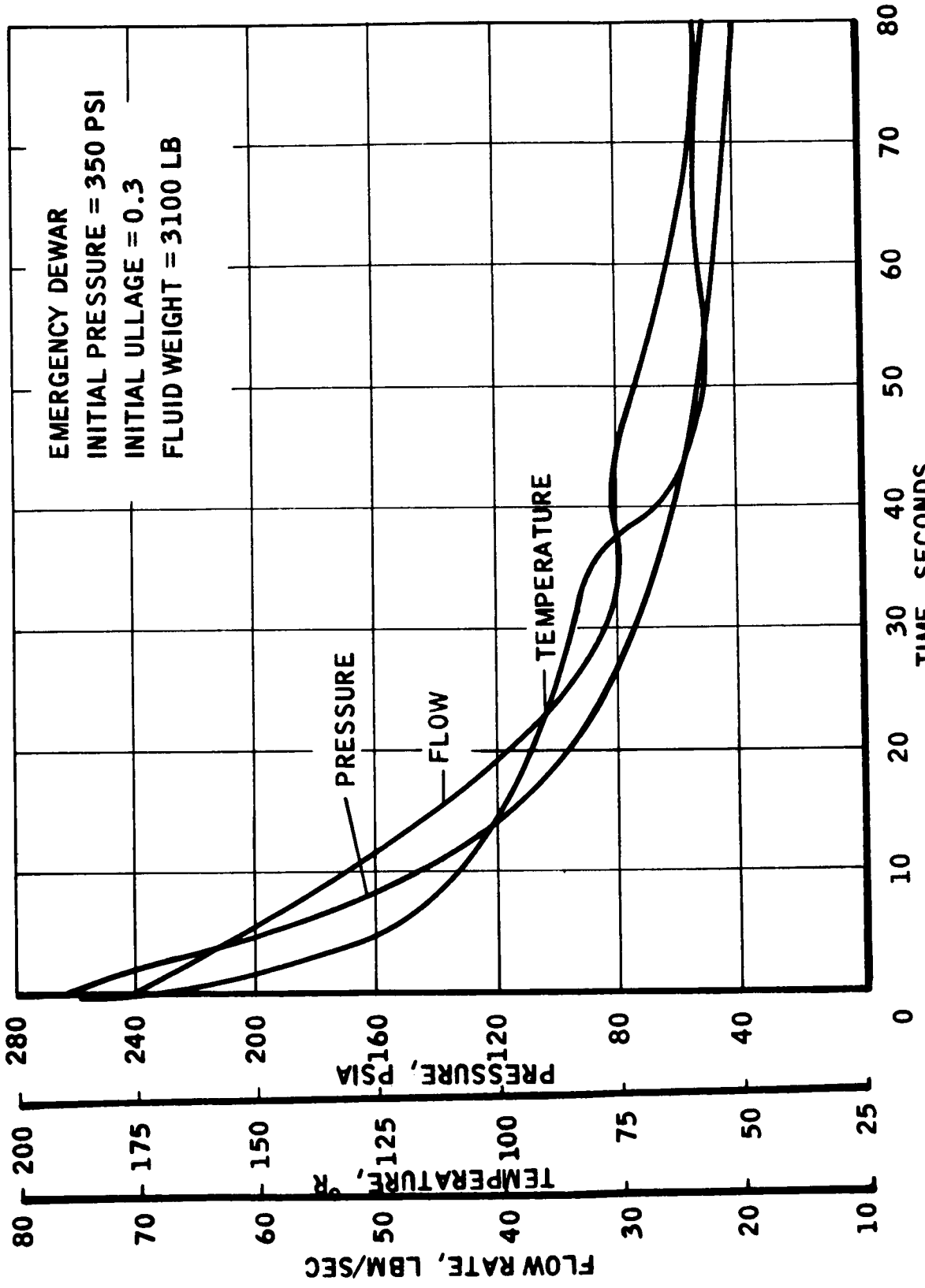


Figure 104 - NERVA Emergency Cooldown Reflector Inlet Conditions

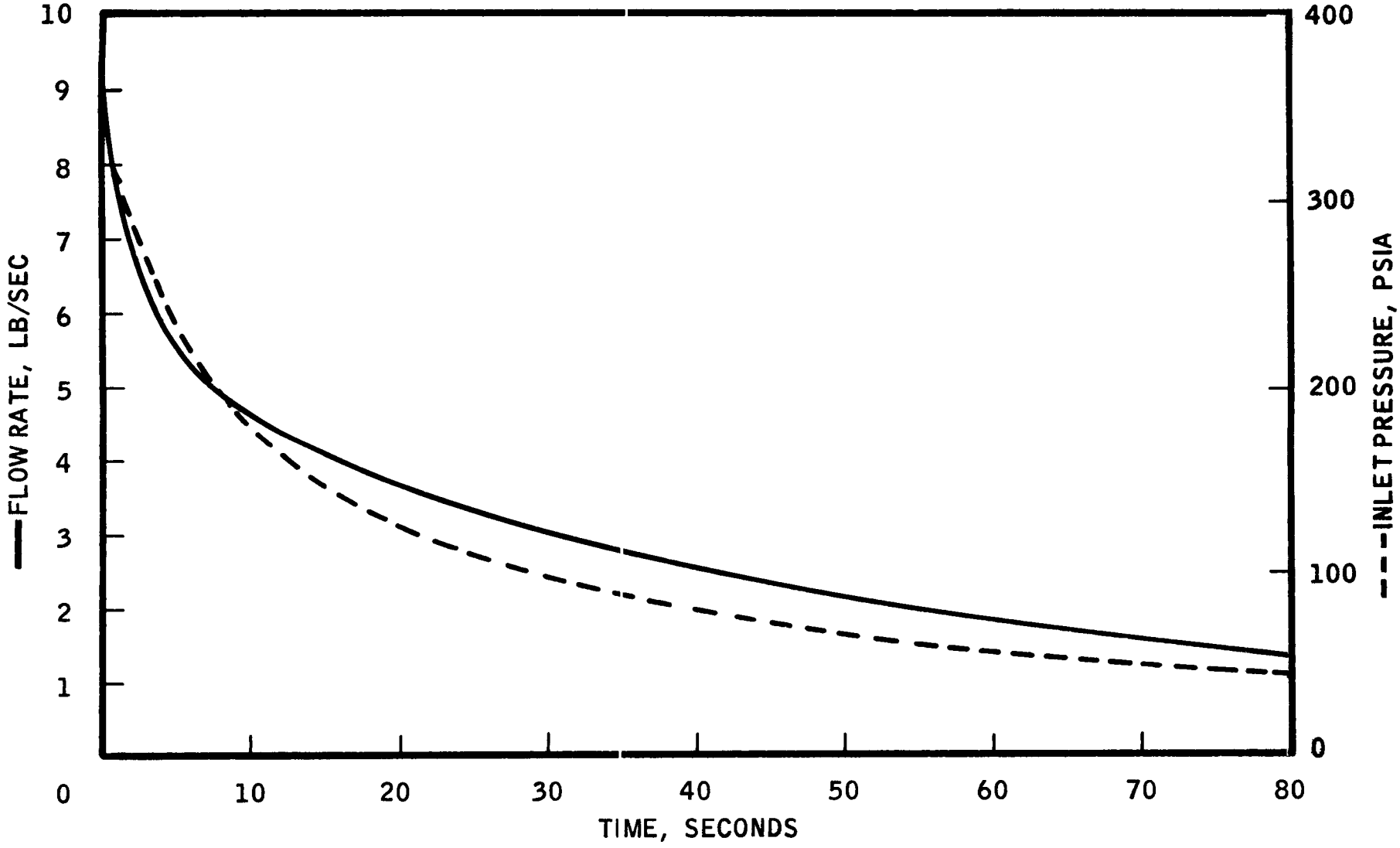


Figure 105 - Emergency Cooldown - Support Structure Inlet Conditions (Ullage = 0.3, Temperature = 38°R)

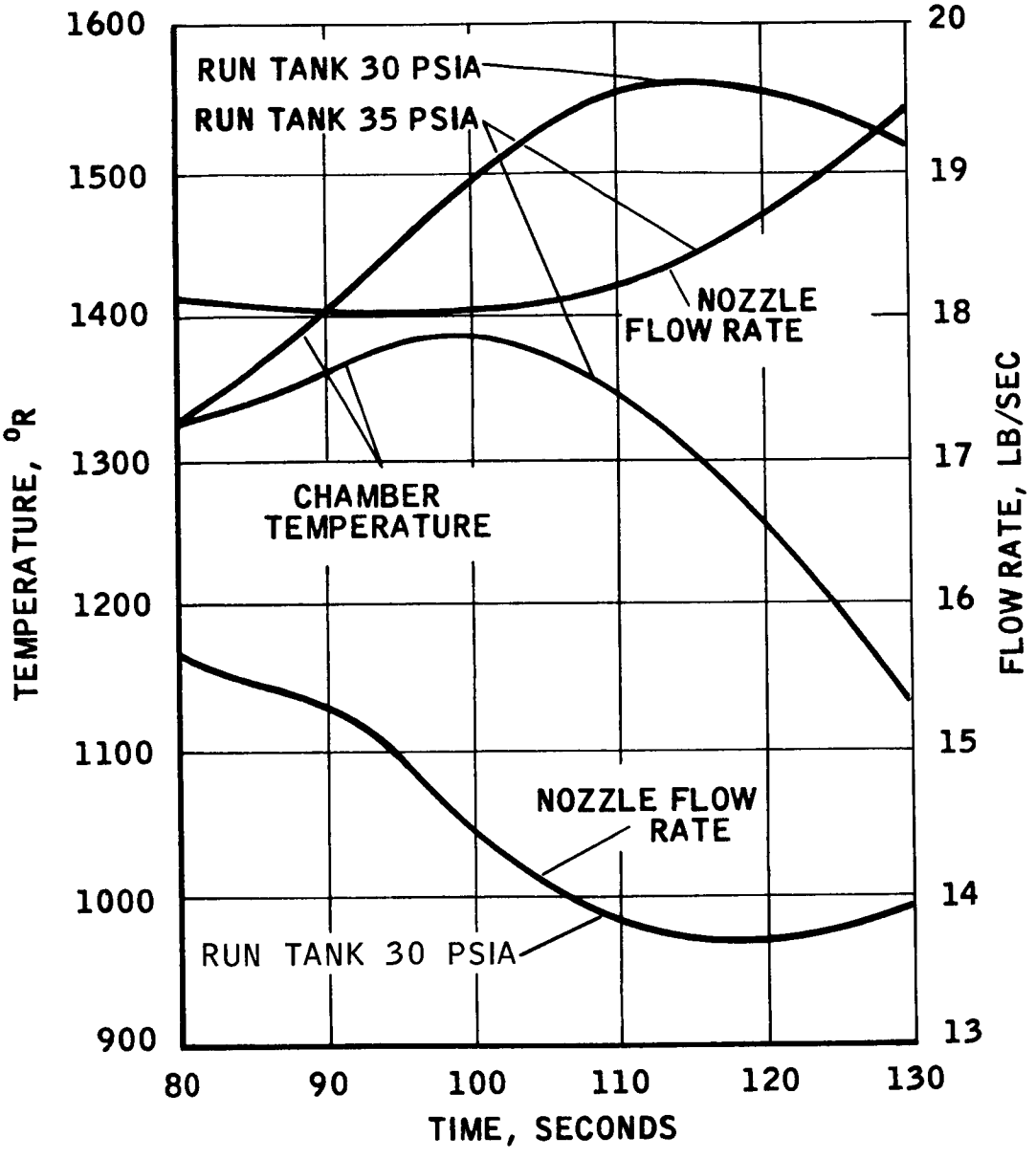


Figure 106 - 5000 Mw NERVA Emergency Cooldown System

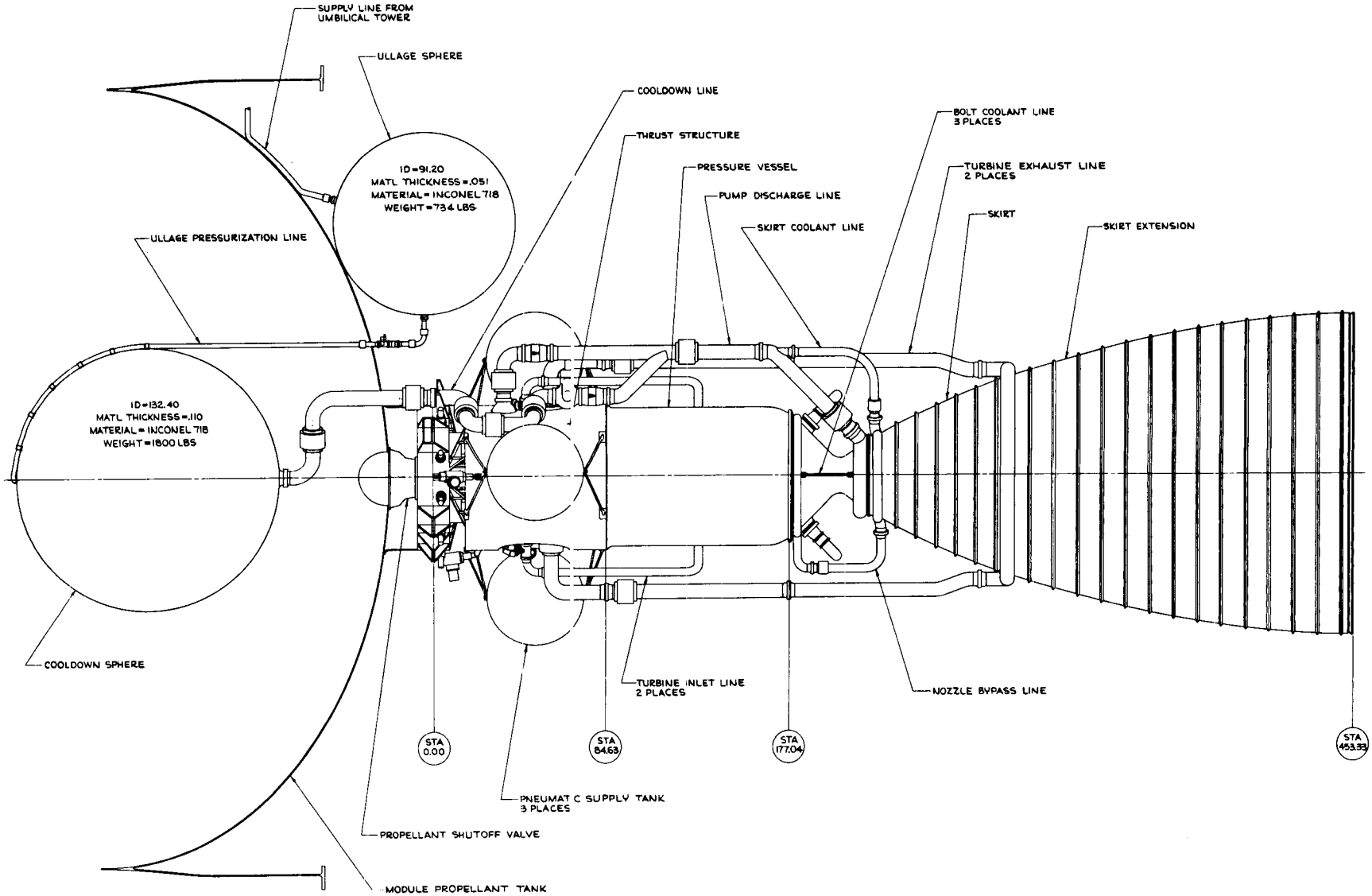


Figure 107 - NERVA Engine Emergency Cooldown Concept,
One Cooldown and Ullage Sphere

indicating a probability of 17 failures in 10,000 attempts. The probability of failure occurring in both the engine system and the EACS is estimated to be 36 in 10^7.

i. EACS Performance

During emergency cooldown, engine thrust and specific impulse are developed as shown in Figure 108. This thrust produces a velocity increment of 255 ft/sec during the initial 80 sec of cool-down.

j. Anti-Criticality Poison System (ACPS)

A poison wire system has been proposed by WANL to meet the need to protect the reactor from going critical from the time of assembly to its eventual use in outer space. The system consists of a large number of flexible wires that are withdrawn from the reactor through the nozzle throat.

Operation of the ACPS relative to time required to complete the withdrawal sequence must be compatible with the programming of flight-vehicle staging for either suborbital or orbital start. At the time of nuclear stage separation significant disturbances may occur due to thrust termination of the S-II stage. The effects of large pitch and yaw separation disturbance is further complicated by the long thrust-buildup period of the nuclear engine, which depends on the startup temperature ramp.

To compensate for the disturbances caused by separation, the thrust level must be high enough to constrain the vehicle so that certain altitude limits are not exceeded. Ideally, the thrust level should be at or near the design value at the time of separation. However, problems related to symmetrical venting of the interstage structure and to high-temperature exhaust gases impinging on the second stage structure could limit the initiation of nuclear thrust build-up after S-II separation. An additional consideration in selecting the nuclear engine start mode is the payload penalty due to gravity losses if nuclear startup is delayed too long after stage separation.

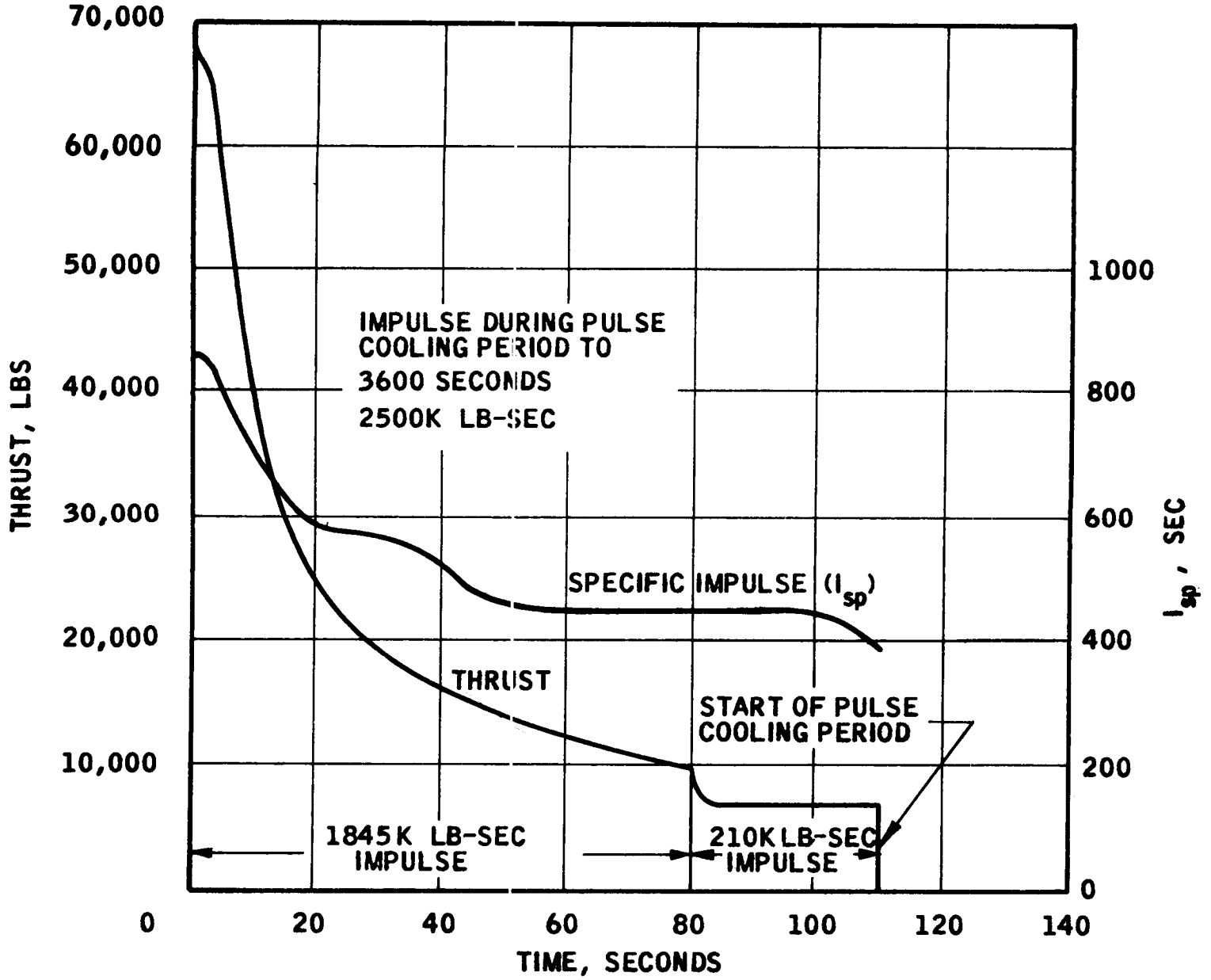


Figure 108 - NERVA Engine Emergency Cooldown

During the launch sequence for the dual-burn, lunar-transfer mission, the S-II stage burns for 348 sec. Before nuclear engine start, the poison wires must be removed from the reactor core so that the subpower buildup can begin. After poison wire removal and before propellant flow initiation, the retracted poison wires and the entire ACPS assembly must be ejected from the nozzle. If separation of the S-II has occurred before wire extraction, wire ejection can follow immediately. In the suborbit start case, however, it may be necessary to remove the wires during second-stage burn and to have subpower start completed before S-II separation occurs.

Figure 109 shows the effect of nuclear engine gimbal angle on the recovery of the vehicle after stage separation. Nuclear engine thrust is used to stop the initial rate and no consideration was given to trimming the gimbal angle to reorient the vehicle attitude. The maximum altitude rate imparted to the nuclear stage due to separation disturbances was assumed to be 0.25 deg/sec. The nuclear engine thrust buildup is based on a 100 deg/sec temperature ramp. Since the subpower start phase requires 60 sec, the poison wires would be removed during the final phase of the S-II burn. The maximum excursion time (time to recover vehicle stability) using a 1.5-degree gimbal angle is 24 sec, and the maximum vehicle deflection from the commanded flight path is about 3 degrees. Doubling the gimbal angle to 3 degrees reduces the recovery time to 19 sec, and the maximum deflection is 2.2 degrees.

To avoid the design and operational problems of preseparation startup, the effect of delaying propellant flow was investigated and the results are illustrated in Figure 110. Delay times of 5 and 10 sec are shown. As opening of the PSOV is delayed, vehicle excursion angles and recovery times are increased.

The effect of nuclear engine startup and coast time prior to startup on lunar transfer payload is shown in Figure 111. This curve shows that the penalty for each second of delay in initiating propellant flow would

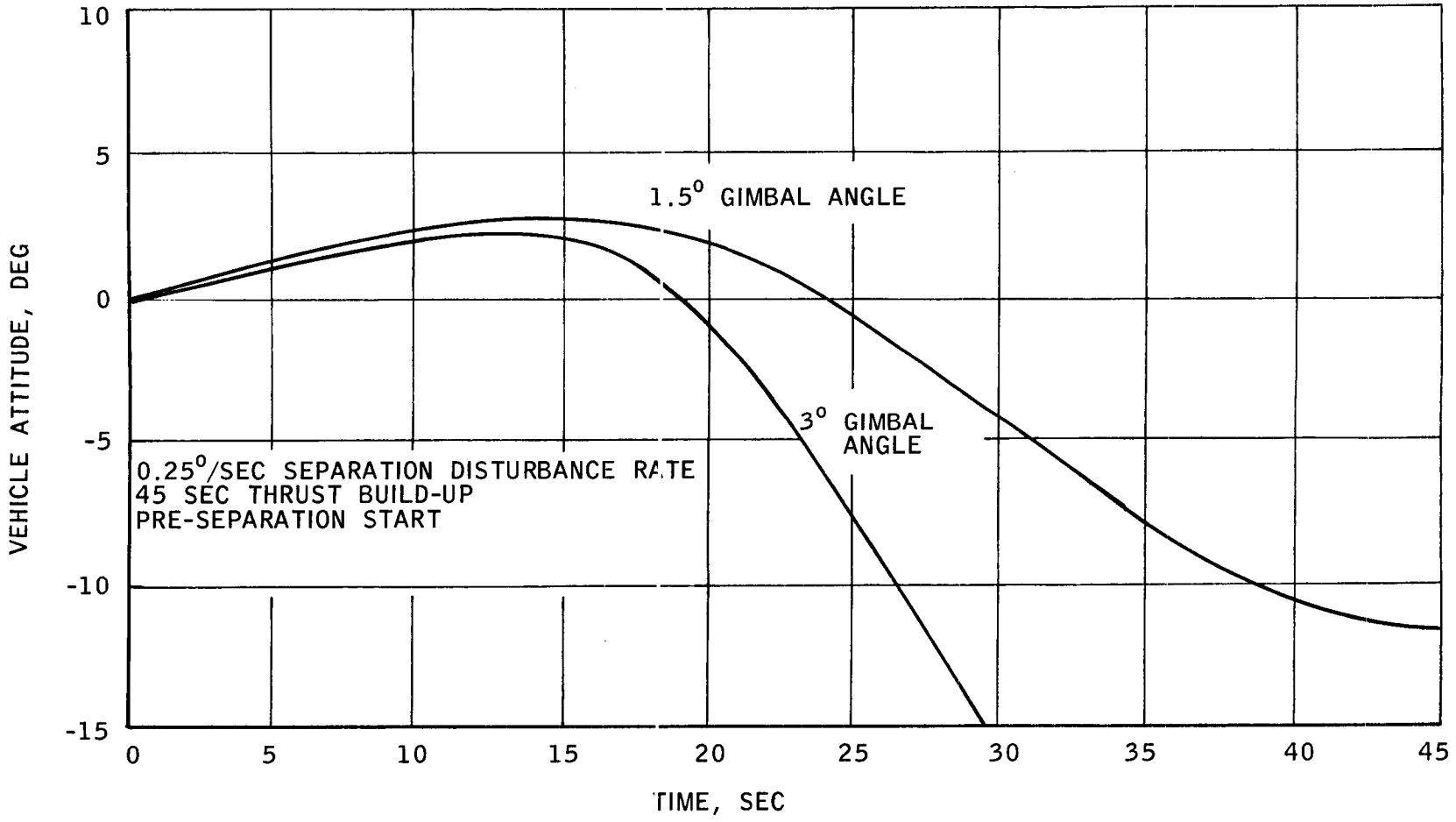


Figure 109 - Effect of Engine Gimbal Angle on Vehicle Separation Recovery

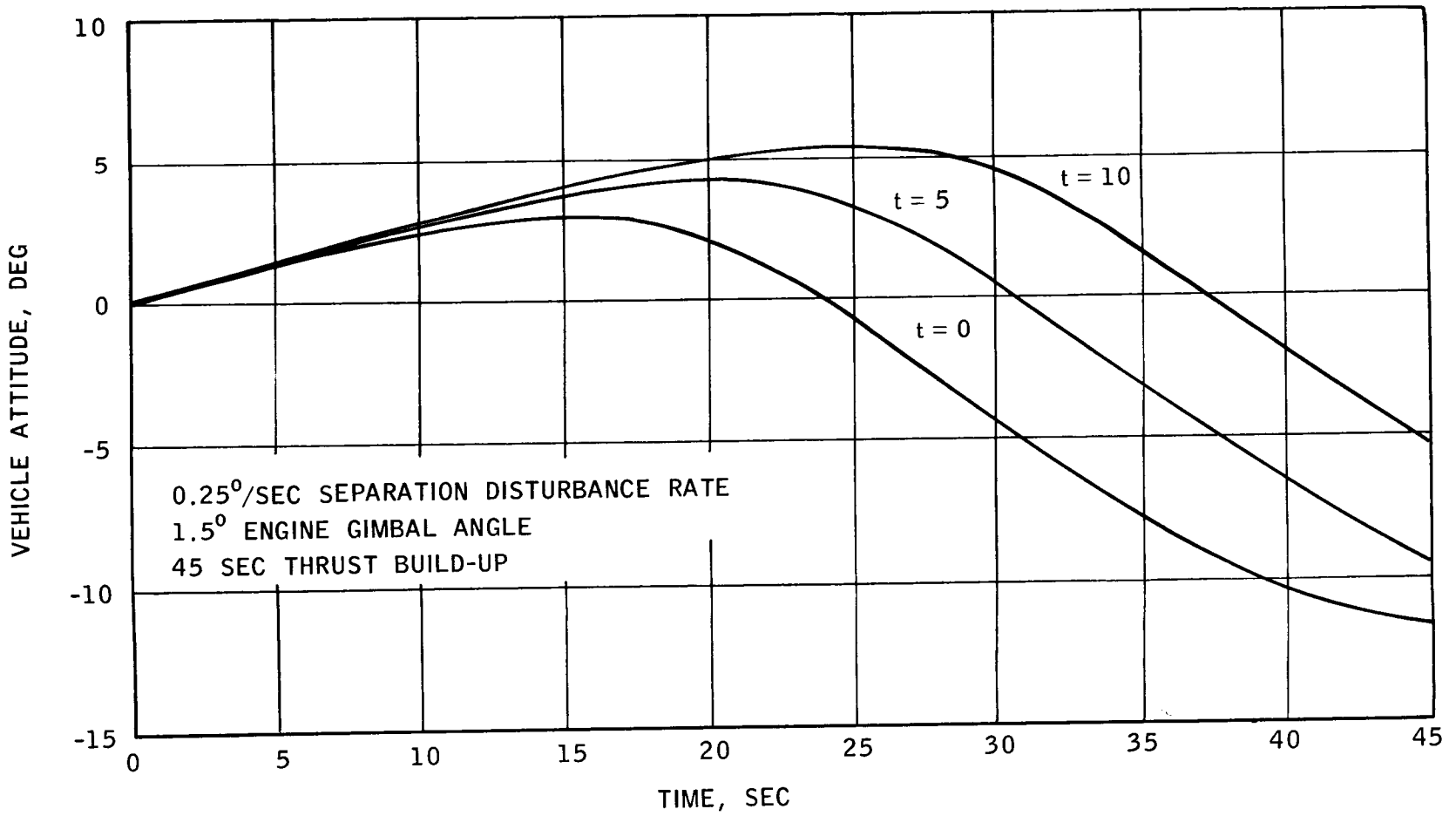


Figure 110 Effect of Delay in Opening PSOV on Vehicle Separation Recovery

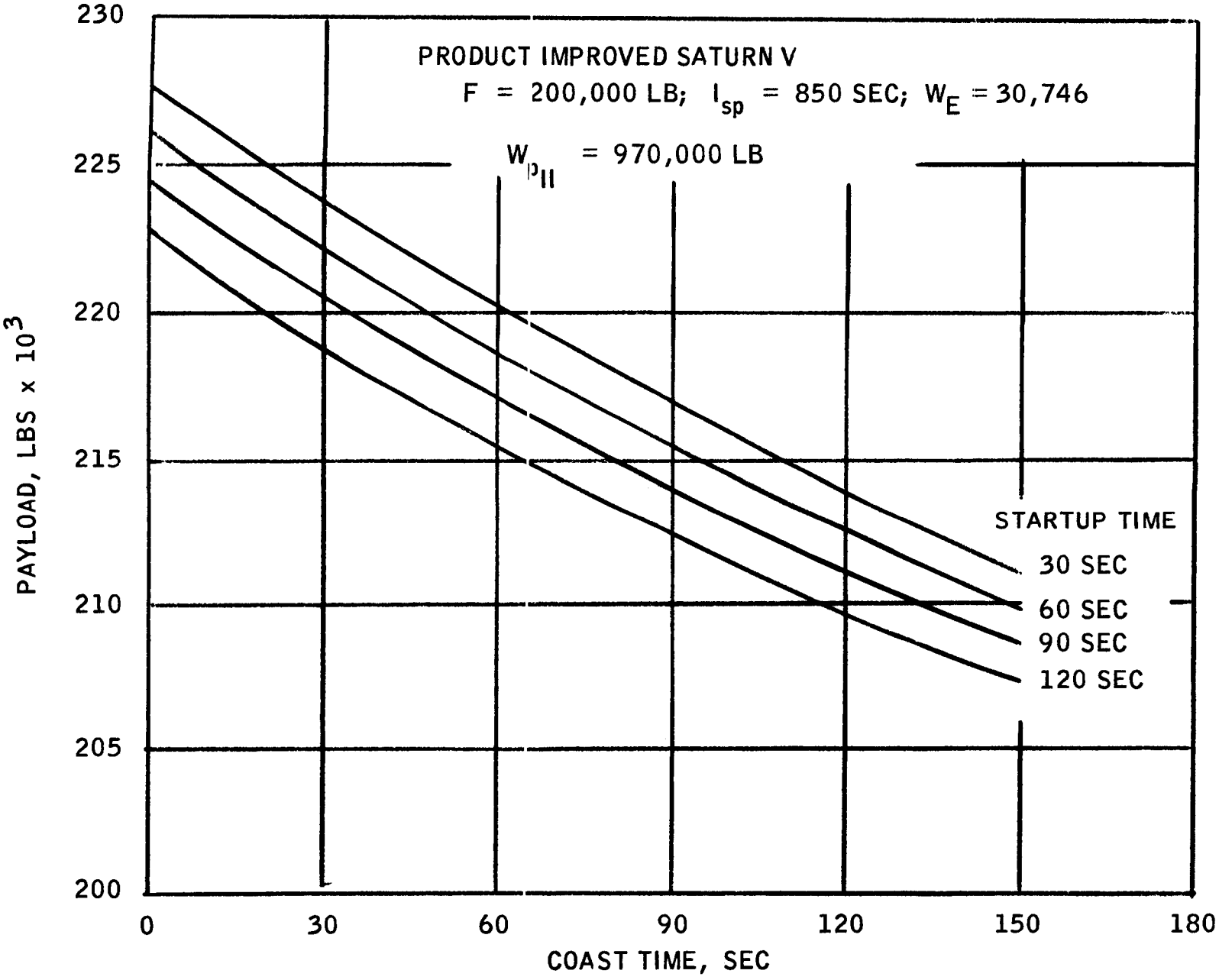


Figure 111 - Effect of Startup/Coast Time on Lunar Transfer Payload

be approximately 120 lb in payload. Also, the desirability of a rapid nuclear startup is indicated; each second of delay would be equivalent to about 50 lb of payload.

This study showed that poison wire withdrawal rates on the order of 0.15 ft/sec have no significant effect on nuclear engine operation because of the long start transient time. For the suborbit start mode, poison wire extraction will have to occur prior to S-II separation. Ejection of the ACPS will probably have to occur during or after separation to avoid design and operational problems associated with preseparation thrust buildup.

7. Materials Engineering and Development (2.8)

a. Materials Engineering (2.8.0)

(1) Drawing Review

During CY 67, 706 engineering drawings were reviewed; approximately 40% of these required alteration before approval by materials personnel. The changes involved incorporation of improved materials selection and specifications, methods and sequence of fabrication and heat treatment, cleaning and surface treatment, and location of test coupons. Each application required consideration of mechanical and physical properties from cryogenic to elevated temperatures, as well as consideration of exposure to nuclear radiation. Alterations involving weld design were the most frequent.

(2) Materials-Properties Data Book

Report 2275 was completely revised and was printed and distributed during October 1966. This document consisted of 604 pages of mechanical and physical properties of materials for application in NERVA engine design. During the balance of CY 67, three supplements to the data book were completed.

(3) Engineering Support

Materials-engineering support was provided for the design and fabrication of NERVA engine components, such as the turbopump, pressure vessel, nozzle, lines, valves, and test facilities. Significant accomplishments were (1) establishing the fracture toughness and fatigue of the turbopump impeller alloy, TI-5Al-2.5Sn(ELI), at -423°F; (2) material selection and establishing of mechanical properties of aluminum alloy 7039-T61 for the pressure vessel; (3) testing for high-temperature radiation embrittlement and (in conjunction with ORNL) for thermal fatigue of nozzle-material candidates Hastelloy X, Inconel 625, and AISI 347; (4) development of electrolized chromium against gold as an outstanding solid-film lubricant combination for cryogenic service on valve seals; (5) weld repairs of five gaseous-hydrogen receivers at the Sacramento Plant test area. The foregoing items are covered in detail in the quarterly reports on NERVA materials developments, RN-S-0372, RN-S-0393, and RN-S-0407.

(4) Documentation

Papers were presented on the following topics:

(1) Cryogenic radiation damage in structural polymers, ANS

(2) High-temperature radiation embrittlement of Hastelloy X, Inconel 625, AISI 347; ANS

(3) Friction evaluation of materials for nuclear-rocket valve applications, ASME

b. Materials Development (2.8.1)

(1) Wear Testing of Bearing Retainer Materials

The cryogenic-materials wear tester was assembled and used to perform seven wear-test runs during CY 67. In the first two runs,

the apparatus was qualified and Armalon was tested in all six specimen positions. The remaining five runs were used to screen nine prospective materials that have significantly higher radiation resistance than Armalon. Wear rates for these materials are shown in Table 18. The test runs measured wear rates over a 30-min duration in LH_2 on six 0.375-in.-dia, 0.5-in.-long specimens at a 35-psi contact pressure (1600-psi initial Hertz stress) against an AISI 440C stainless-steel shaft rotating at a surface velocity of 8500 ft/min (10,800 rpm). Five of the materials were considered sufficiently promising to warrant further evaluation during CY 68. In order of performance and state of development, these materials are: (1) PI/glass cloth, (2) Carbitex 700, (3) PBI (or PI)/graphite cloth, (4) Boeing-108, (5) PBI/glass cloth.

Because of these favorable results, retainers were fabricated of PI/glass and PBI/glass for testing in 50-mm ball-type thrust bearings assembled in a NERVA technology-bearing tester. The PI/glass was undamaged after 135 min of a scheduled 180-min run. The PBI/glass ran for 30 min but was damaged by debris from an adjacent bearing. Both tests were terminated prematurely after adjacent shaft-support roller bearings malfunctioned. The satisfactory performance of the PI/glass and its excellent fabrication characteristics give it first priority as a prospective material for replacing Armalon. On the basis of irradiation tests performed to determine mechanical properties, the PI/glass is estimated to be capable of structural service at doses in excess of 1×10^{11} ergs/gm(C). The determination of wear resistance after irradiation requires further testing.

(2) Space Environment

The effects of space environment on operation of the NERVA engine system were investigated during CY 67. An SNPO-C space committee including design and material personnel from AGC, WANL, TRW, and ORNL was formed to conduct the investigation. Scientific and engineering

TABLE 18

AVERAGE WEAR-RATE DATA FOR PROSPECTIVE RETAINER MATERIALS, TESTED IN LH_2 AT 8500 FT/MIN FOR 30 MIN

Material*	Quantity Tested	Weight Loss, gm	Wear Rate, cc/min x 10^8	Remarks
Armalon (std)	14	0.0018	1.0	Wear-rate goal
Boeing-108	3	0.0053	1.2	Rated priority of 4 because of processing and fabrication
Carbitex 700	3	0.0017	1.5	Rated priority of 2
PI/glass cloth	2	0.0038	3.1	Retainers tested rated priority of 1
PBI/graphite cloth	3	0.0091	8.8	Rated priority of 3
PBI/glass cloth	1	0.0227	18.8	Rated priority of 5
SP/bronze powder	1	0.0359	12.6	Bronze melted, forming excessive debris
SP-3 (MoS_2)	1	0.0519	38.2	Overheated, causing plastic flow
PBI/glass cloth/MoS_2	1	0.0376	32.2	No advantage over PBI/glass cloth
Boeing 108-46-45	3	0.0067	1.6	Erratic performance due to prior processing control
	1	0.7029	169.1	

*PI and SP are polyimides;
PBI is polybenzimidazole;
Armalon is DuPont tradename for Teflon/glass-cloth laminate;
Boeing compounds are proprietary powder-metallurgy products;
Carbitex 700 is a graphite/graphite-cloth material.

literature was surveyed to establish a background for the evaluation. This survey was supplemented by contact with several of the principal investigators. Adhesion of dynamic metal-component surfaces was determined to be the most significant problem that could occur during space exposure. Adhesion could cause malfunction of sliding-surface components in space. The uncertainty of the engine pressure-temperature environment and the uncertainty of the effectiveness of hydrogen in preventing adhesion of the engineering materials used for NERVA were established as areas of concern.

A test program was established at Syracuse University to resolve the pertinent NERVA environment factors that influence adhesion. Both reactor and nonnuclear component materials will be examined, with the major test objective being to determine the effectiveness of hydrogen and other contaminant gases in preventing adhesion.

Other problem areas identified included sliding effects that could induce adhesion, effects of contaminant gas on solid-film lubricants, and sublimation and decomposition of materials. Sublimation and decomposition of materials can be avoided by judicious selection of materials. The determination of sliding effect and the effects of contaminant gas on lubricants would require further experimental investigation. From the information gathered during the investigation, guidelines were formulated (see table below) to control the design of components for space exposure.

GUIDELINES FOR PREVENTING ADHESION IN VACUUM

Significance Priority	Material Design Guideline
1	Contaminate or lubricate sliding surface with compound stable at predicted vacuum-duration-radiation dose.
2	Seal components from vacuum (such as throat plug and external bellows) or maintain contaminating atmosphere.
3	Cool sliding surfaces below surface outgassing temperature and dissociation temperature of lubricant.

Significance Priority	Material Design Guideline
4	Maintain contact pressure below yield strength or use maximum-hardness or maximum-yield-strength alloys.
5	Minimize sliding, shear, and vibration.

(3) Radiation Damage of Materials

Polyimide SP-3, for antifriction applications, exhibited no measurable damage in LH_2 at 3×10^{10} ergs/gm(C), the highest exposure dose used. However, because of strength loss, Teflon and Armalon were found to be limited to a maximum service dose at -423°F of 1×10^{9} ergs/gm(C) for static applications[1]. For dynamic design applications, this radiation limit of the material has been reduced by approximately one order of magnitude.

Ten alloys were tested in liquid nitrogen, and radiation-induced changes in mechanical properties were determined after neutron fluences of up to 1×10^{18} nvt (E > 1.0 Mev). These tests included notched and unnotched tensile specimens of both parent metal and weldments[2]. Seven of these alloys were tested in liquid hydrogen to investigate the possibility of extrapolating to determine radiation damage at liquid-hydrogen temperature (-423°F) from information developed at liquid-nitrogen temperature (-320°F). This investigation showed that approximately the same magnitude of change occurred at each temperature in properties tested before and after irradiation. With the aid of these data, it is feasible, with similar alloys, to make qualitative estimates of properties to be expected after LH_2 irradiation on the basis of liquid-nitrogen test data.

(1) Dixon, C. E., and Funk, C. W.; Cryogenic Radiation Damage in Structural Polymers, ANS, 1966.
(2) NRO Report RN-S-0407, Materials Developments, Third Quarter, CY 1967.

The elevated-temperature embrittlement of high-temperature alloys containing as low as 0.001% boron when they are exposed to thermal neutrons was investigated. These alloys are typical of prospective materials for lines, turbine, and nozzle. Embrittlement was found to result from accumulation of helium at grain boundaries during service above 1000°F after transmutation of boron to lithium by the reaction B^{10} $(n,\alpha)Li^{7}$. A literature survey was conducted, and results of the review were published in Report RN-S-0365, Review of High Temperature Radiation Embrittlement of Engineering Alloys. GTR-18 tests showed that the annealed alloys Hastelloy X, Inconel 625 A, and AISI 347 (prospective nozzle materials) retained sufficient ductility at 780 to 1540°F after exposure to a neutron fluence of 1×10^{19} nvt (thermal)[1]. However, data on age-hardening alloys such as Inconel 718 indicate that tensile elongation can be reduced to less than 1% under similar radiation and temperature conditions. Because of numerous applications for age-hardened nickel-base alloys, specimens of Waspaloy (47 ppm boron), Rene 41 (50 ppm boron), and Inconel 718 (0.6 ppm, 38 ppm, and 46 ppm boron) have been prepared for irradiation testing in GTR-21, scheduled for October 1967.

8. Assistance to LASL (2.9)

Aerojet provided technical assistance to the Los Alamos Scientific Laboratory on an as-required basis. Liaison was maintained to provide interchange of technical and schedule information and planning in areas of mutual interest between the NERVA, Phoebus, and Pewee programs.

1 Dixon, C. E.; Funk, C. W.; Welef, W.; High Temperature Radiation Embrittlement of Hastelloy X, Inconel 625, and AISI 347, ANS, 1967

C. NRDS SUPPORT (TASK 3)

1. NRDS and Advanced-Facilities Support (3.0)

a. Engineering Support for Existing NRDS Facilities (3.0.1)

(1) Design Modifications

Coordination of XE-engine test and facilities requirements with NRDS was performed on a continuous basis. The development of requirement documents and design criteria, design and procurement packages for facility changes were initiated or completed and transmitted to NTO for implementation at NRDS as follows:

(a) Engine External-Shield Fill-and-Drain System

The design and procurement package for this system (prepared in CY 66) was completely revised to incorporate new engine requirements and additional safety features. The design and procurement package for this system received SNPO-C approval 25 April 1967 at a meeting held at Sacramento. The fabrication contract for the mix tank and associated equipment was awarded to Capital Westward Inc. on 12 May 1967. Fabrication approval was received from SNPO-C on 29 May 1967. Fabrication and acceptance testing were completed on schedule and the unit was shipped to NRDS. The unit was received at NRDS on 26 July 1967.

The piping and other components required to complete this system were ordered through the Aerojet-Sacramento procurement channels. All components were delivered on a schedule compatible with the ETS-1 activation schedule.

(b) Control Drum Actuator Vent System

To ensure that the control drum actuators are not subjected to back pressure at the exhaust ports in excess of 50 psi or fluctuation in the allowable back pressure, it was necessary to revise the vent system for these actuators. This revision consists of providing a new 4-in. vent from above the top shield running up the stand and dumping into the plume of the V5001 flare stack.

The design and procurement package for this addition received SNPO-C approval 25 April 1967 at a meeting in Sacramento. The procurement and fabrication activity was assigned to Aerojet-AGN on 24 May 1967. Hardware was completed and ready for shipment to NRDS 29 June 1967.

(c) Alternate Cooldown Path

Studies and analyses conducted during CY 66 indicated the desirability of a system to provide a pulse cooling and an alternate cooldown path if the cooldown shutoff valve fails to open. Accordingly, a system design was developed and procurement of the required valves was initiated. Completion by the vendor of the valves required for this system was not on schedule, and three valves were rejected on 5 May 1967 for failure to meet the nondestructive test requirements. The new valves were shipped by the vendor on 26 July 1967. Another valve, on order from a different vendor, repeatedly failed to pass the leak and functional tests. Valve seat and actuator modifications were required to correct the problem. The valve was shipped by the vendor on 12 August 1967. Examination of the valve at NRDS revealed extrusion of the valve seat. Also, it was decided to modify the valve to provide double seals. Therefore, the valve was returned to the vendor for modification. During an ETS-1 status review meeting at NRDS with SNPO on 20 September 1967, it was concluded that the pulse-cooldown system was not mandatory at this time, and the valves will be stocked as spares.

(d) Cryogenic Trap - Control Drum Actuator Supply

Bench testing of the control drum actuator at WANL laboratories indicated that condensibles existing in pure hydrogen and helium, mainly CO_2 and N_2O, have an adverse effect on the control drum actuator during operation at cryogenic temperatures. On the basis of these bench tests, Revision 1 of E & FE-FR-237 Pneumatic Supply and Exhaust System for Control Drum Actuators for ETS-1 Application, Functional Requirements Document dated 27 April 1967 was developed. This revision established the requirement to cool the actuation gases to below 175°R with a LN_2 cryotrap so that the condensibles could be filtered out.

The system design requirements were established during a WANL/NTO/NRO meeting at Sacramento, and the bid was awarded to Aerojet/AGN 17 May 1967. Fabrication and acceptance testing were completed, and the unit shipped to NRDS on 5 September 1967. The unit was damaged due to excessive vibration during shipment. Damage consisted of minor weld failures of structural members, failure of chiller cooling piping on each side of the filter, and wear on the lower portion of the chiller cooling coil.

All damaged parts were replaced at NRDS. The unit was hydrostatic and leak tested, all piping welds were radiographed, and structural welds were dye-penetrant checked and cleaned. The unit satisfactorily passed all the tests. A packaging procedure was developed to prevent damage during future shipping. The unit was packaged and shipped to Lewis Research Laboratories on 22 September 1967 for use in conducting actuator tests.

(e) ETS-1 Thrust Ring

Examination of the ETS-1 thrust ring revealed weld defects that rendered the ring unsatisfactory for engine testing. Several methods for repairing or replacing the ring were investigated, and bolted and welded doubler plate designs were developed. The welded doubler plate design

was selected. The required plates and a weld fixture were provided by NRO and the repair work was completed by NTO.

As a parallel effort, additional thrust ring design studies resulted in a circular rather than octagonal thrust ring fabricated of a mild steel. Fabrication of this design was accomplished at Aerojet-Sacramento. After stress relieving and machining, the unit was delivered to NRDS on 27 June 1967. This ring was subsequently installed in ETS-1.

(f) Relief Valves

Analyses of critical fluid systems revealed that several relief valves in the ETS-1 fluid systems were inadequate to protect the systems and test article during malfunction conditions. As a result Engineering Change Requests were issued and procurement action was initiated to replace the inadequate valves or to provide for additional relieving capability.

(g) Heated-Helium Purge

The design requirements were transmitted to NTO establishing the revisions required in the ETS-1 facility to provide a capability for heated-helium purge to the engine and TPA through the ambient engine purge line. This revision was required to reduce the number of remote connectors at the engine interface.

(h) Engine Pneumatic-Supply Flow Meters

The functional requirements for flow meters in the pneumatic supplies to the engine valve actuators were transmitted to NTO for incorporation at ETS-1. These requirements were based on the need to detect any leakage that could occur within the engine module at the remote connectors.

(i) Pneumatic Supply

Studies were conducted of methods to provide a GN_2 purge capability for the engine before and after an engine firing to conserve helium. In addition, acceptance tests of the turbine block valve indicated that tests of this unit in the unloaded condition must be conducted with reduced actuation pressure to prevent damage to the butterfly and stem. A modification design package was developed to provide the necessary purge capability and to reduce the actuation pressure for prerun checkout of the turbine block valve. The package was submitted to NTO for implementation.

(j) NES Exhaust Scrubber

Techniques for reducing contamination of ETS-1 during engine testing and cooldown were investigated, and design criteria for an exhaust gas scrubber have been developed. The criteria establish the requirement to remove 90% of the particulate matter 10 microns or larger from the exhaust during inert pulse cooling of the engine. This system will not be used during power tests or H_2 cooling. Therefore, it must be removed and protected from thermal radiation during hydrogen flow.

The design of the scrubber system has been initiated and vendors are being contacted to obtain data for the preparation of detailed schedules and cost estimates and to determine vendor capabilities.

(k) H_2 Leakage

Reduction of H_2 leakage hazards above the ETS-1 top shield was investigated, and the necessary shrouding, flange joint seal, and vent system to enclose all potential H_2 leaks above the top shield (venting the enclosures) were designed. Materials are being procured for the modifications.

(l) Thrust Columns

Analyses indicated that the ETS-1 thrust columns and load cells are not rigid enough to meet engine vibration limits during testing. Accordingly, the load cells were removed and new thrust columns were designed and procured. These columns were installed as a part of the thrust ring activity.

(m) ETC Latches

Analyses indicated that over pressurization of the ETS-1 Engine Test Compartment (ETC) could occur during some malfunction conditions. Since the ETC was not designed for an over-pressure condition, reinforcement of the ETC was required. To expedite NES testing, the ETC was banded with preloaded cables to withstand a 2 psi over-pressure.

NES tests confirmed that over-pressures would result from some malfunction conditions. Therefore, a modification of the ETC latches was designed for a 2 psi over-pressure condition, and the required material was procured and shipped to NTO for fabrication and installation.

(n) ETC Purge

Analysis of the ETC purge system indicated that portions of the system would be over pressurized during planned purge and NES tests. A temporary modification design was completed and supplied to NTO.

The original purge system design was marginal under some system malfunction conditions. Therefore, a new design was developed and supplied to NTO for implementation.

(o) ETC Intermediate Shield

An analysis of the ETC pressures resulting from a major rupture of the main propellant line discussed below indicated that a differential pressure across the intermediate shield could be as high as 1.6 psi. Since the supports for this shield were not designed for a differential pressure condition, a new stress analysis of the shield support system was conducted. This analysis indicated that the support system was marginal for the 1.6 psi condition based on the calculated load distribution among the support members. A test is planned that will provide the actual load distribution, which will enable definition of any required modifications. To make a reinforcement design available if it is required, a design, based on the calculated load distribution, that will reinforce the supports to withstand a differential pressure of 2 psi has been initiated and will be released in October 1967.

(2) Evaluation and Analysis

(a) Engine Test Compartment Pressures

Analysis of the dynamic mass transfer into, within, and out of the engine test compartment during most of the expected period of operation of ETS-1 was conducted using the 1130 computer. This program was used to determine pressure difference across the intermediate shield and maximum pressure in the test compartment during various operating conditions and modes of failure. Results of this program have indicated that with a rupture of the liquid H_2 propellant line above the turbopump (worst condition) with the engine operating at full power, hydrogen spillage into the compartment would be 162 lb/sec for 5 sec. This will result in a maximum pressure differential across the intermediate shield of approximately 1.6 psia. The maximum pressure buildup in the compartment would be 12.4 psia.

The computer program was modified to enable a continuous system modeling of addition or discharge of any applicable gas (He, N_2 and H_2) into either section of the ETC. Subsequently, runs were made to determine the effect on differential pressure of the proposed 30 lb/sec He repressurization flow, which was found to be 0.6 to 0.8 psi.

The results obtained with the modified program compared favorably with similar steady-state calculations made by other NRO departments, with different techniques, relative to hydrogen system ruptures and helium flow within the upper portion of the ETC.

(b) ETC Repressurization

The ETC repressurization activities were related to the NES duct and steam generator systems and are reported under sub-subtask 3.1.0. Those sub-subtask 3.0.1 items reported under sub-subtask 3.1.0 include the following:

1 Steam accumulator system for ETS-1
2 ETC emergency helium system (PCV 449)
3 Design of ETS-1 duct drain modifications

(c) ETS-1 Modification Surveillance

NTO activities relative to ETS-1 modifications have been reviewed on a continuous basis and design assistance was provided. These activities included the following:

1 Pressurization and inerting system for ETS-1 duct vault.
2 Pressurization system for the ETS-1 pipe chase.
3 Protection for ETS-1 stand components from exhaust plume heat.

4 Redundant flare system for the ETS-1 NES.

5 Process water system repair.

6 Removal of weather doors.

(d) Plume Heating

An analysis of the radiation-heating effect on the ETS-1 test stand from the exhaust plume of the NES and the temporary flare stack used during the FEP tests was conducted. Assuming that the thin-walled elements of the stand are not conductively cooled, that no heat is lost by conduction, and that temperatures are to remain below 900°R, exposure to the plume must be less than approximately 1 minute. For the minimum gage (1/4 in.) structural members on the stand, exposures of 9 minutes are permissible. For wall thicknesses greater than 1/4 in., exposures of greater than 20 minutes are possible. During NES tests and FEP's radiometers, thermocouples, heat flux gages, and smoke bombs will be used to determine experimentally the actual heat-flux conditions. These data will be used to verify the analytical techniques.

(e) Source Drive

Coordination of the WANL design and fabrication effort for the source drive and associated nuclear detector thimbles was completed, and the equipment was shipped to NRDS during the second quarter of CY 67.

(f) Failure-Mode Analysis

Detailed analysis of the failure modes of the components in the ETS-1 fluid systems was conducted on a continuous basis. As a result of this analysis and other joint NRO/NTO evaluations, several changes in the electrical and actuation gas systems have been identified that are

necessary to improve the reliability of the cooldown and other critical ETS-1 fluid systems. The previously discussed relief valves are a typical example.

(g) Steam Line Dynamic Analysis

A dynamic analysis of the ETS-1 steam line was made. This analysis indicated that an additional snubber is required on the horizontal section of the steam line under the ceiling of the pipe chase. The new snubber should be mounted in the horizontal axial direction of the pipe at the elbow location, immediately above the existing snubber on the floor of the pipe chase. The new snubber should be capable of withstanding a load of 20,000 lb.

(h) Change Control

A procedure for maintaining configuration control of NRDS facilities was developed to define the responsibilities of participating organizations and the review and approval requirements for accomplishing designs and modifications.

(i) Engine Test Compartment (ETC)

The Task Force established in January 1967 to resolve problems associated with the ETC shields was assisted at the site and a thermal analysis to establish water flow requirements and radiation heating in the eutectic was provided.

(j) Safety Analysis

Assistance was provided in the development of the Safety Analysis Report (SAR) for ETS-1. Assistance included system analysis and detailed operating information for systems for analysis by others.

(k) ETS-1 Activation Support

Support has been provided to the facility data evaluation team in the analysis of the facility experimental plan data. Support has also been provided for the review of facility experimental plan procedures.

(1) Vibration and Acceleration Data

The NES test vibration and acceleration data were reduced for futher analyses.

(2) E/STS 2-3 Facility Support

During CY 67 technical support was provided to SNPO in activities related to criteria for and design of Engine/Stage Test Stands 2-3 (E/STS 2-3). Coordination was provided within Aerojet to ensure that the design was compatible with the NERVA engine requirements, with safety considerations, and with the capabilities of existing or planned Ground Support Equipment (GSE). Nuclear analysis and engineering efforts were provided in support of Kaiser Engineers design work and in the coordination and review already indicated above.

Technical support included participation as members of the government committee on E/STS 2-3 and continuing review of Kaiser Engineers design and specification work. Design information memoranda (DIM's) and document transmittal letters (DLT's) were received and reviewed and technical comments or other necessary answers provided. Design concepts were generated by Aerojet, evaluated by SNPO, and presented for use by Kaiser Engineers. Support was also provided to the Marshall Space Flight Center effort in preparing the specification for the Nuclear Ground Test Module (NGTM) and in coordinating the Module Propellant Tank (MPT) interfaces with the engine and the facility. Some specific accomplishments were as follows:

The Kaiser Engineers E/STS 2-3 work was reviewed at the 30% design completion milestone. Fifty-two drawings and six books of backup information were reviewed by an Aerojet team representing all the required disciplines. Comments were presented to SNPO at the Kaiser Engineers office in Oakland in February 1967. SNPO, MSFC and WANL comments were also reviewed, and a consensus was reached relative to instructions from SNPO to Kaiser. Similar reviews and discussions were also held on various individual design/ bid packages at further points of completion.

Bid Package No. 5, Cryogenic and Gas Systems, was reviewed during the August 1967 meetings in Oakland. Detailed comments on the specifications and drawings were provided during the meeting and Aerojet helped prepare the instructions given to Kaiser. Following these meetings, cryogenic gas system piping layout drawings were reviewed with SNPO. After this review the drawings were discussed with Kaiser personnel and piping changes were recommended. In addition, discussions were held with NERVA system personnel to determine the information required by SNPO to enable optimization of the facility design. The procedure and tabulation of requirements agreed on is expected to be available during the early part of CY 68.

A conceptual design was prepared for a continuous-ring duct-extension adapter between the NERVA engine nozzle exhaust plane and the E/STS 2-3 ducts. Figure 112 shows the concept recommended.

A study was made to develop a new concept for the E/STS 2-3 intermediate shield system. Five preliminary concepts were proposed, analyzed, and evaluated and recommendations were made in a report presented to SNPO-C early CY 67. Figure 113 shows a recommended concept utilizing support from the test stand structure.

Design criteria were formulated and a study was undertaken to develop a detailed preliminary design for a specific aluminum-water facility intermediate shield to meet the nuclear and geometric requirements of the facility. Using a series of iterations, a configuration was

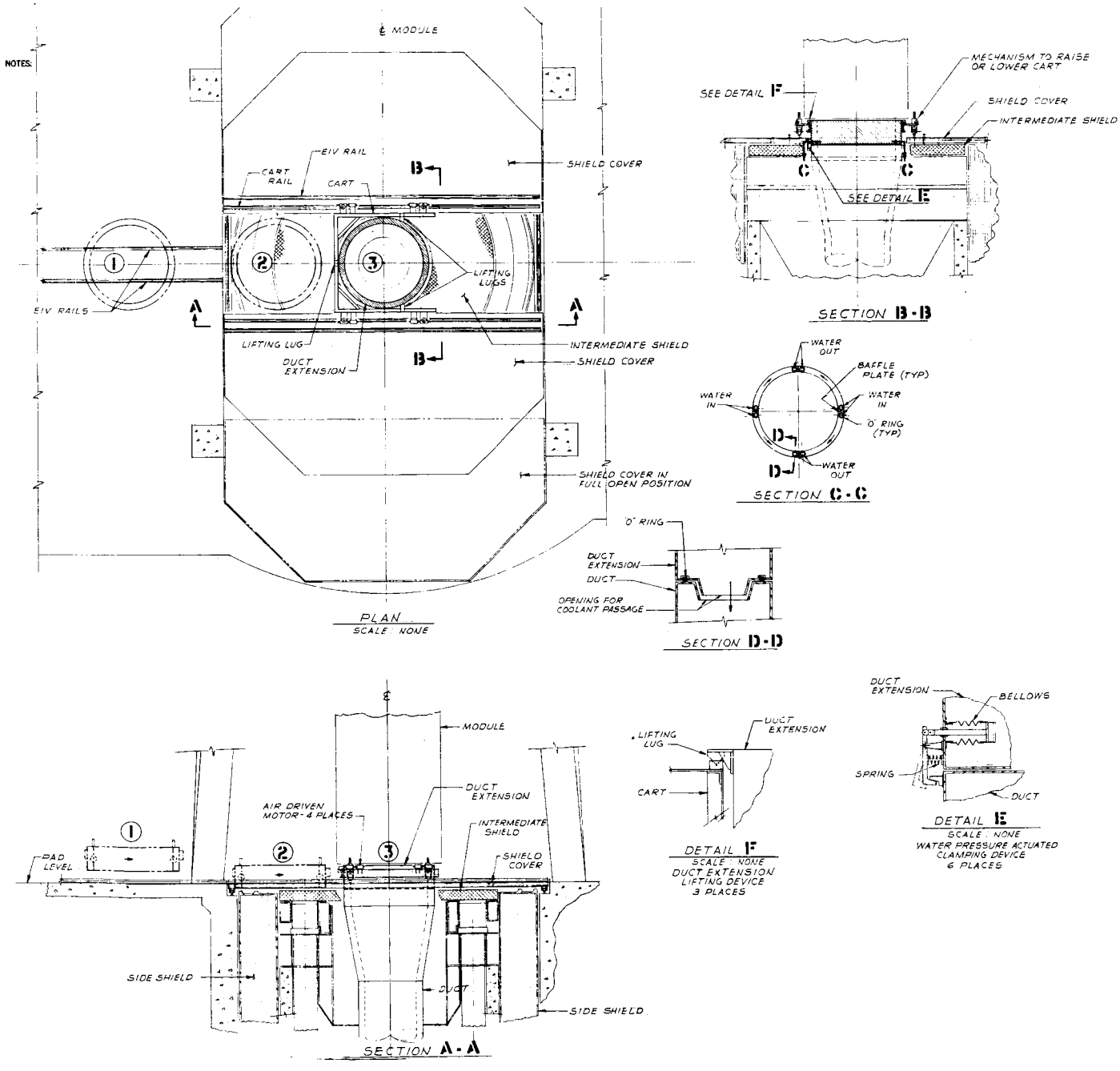


Figure 112 - E/STS 2-3; Study for Duct Extension

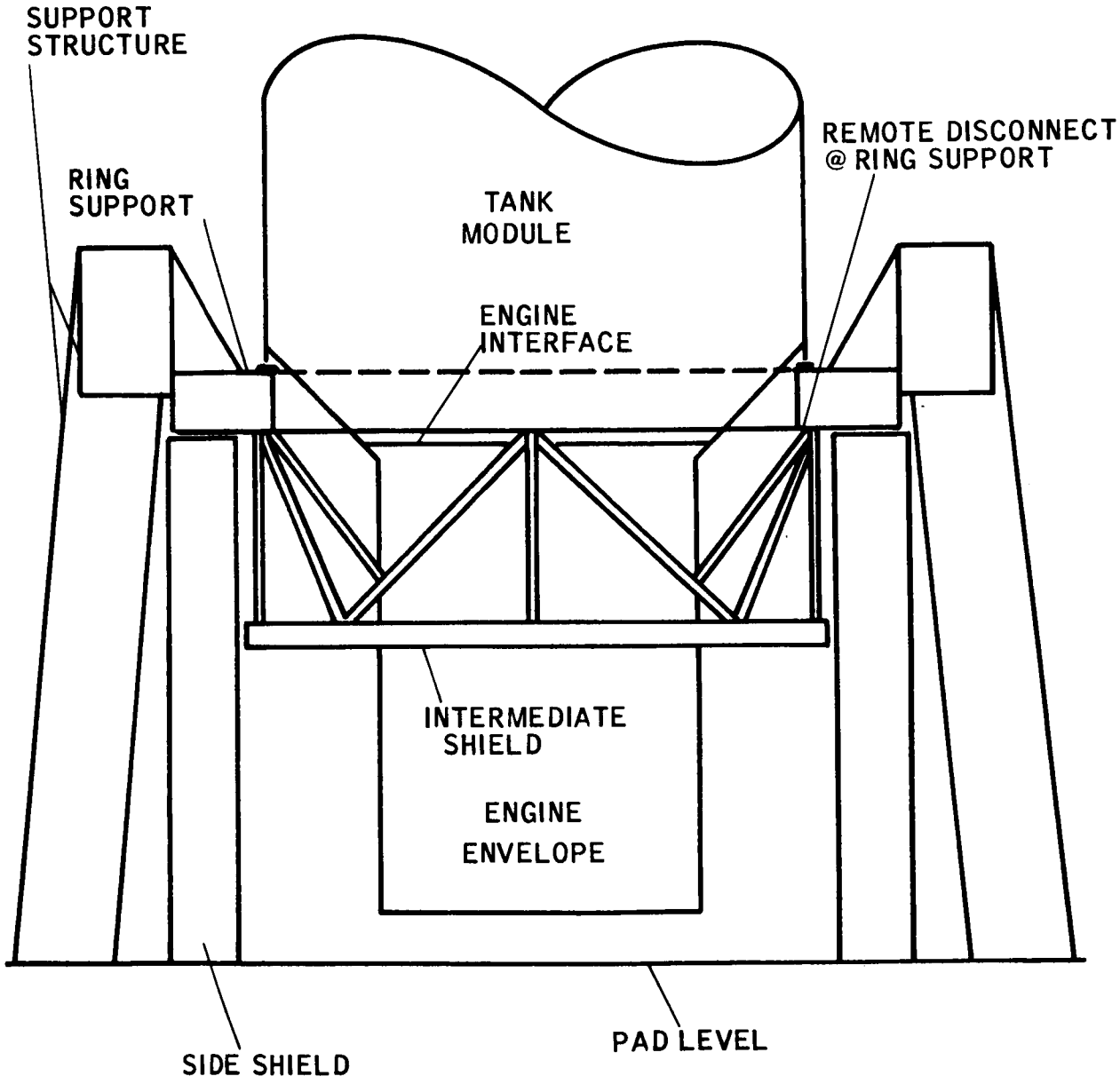


Figure 113 - E/STS 2-3 - Intermediate Shield Concept

developed that will provide the necessary nuclear-radiation shielding while enabling adequate cooling within a feasible structure. The preliminary radiation-heating estimates used as a basis for an early iteration of the shield design are shown in Figure 114 and in Table 19. These rates were increased in calculating the cooling requirements for the final iteration, as shown in Table 20. The recommended concept was presented at meetings in Oakland in June and is shown in Figures 115, 116, and 117. The cooling-water flow required to prevent surface boiling was calculated to be approximately 7000 gpm. Subsequent work by Kaiser Engineers in this area has been monitored and reviewed and assistance has been provided in interpreting criteria, in analyzing hydrodynamic, structural, radiation heating and heat-transfer data and in recommending modifications of the preliminary design. A possible heating problem was resolved by a two-dimensional thermal analysis. Suggestions were made relative to the structural arrangement of the pressure-vessel portion and to methods for supporting the shield slabs. A new thermal analysis was made to determine the effect of an increase in cooling water temperature from 80° to 97°F. The flow requirement would increase from 7000 to about 7800 gpm. Suitable shielding material is being evaluated, and boron-aluminum appears to be the best. Concentration of the boron in the outer layers of shielding materials may enable cost reduction. This and other details of the preliminary material specification are under study.

Information was provided regarding radiation-resistant elastomers suitable for sealing the engine test compartment.

(3) Nuclear Ground Test Module (NGTM) Support

Assistance was provided in preparing material for a presentation to Marshall Space Flight Center (MSFC) on a facility for cold-flow testing of the NERVA ground test module. This information was presented at a meeting at MSFC on 12 October 1966.

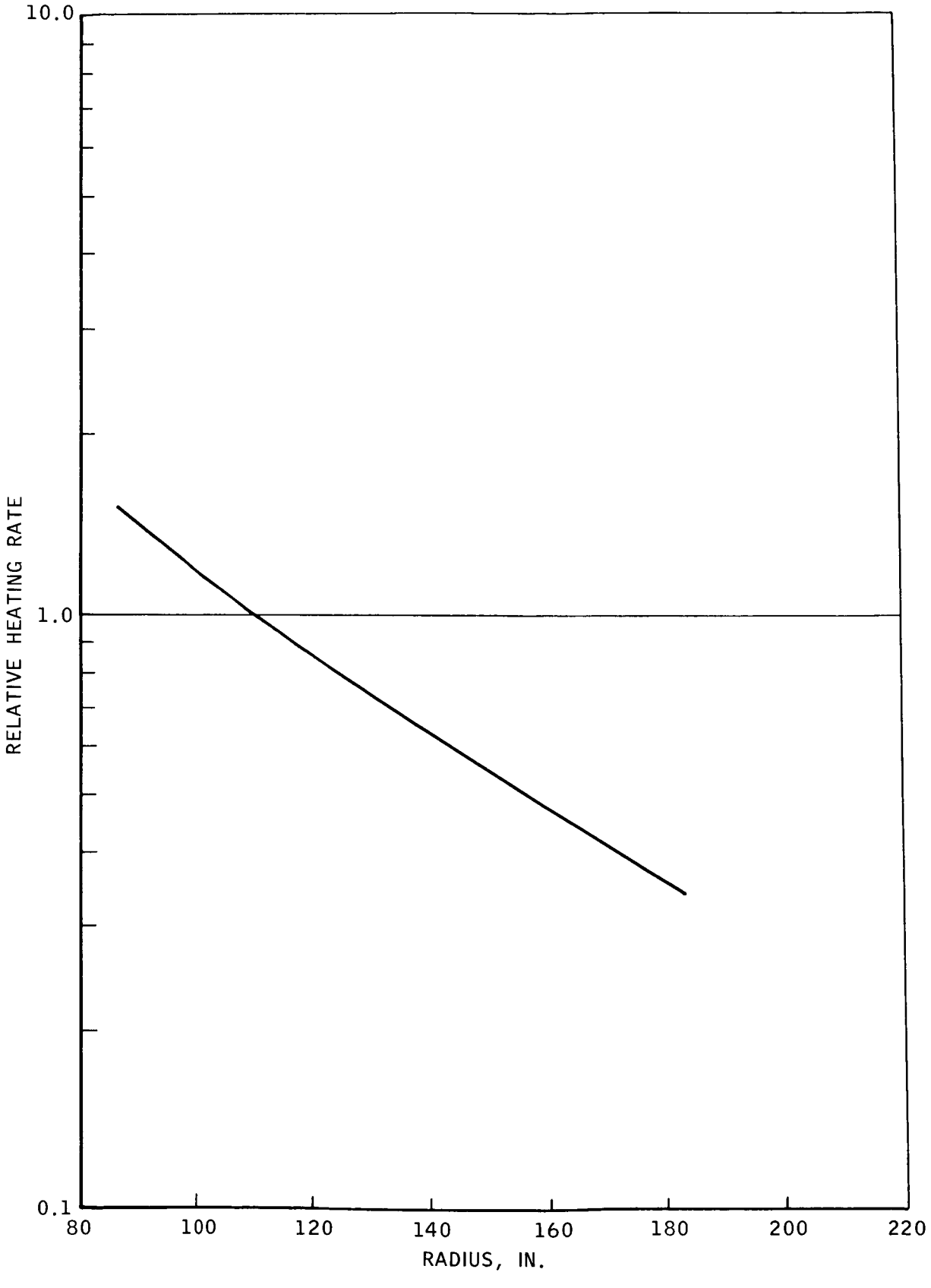


Figure 114 - Relative Radial Distribution of Heating Rates in Intermediate Shield

TABLE 19

PRELIMINARY RADIATION-HEATING ESTIMATES FOR E/STS 2-3
FACILITY INTERMEDIATE SHIELD

Shield Region		Radiation Heating Rates at 5000 Mw, Btu/sec per region
1/2 in. aluminum bottom plate		1.3×10^{3}
1 in. borated water		1.12×10^{4}
1/2 in. borated aluminum		2.4×10^{3}
5 in. borated water		8.8×10^{3}
1 in. aluminum support plate		2.1×10^{2}
2 in. borated aluminum		3.5×10^{2}
2 in. borated water		2×10^{2}
2 in. borated aluminum		$2 \times 10^{2*}$
2 in. borated water		$3 \times 10^{1*}$
1/2 in. borated aluminum		$1 \times 10^{1*}$
1-1/2 in. borated water		$2 \times 10^{1*}$
1 in. aluminum top plate		$3 \times 10^{1*}$
	Subtotal	2.5×10^{4}
Inner Annulus		
1-1/2 in. aluminum		7.3×10^{3}
3/4 in. borated water		4.0×10^{2}
1/2 in. borated aluminum		5.5×10^{2}
5-1/4 in. borated water		3.0×10^{3}
	Subtotal:	4.6×10^{3}
	Grand Total:	3.0×10^{4}

*These data are based on heating conditions with an engine intermediate shield and with a relatively thick internal engine shield. The shield and coolant flow passages are designed to accommodate operation with no internal engine or engine intermediate shields.

All heat generation rates should be doubled in determining temperature rises for coolant-passage requirements.

TABLE 20

PRELIMINARY RADIATION-HEATING ESTIMATES USED IN THERMAL ANALYSIS

Shield Region		Heating Rate, Btu/sec
1/2 in. aluminum bottom plate		2.6×10^3
1 in. borated water		2.24×10^4
1/2 in. borated aluminum		4.8×10^3
5 in. borated water		1.76×10^4
1 in. aluminum support plate		4.2×10^2
2 in. borated aluminum		7.0×10^2
2 in. borated water*		4.0×10^2
5 in. borated aluminum*		5.0×10^3
2 in. borated water*		7.5×10^2
1/2 in. borated aluminum		3.75×10^2
1-1/2 in. borated water		7.5×10^2
1/2 in. aluminum top plate		$3\ 75 \times 10^2$
	Subtotal:	5.62×10^4
Inner Annulus		
5/8 in. aluminum		7.4×10^2
3/4 in. borated water		11.0×10^2
1/2 in. borated aluminum		15.2×10^2
5-1/4 in. borated water		6.0×10^3
	Subtotal:	9.4×10^3
	Grand Total:	6.56×10^4

* The heating rates for these regions were not changed when the section was changed to four 1-in.-layers of borated water separating three 2-in. borated aluminum plates (from the original 5-in. borated aluminum slab with 2 in. of borated water on each side).

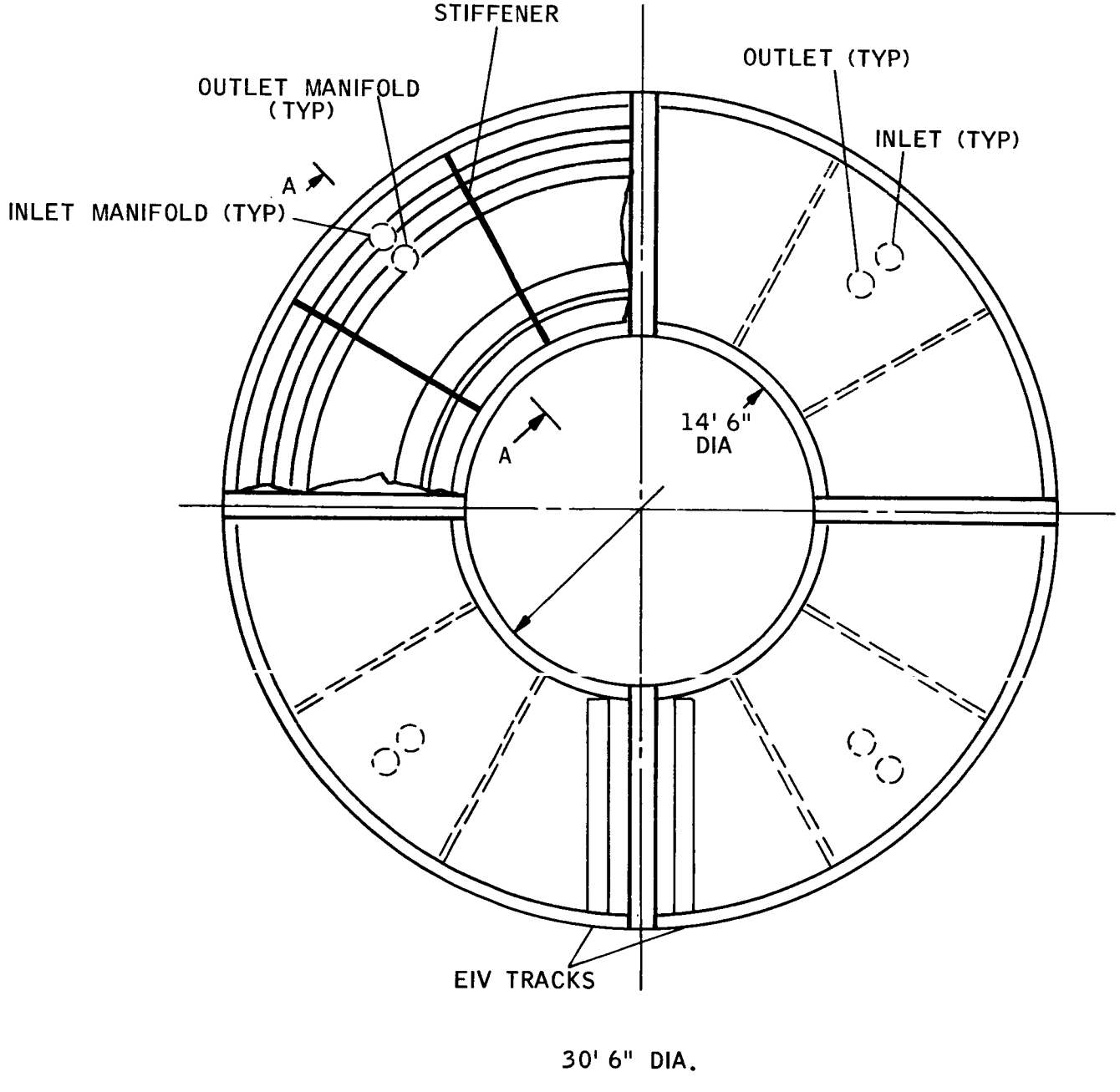


Figure 115 - E/STS 2-3 Conceptual Design, Facility
Intermediate Shield, Plan View

VIEW A-A
(SEE PRECEDING FIGURE)

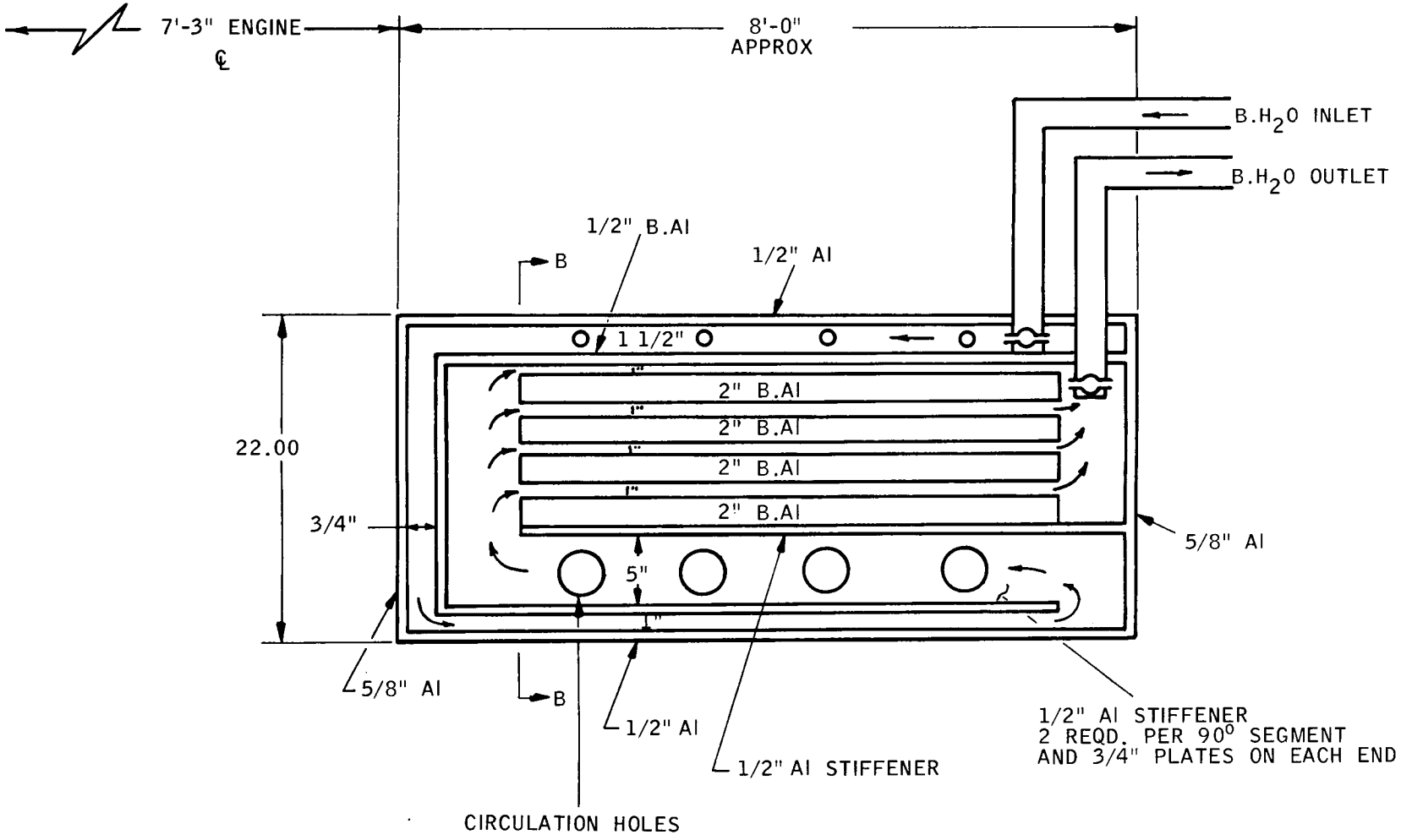
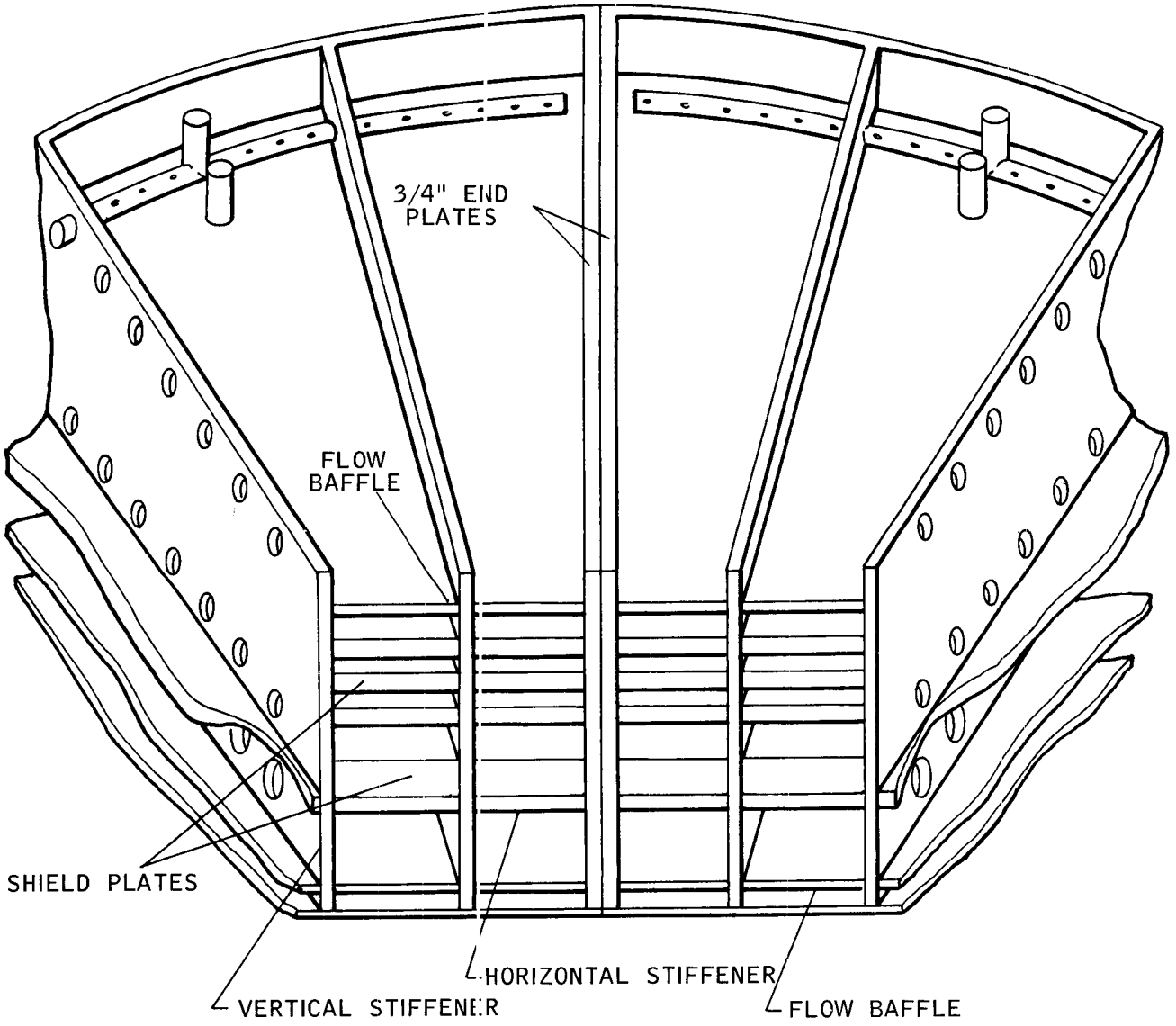


Figure 116 - E/STS 2-3 Conceptual Design, Facility Intermediate Shield, Section A-A



VIEW B-B
(SEE PRECEDING FIGURE)

Figure 117 - View B-B, Oblique Section with Upper Plate Removed

Coordination has been provided to define E/STS 2-3 interfaces with the nuclear ground-test module. At a meeting with Kaiser Engineers three concepts were presented for routing the ground-test cooldown line from Engine Station 0-0 to the Facility. These concepts (Figures 118, 119, and 120) are still under consideration.

Two MSFC documents were reviewed: Nuclear Ground Test Module System Specification, and End Item Specification - Tank Assembly for Nuclear Ground-Test Module (NGTM). Comments were prepared and presented to SNPO and MSFC at meetings in Huntsville, Alabama, on 5 January 1967.

Aerojet has been directed to provide assistance to MSFC in the preparation of an NGTM system specification. A preliminary draft was prepared and rough draft copies were provided to SNPO-C and MSFC in May 1967 for preliminary information and comment.

Coordination with MSFC was continued relative to the nuclear ground test module (NGTM). MSFC's NGTM Program Specification (Preliminary), MSFC-R-P-VE-VNC, dated 22 May 1967 was reviewed. Facility-to-service-arm interfaces and tank-to-engine interface requirements were reviewed.

A meeting was held on 23 August 1967 at Kaiser Engineers in Oakland to review Interface Control Documents (ICD) prepared by MSFC. All interface fluid requirements were discussed with MSFC/SNPO/KE personnel. Aerojet personnel reported that engine fluid requirements do not conform with the latest engine concept and with Aerojet effort to eliminate or reduce the use of GHe. However, Aerojet verified that the engine fluid requirements shown in the ICD were the same as those shown in DIM 1006, Rev. 4.

Continuing interface integration and technical coordination have been provided between the NGTM and E/STS 2-3 facility designs.

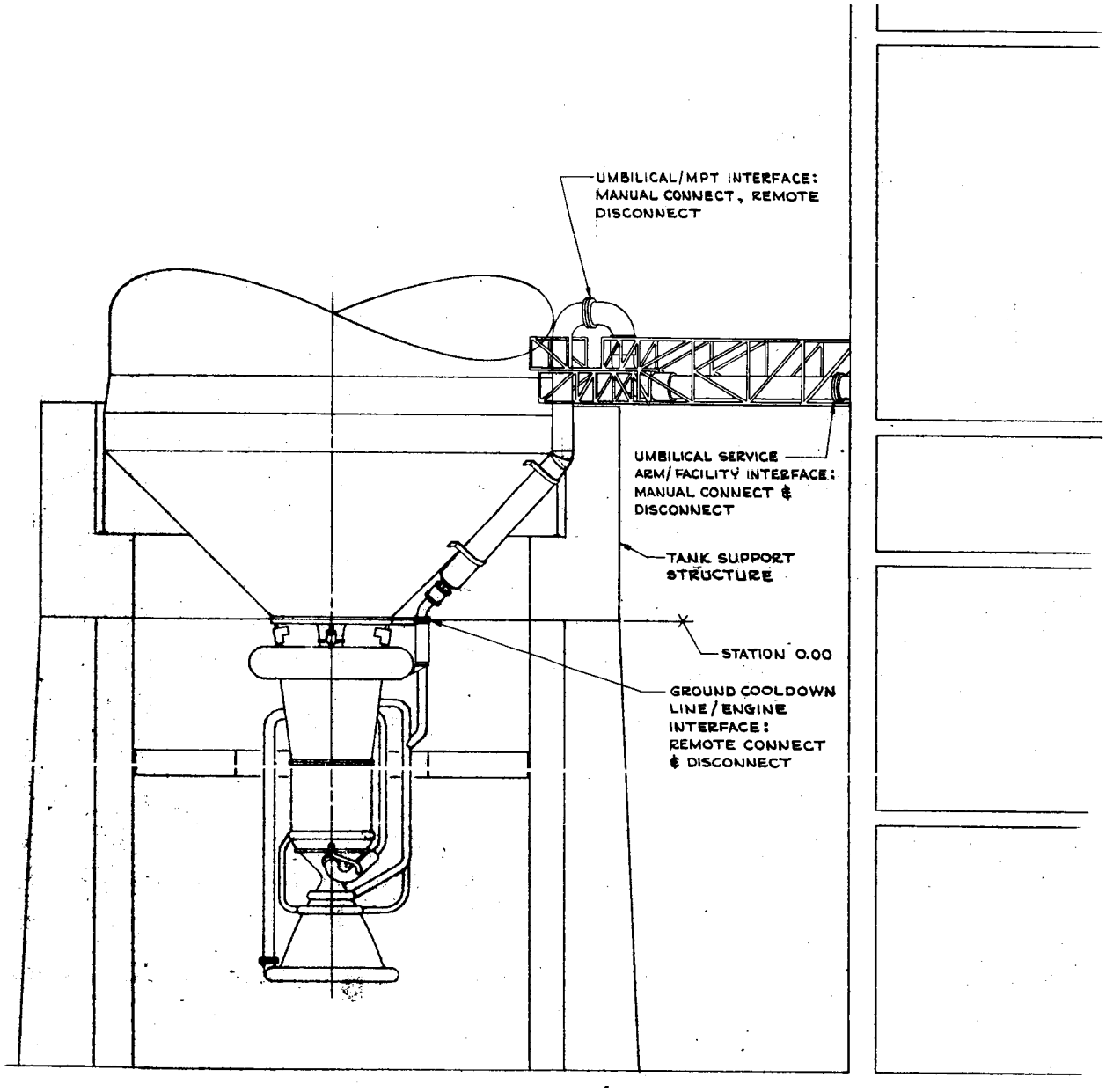


Figure 118 - Routing of Ground-Test Cooldown Line, Concept A

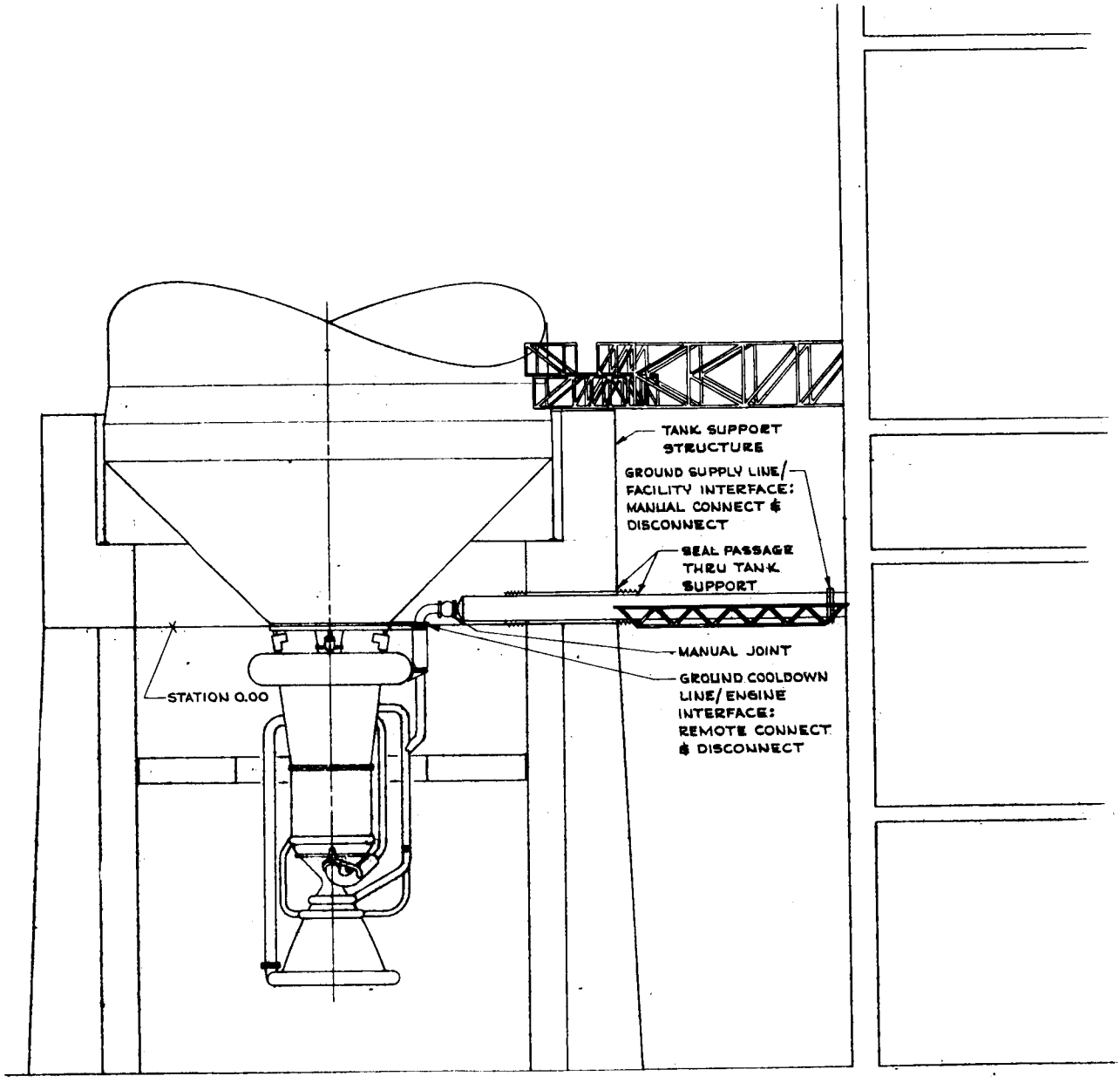


Figure 119 - Routing of Ground-Test Cooldown Line, Concept B

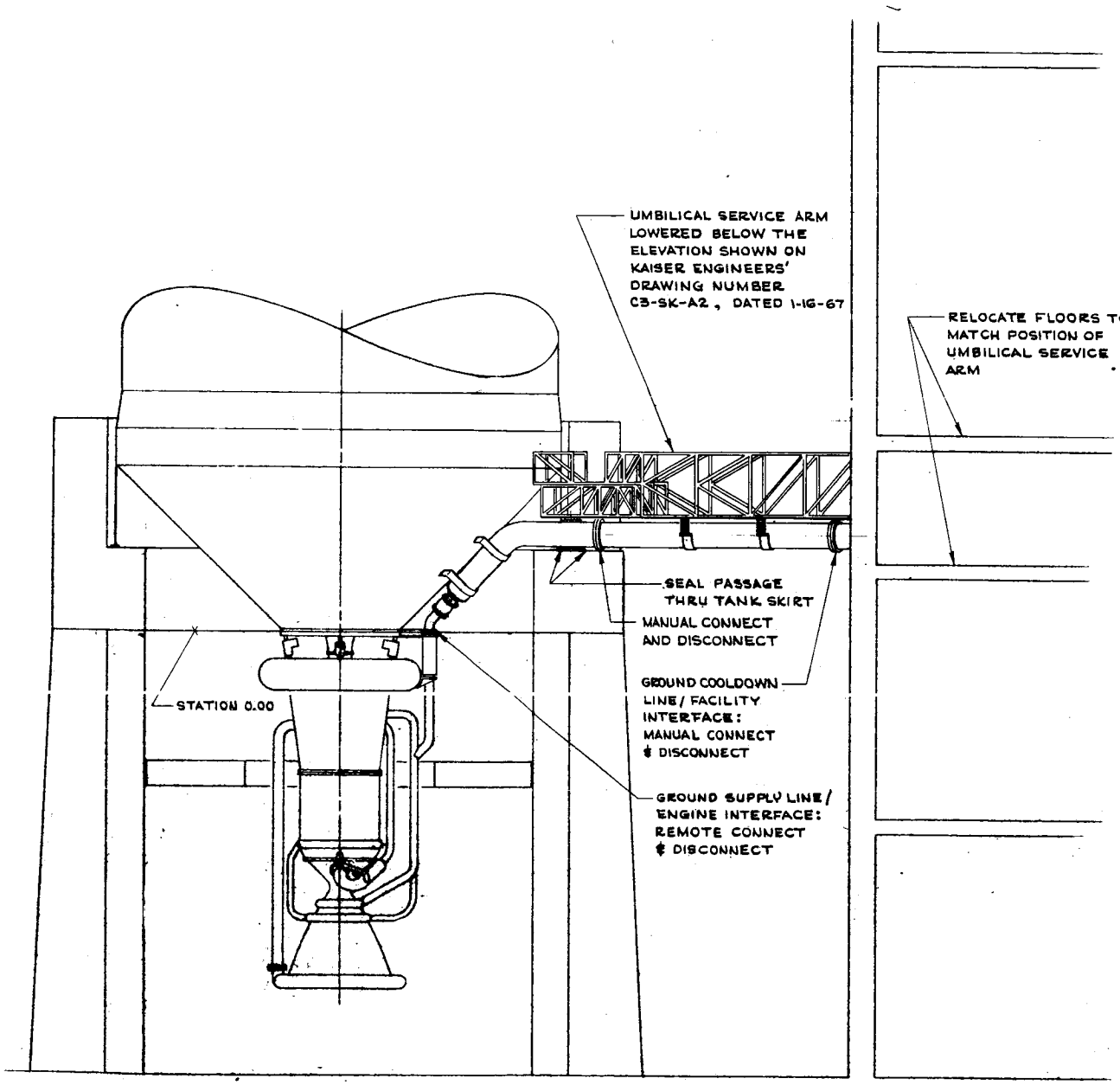


Figure 120 - Routing of Ground-Test Cooldown Line, Concept C

(4) ETS-1 NERVA Test Capability Studies

Information was provided to the NERVA system design section regarding the disposal of TPA turbine exhaust gases when NE-1 is being tested in the ETS-1 facility. Estimated costs were provided for accomplishing this with ejectors available from Sacramento test areas and steam generators from NRDS. Also it was established that tests would be necessary to determine if this exhaust could be tied directly into the proposed duct extension. Information relative to ETS-1 capability for NERVA testing with minimum facility changes was also provided. This effort necessitated the review of the latest NE dimensions and facility requirements and determination of mandatory modifications test limitations that will be imposed by the facility.

Further studies were initiated to evaluate a proposed NERVA test program in ETS-1 and to determine the modifications necessary to test NERVA engines in this test stand.

(5) Electric Power, Grounding Systems and Test Control and Simulation System (TCSS) Support

General technical support was provided for facility Instrumentation and Control (I&C) systems design and specification.

Initial system functional requirements for the Test Control and Simulation System (TCSS) were obtained and used to formulate and develop preliminary TCSS design concepts. System engineering review of E/STS 2-3 I&C designs was provided to determine interface requirements imposed by TCSS design concepts. Initial interface requirements between TCSS and the NGTM System were developed. E/STS 2-3 Cryogenic and Gas (C&G) System valve performance requirements were established together with requisite instrumentation locations and performance criteria.

Early in the first quarter of the contract year a presentation was made to SNPO representatives describing the initial concept

that would be investigated for NE controls, including the TCSS. Subsequently, a preliminary TCSS functional requirements document was prepared. This document was reviewed with SNPO-C representatives during meetings in Sacramento. The MSFC version of the NGTM specification was reviewed for identification and description of TCSS interfaces with the NGTM System. A presentation of TCSS requirements and design concepts was made to SNPO and MSFC at MSFC, Huntsville, Alabama. During this meeting, initial concepts for the NGTM propellant tank pressurization and vent control were discussed to establish TCSS operational requirements. In discussions with Kaiser Engineers in March 1967 between representatives of Aerojet and MSFC, a preliminary interface definition between the TCSS and NGTM tank GSE was established. This information was recorded in minutes produced by the E/STS 2-3 Government Task Group on 8 March 1967.

The TCSS portion of the SNPO-C version of the NGTM System specification was generated and issued for SNPO-C review. Figure 121 represents the basic TCSS relationship to the NGTM system in block diagram form.

Technical review of the Kaiser Engineers (KE) 30% E/STS 2-3 I&C design concepts was accomplished, and comments were provided to the E/STS 2-3 Task Group relative to TCSS integration into the I&C System.

Aerojet representatives participated with Kaiser Engineers in the preliminary formulation of the E/STS 2-3 cryogenic and gas system basic control methods and piping layouts. During this period, C&G system transducer types and locations were tentatively established. The designs derived were used to formulate TCSS and facility control system preliminary requirements, shown in Figures 122 and 123.

A meeting was held at MSFC between Aerojet and MSFC personnel to establish detailed requirements for fluid systems that are to be routed over the lower and upper umbilical booms. In addition to these

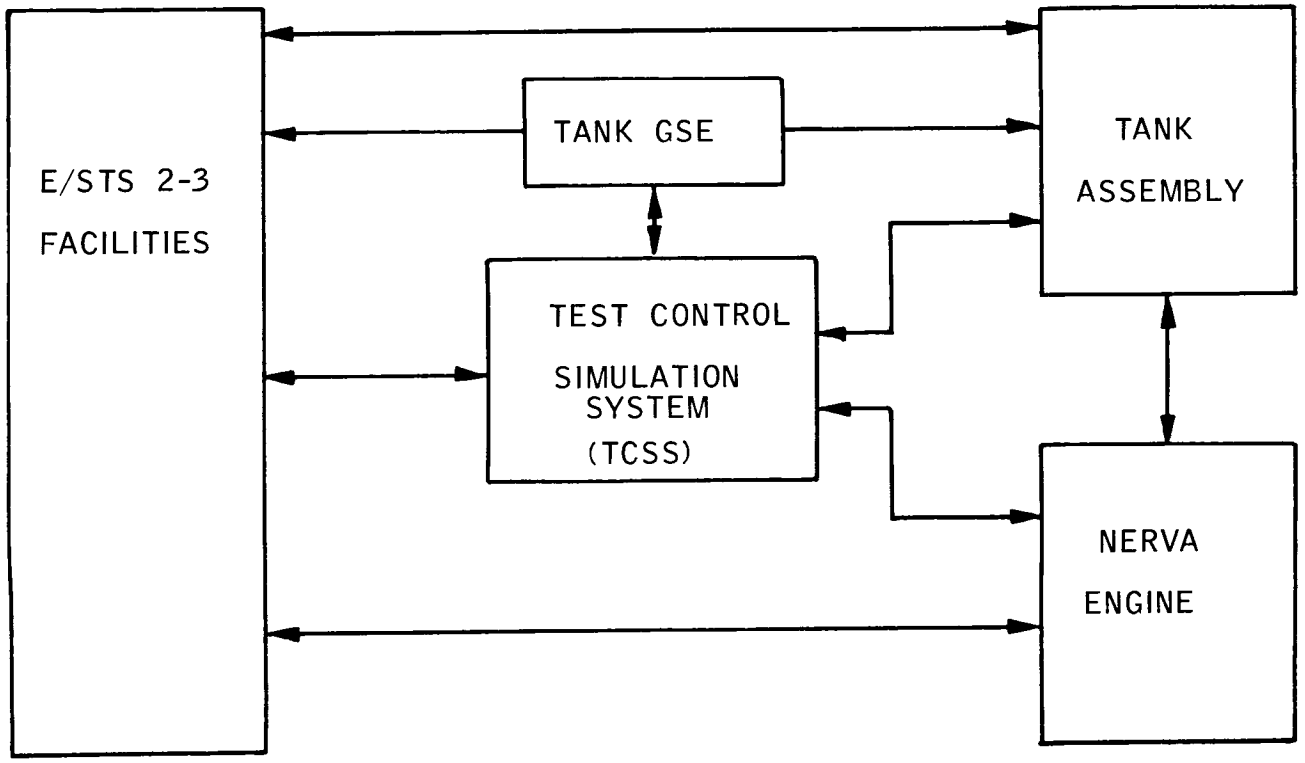


Figure 121 - NGTM System Design

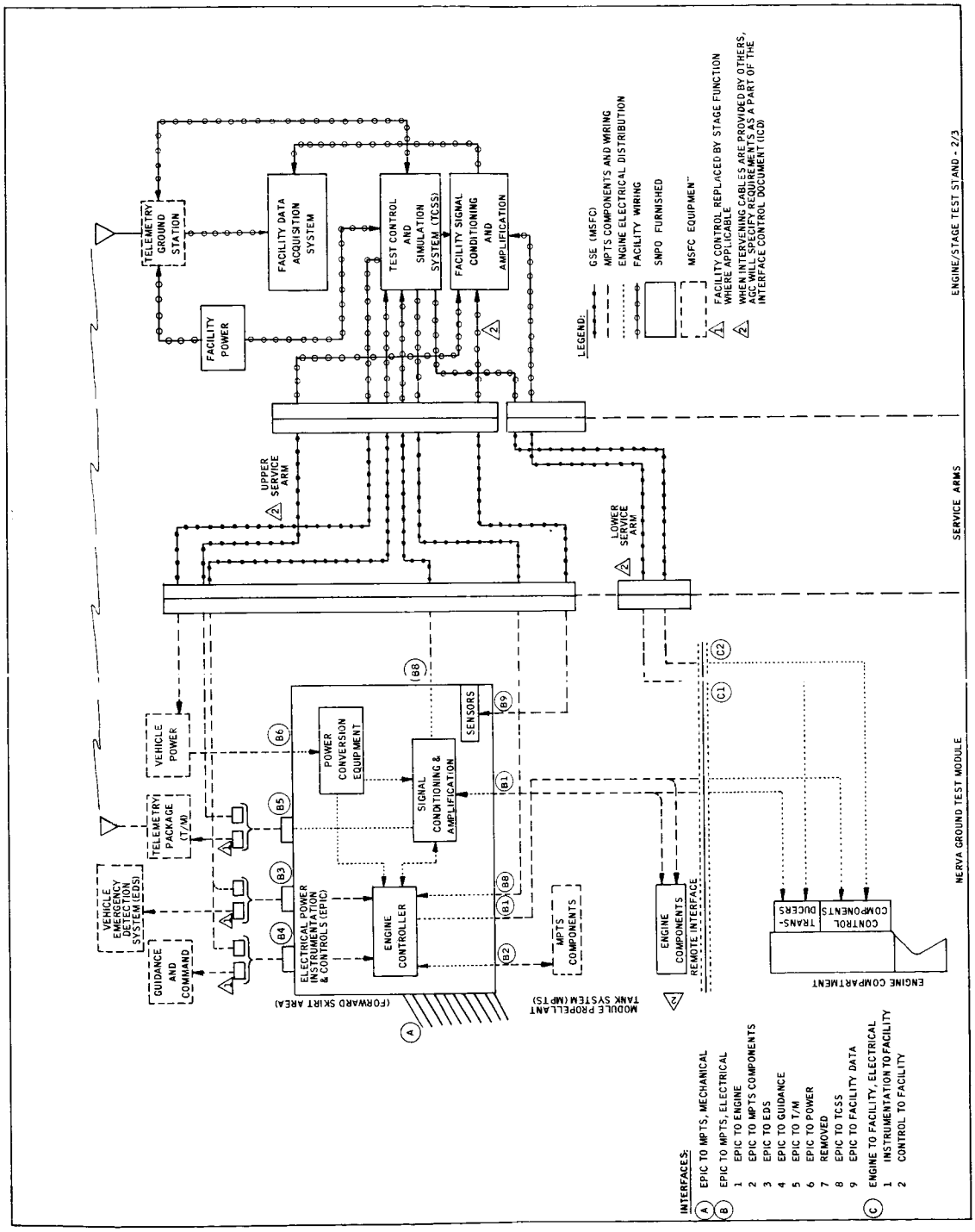


Figure 122 - TCSS Relationship to NGTM System

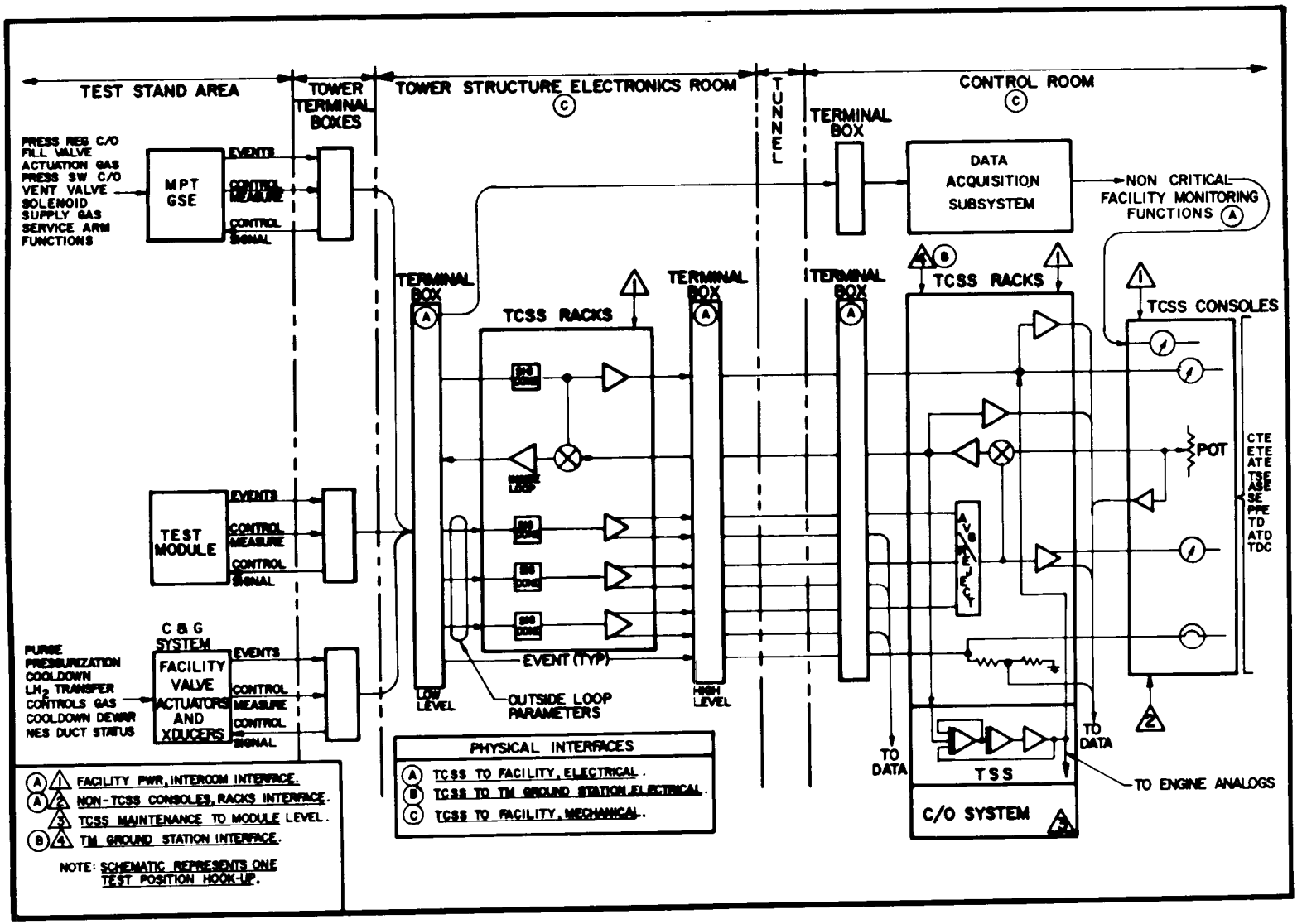


Figure 123 - System Schematic; E/STS 2-3 and TCSS

requirements, basic control schemes and backup analyses for the propellant tank system were discussed to establish TCSS design criteria.

Aerojet participated in a series of decisions regarding basic problems and design efforts pertaining to the cryogenic and high pressure gas systems designs. The main area of contribution was the control philosophy adopted for all high-pressure gas and cryogenic flow systems. Flow, pressure, and transient requirements were investigated, and specific technical data were derived for each analog control valve used in fluid control from the cryogenic and high-pressure gas storage to the umbilical interface.

Aerojet coordinated its efforts with Kaiser Engineers relative to C&G designs. These efforts were related to emergency cooldown techniques, hydrogen disposal problems, and hot-water, heat-exchanger control. The decisions reached were used to define the system designs and to formulate the basis for the design of TCSS closed-loop, servo-control electronics and related operational controls.

During the second quarter, recommendations were made to the E/STS 2-3 task group relative to location of operator stations in the control center control room. These recommendations are indicated in Figure 124.

During the third quarter of CY 67, Aerojet and MSFC Astrionics Division personnel met to establish the electrical interface between the TCSS and the NGTM stage electronics including the NE EPIC. Figure 125 shows the initial identification of these interfaces for the NGTM System.

Separate studies were made relative to optimum grounding of a static test facility (E/STS 2-3) and of a vehicle-grounding configuration for flight application. Figure 126 presents the results of the studies that will be used as the basis for design of TCSS ground connections.

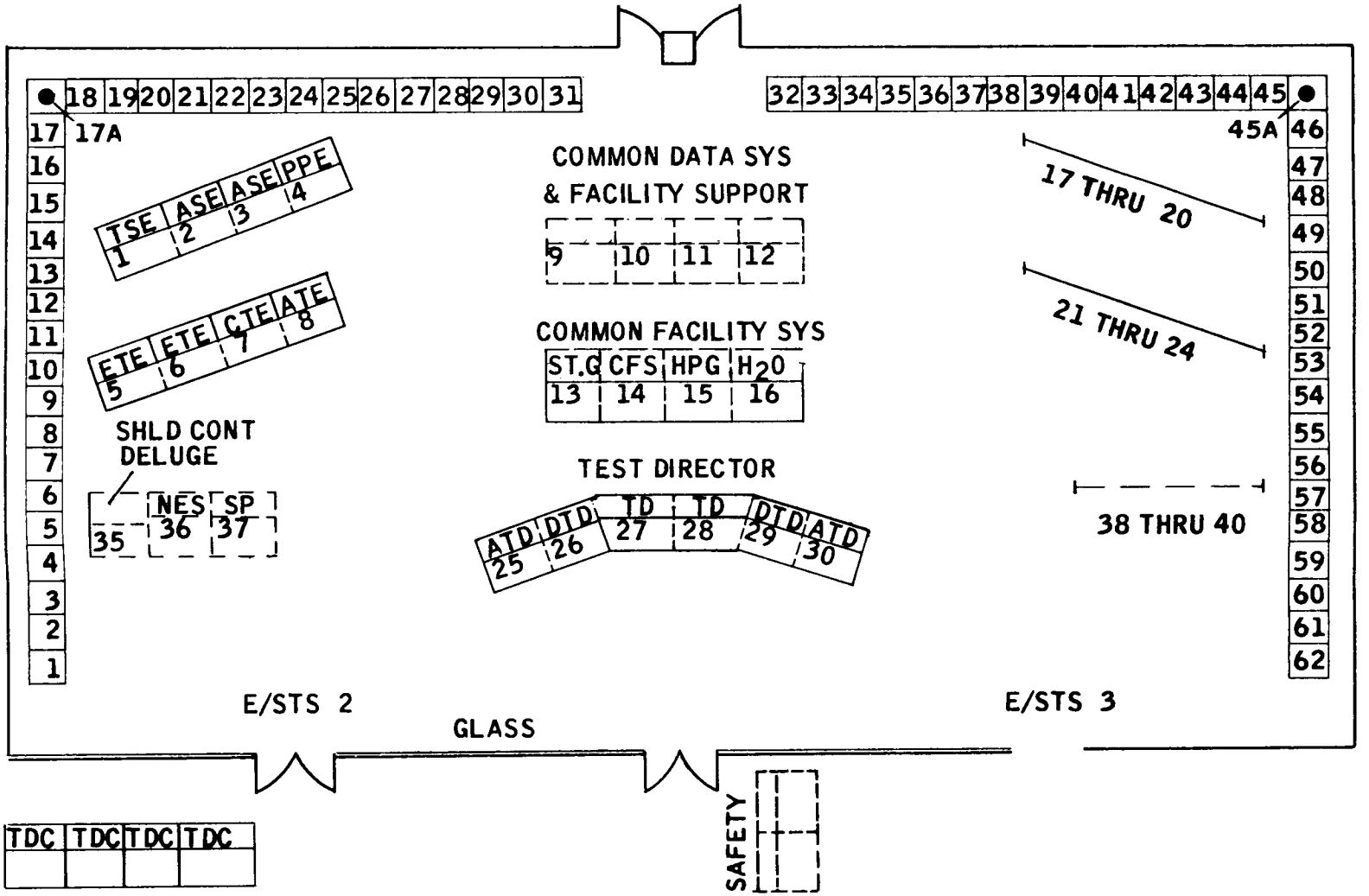


Figure 124 - E/STS 2-3 Control Room Layout

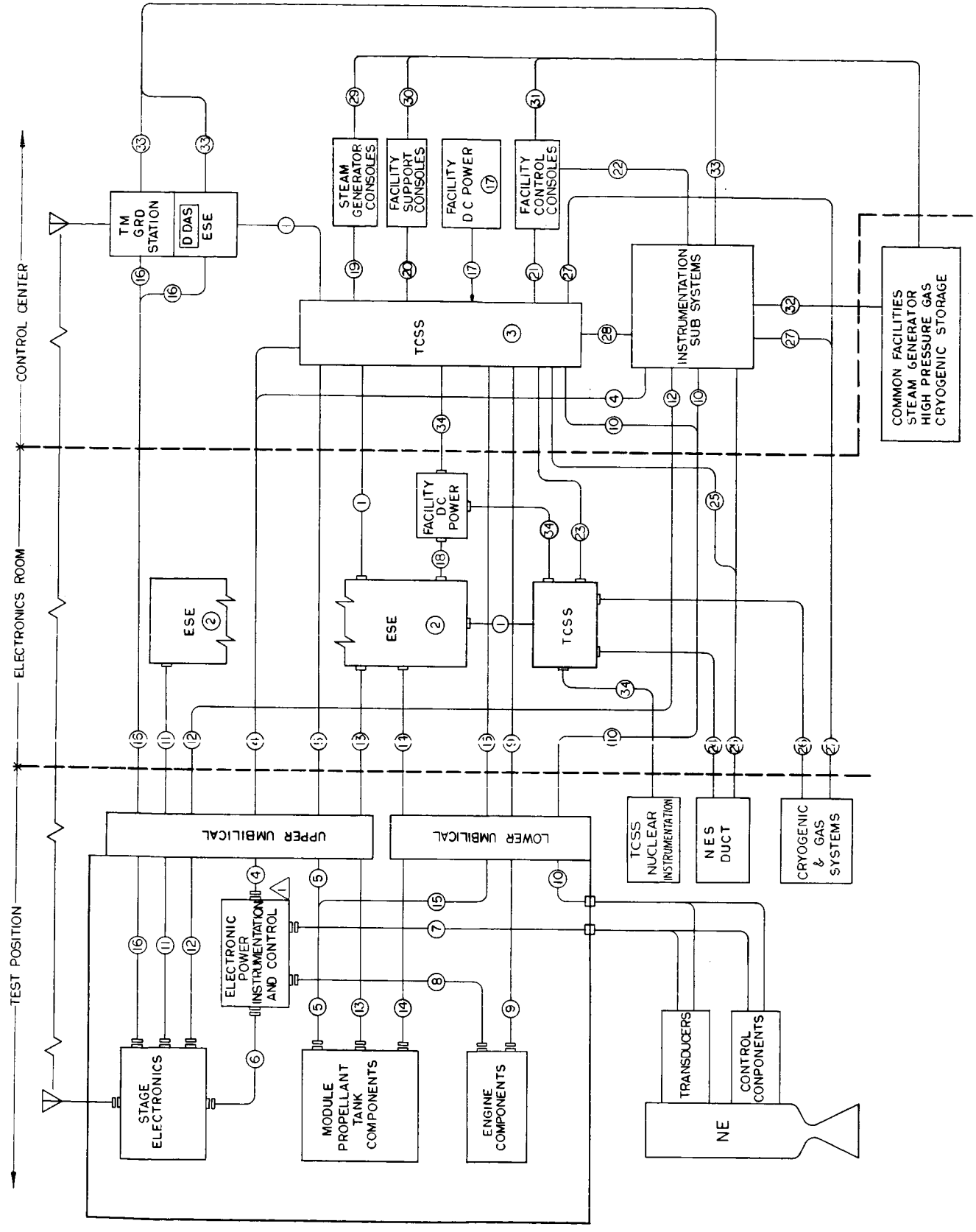


Figure 125 - Block Diagram, System TCSS Concept

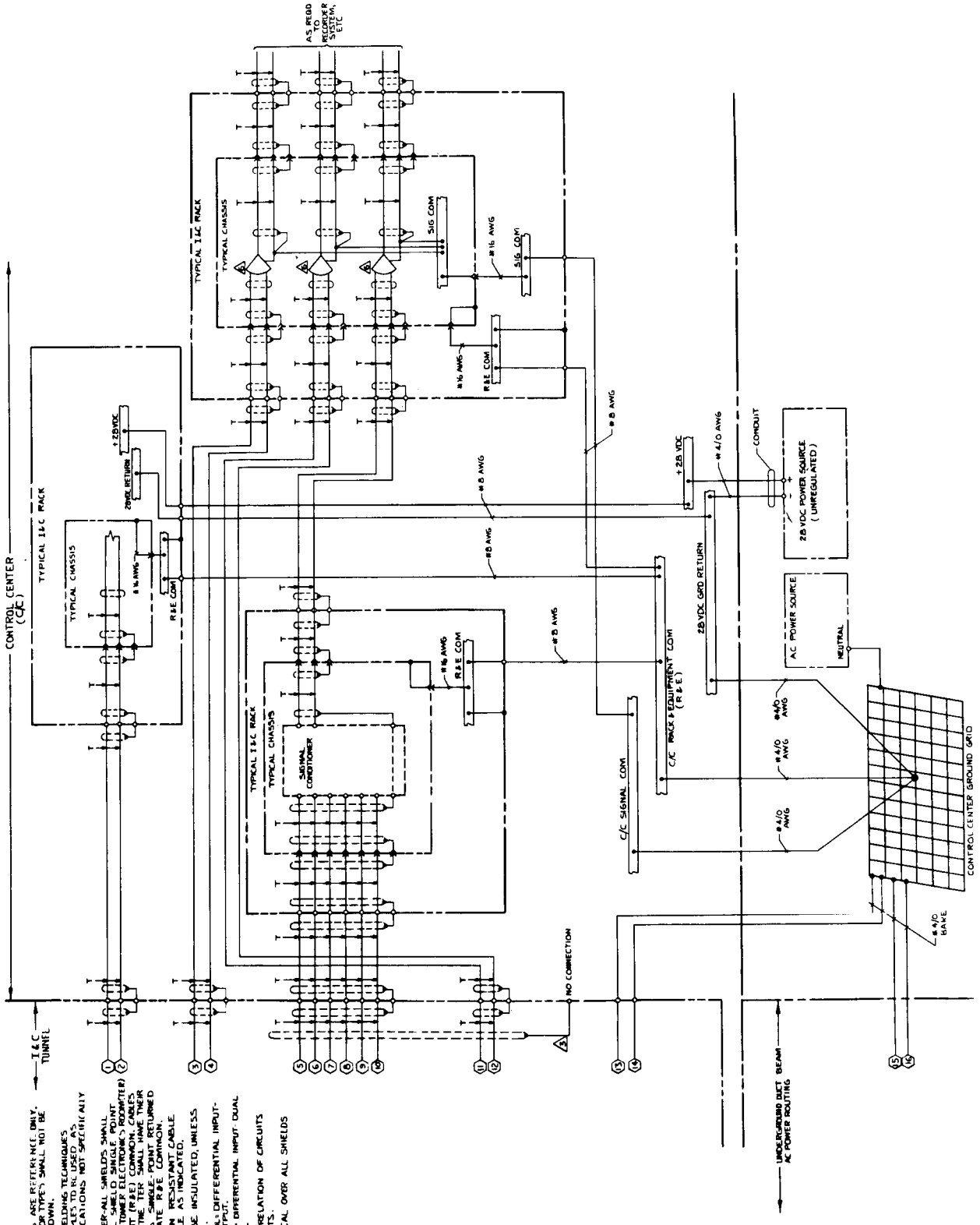


Figure 126 - Functional Diagram, Power and Grounding TCSS Concept (Sheet 1 of 3)

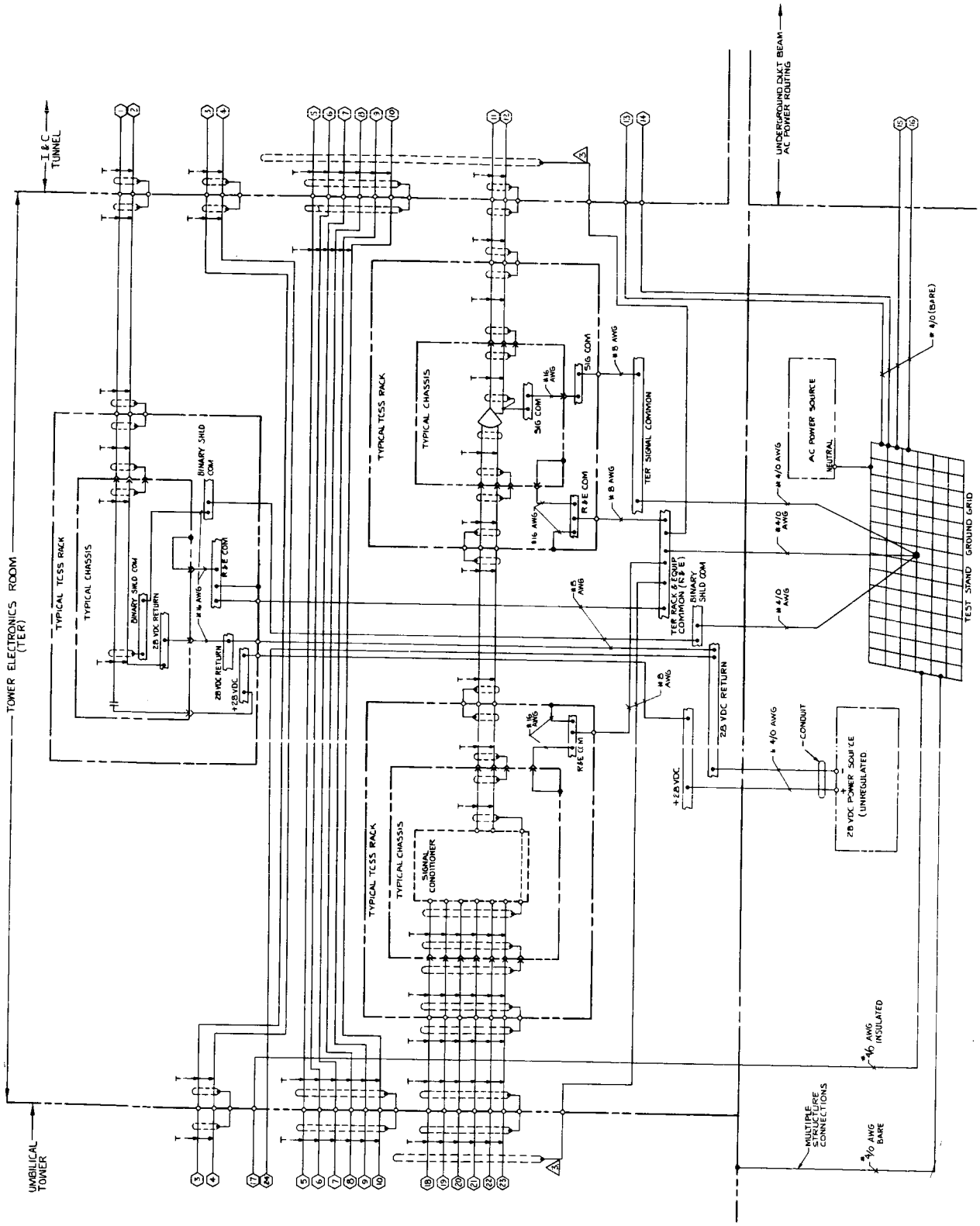


Figure 126 - Functional Diagram, Power and Grounding TCSS Concept (Sheet 2 of 3)

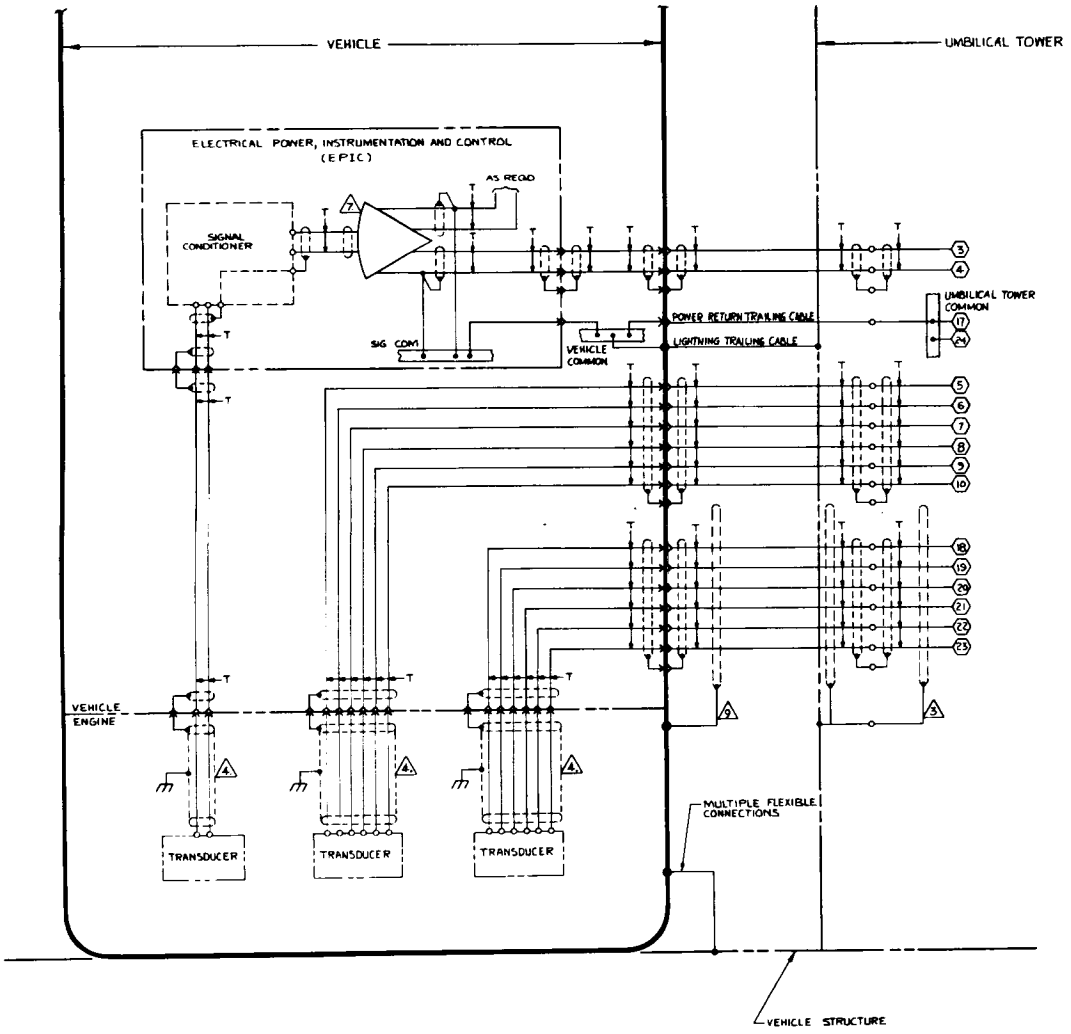


Figure 126 - Function Diagram, Power and Grounding TCSS Concept (Sheet 3 of 3)

Emergency power requirements were established as critical power and super-critical power. Critical power is defined as the ac power required to perform routine engine shutdown and cooldown and to provide sufficient data to evaluate the condition of the engine and its capability for further testing. Super critical power is defined as that 28 vdc power, such as battery power or fuel cells, required to perform an emergency shutdown of the engine, initiation of cooldown, and maintenance of cooldown system control until normal power is restored without undue hazard to personnel.

The critical power bus must be provided with a backup capability that is adequate to carry the critical loads until normal power can be restored (assumed to be 10 hours). Diagnostic data are required during the facility power outage to enable evaluation of the engine condition during and at the conclusion of the routine shutdown. After the data collected during this period are analyzed it will be determined if the engine is ready for restart.

During a shutdown using only the super critical power, damage to the reactor or nozzle may occur without being detected, because no diagnostic data will be collected. About 28 vdc power will be required for 10 hr based on the assumption that ac power will be restored by that time.

The following is a summary of the currently expected critical and super-critical power requirements.

(a) Critical Power Requirements

Instrumentation and Control	160 kw
Hydraulic Pump	5
Control Center H & V Fans	50
Control Center Evaporator Fan & Pumps	60

Equipment Room Fans	10
Coolant and Condenser Pumps	10
Control Center Chiller	165
Control Center Chiller Pumps	20
Test Stand Air Conditioner	1
Environmental Enclosure Heater & Fan	55
Reserve	64 kw
Total	600 kw

(b) Super-Critical Requirements

Control System Electronics	25 kw
Hydraulic Supply Pump	5 kw
Total	30 kw

The preliminary NE measurement requirements document was reviewed. This document and succeeding revisions were used as inputs to the design of the TCSS and to determine associated cable routing, connector requirements, and umbilical boom requirements.

The preliminary TCSS design was presented to SNPO representatives during meetings at Aerojet-Sacramento and Kaiser Engineers, Oakland. The design material that was presented is shown in Figures 127 through 138. Concurrently the section of the MSFC NGTM specification dealing with the definition of the TCSS was reviewed. Comments and suggested modifications of the specification were compiled and forwarded to SNPO-C.

In the third quarter of CY 67 Aerojet participated in a review of the Kaiser Engineers I&C design together with representatives from all user organizations. The results of the coordinated review were forwarded by the E/STS 2-3 Task Group to Kaiser Engineers for implementation into the final I&C design package early in the fourth quarter.

TO SUPPORT ENGINE TEST OBJECTIVES, THE TCSS PROVIDES:

1. SINGLE INTEGRATED CONTROL SYSTEM
   - A. ENGINE CONTROLS
   - B. TANK CONTROLS
   - C. TANK GSE CONTROLS
   - D. CRYOGENIC & GAS SYSTEM CONTROLS
   - E. NES DUCT H_2O FLOW CONTROLS
   - F. ENGINE/TANK SAFETY SYSTEM
   - G. NUCLEAR INSTRUMENTATION
2. OPERATOR/TEST DIAGNOSTIC CONSOLES
3. SYSTEM VERIFICATION/FAULT ISOLATION CAPABILITY
4. OPERATOR TRAINING CAPABILITY
5. SIGNALS TO DATA ACQUISITION
6. FLEXIBILITY FOR NE TESTS:
   - A. ENGINE INLET CONDITIONS
   - B. STARTUP
   - C. POWER
   - D. SHUTDOWN
   - E. COOLDOWN
   - F. TVC INPUT

Figure 127 - TCSS Operational Objectives

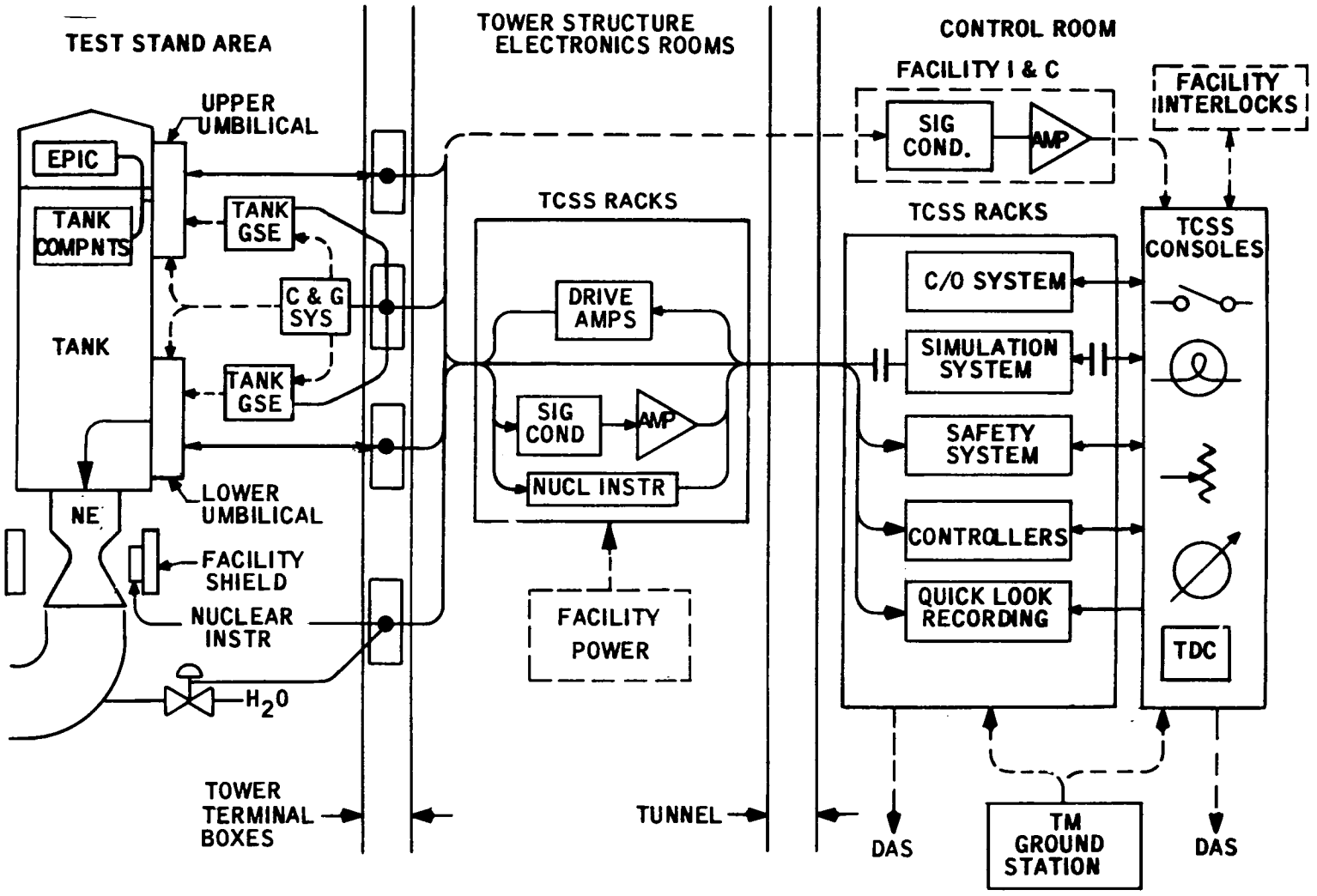


Figure 128 - TCSS Functional Interfaces

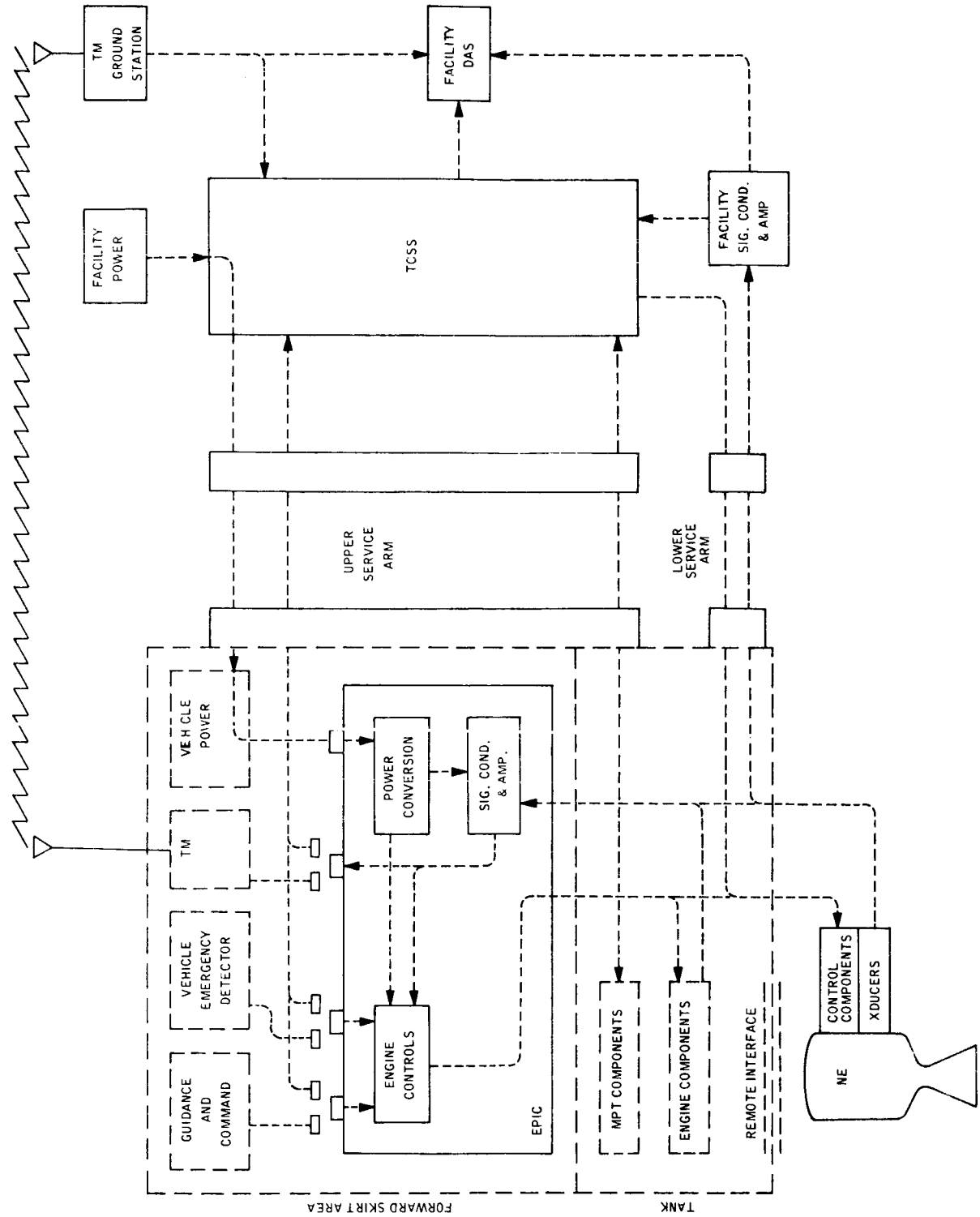


Figure 129 - Integrated NE Engine Controls

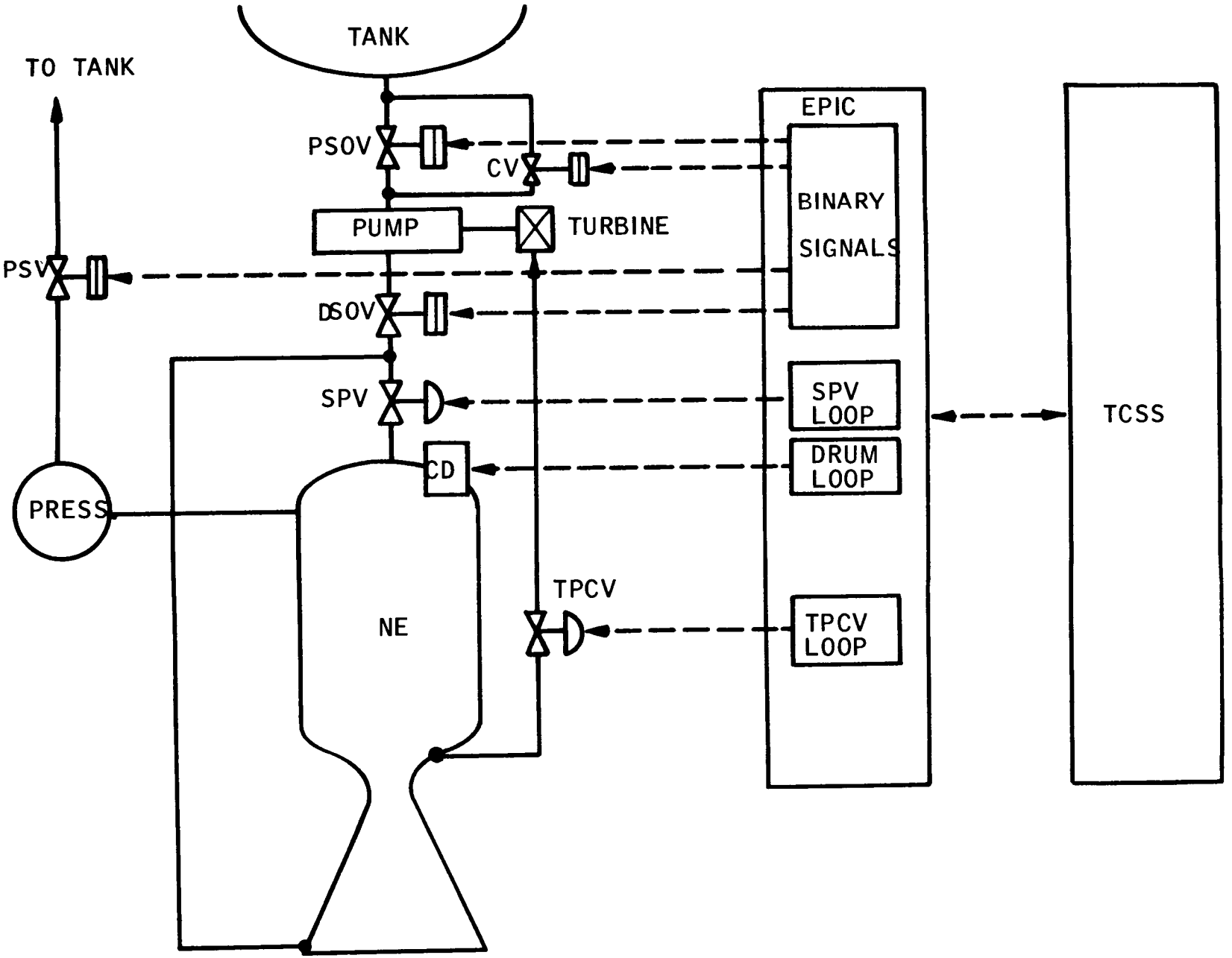


Figure 130 - TCSS/Engine Controls

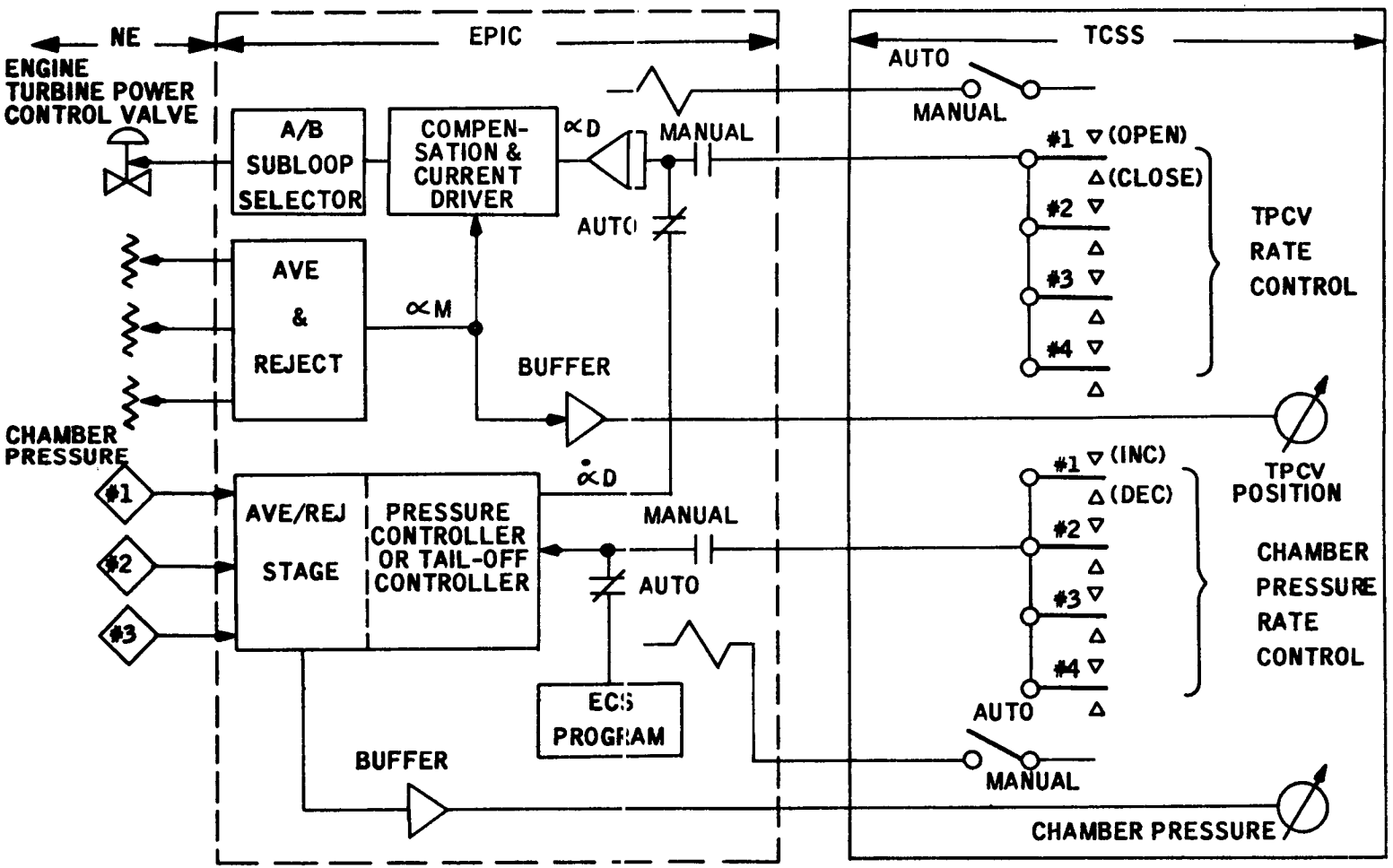


Figure 131 - TCSS/Engine Control Modes

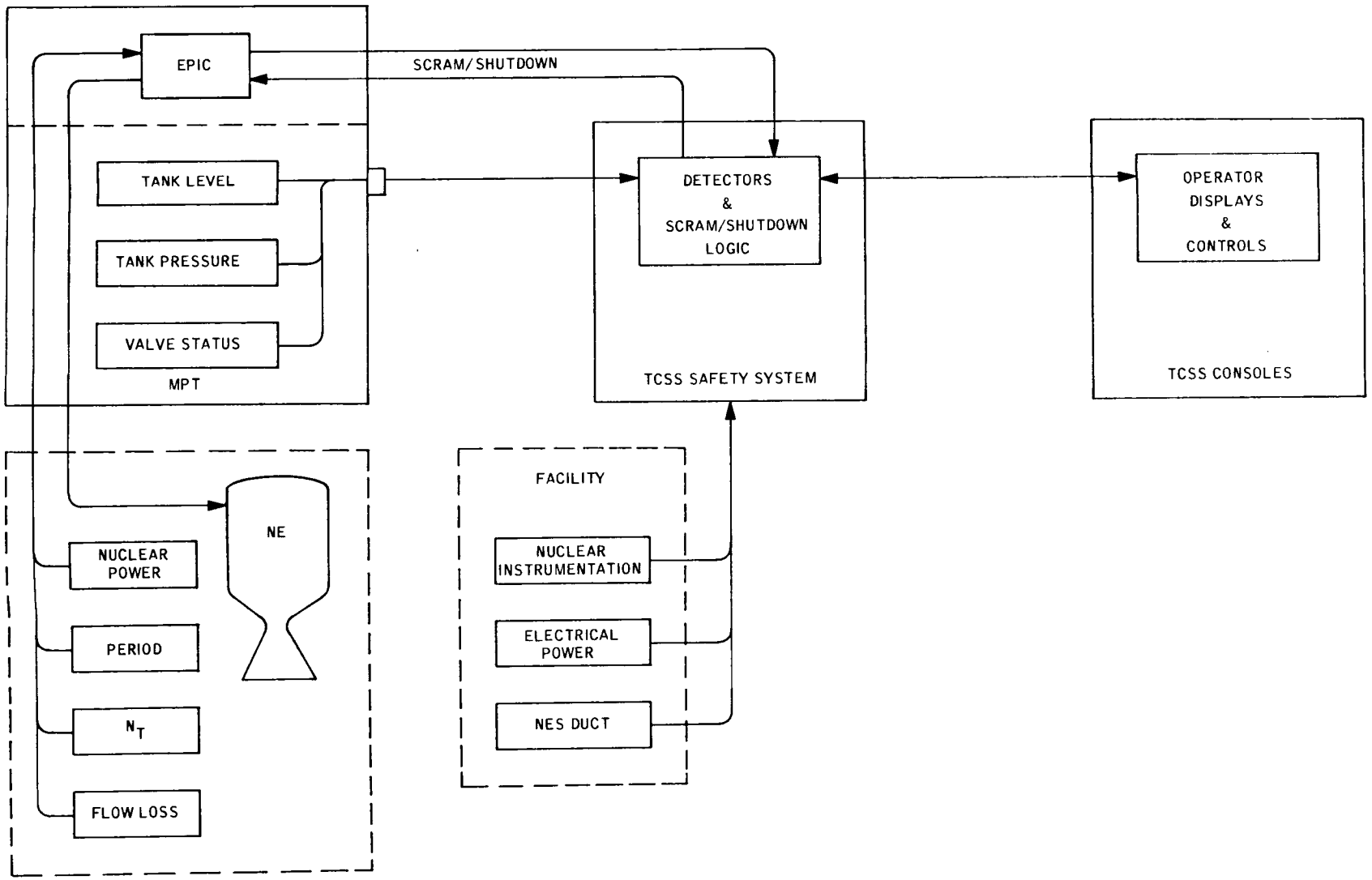


Figure 132 - Integrated Engine/Tank Safety System

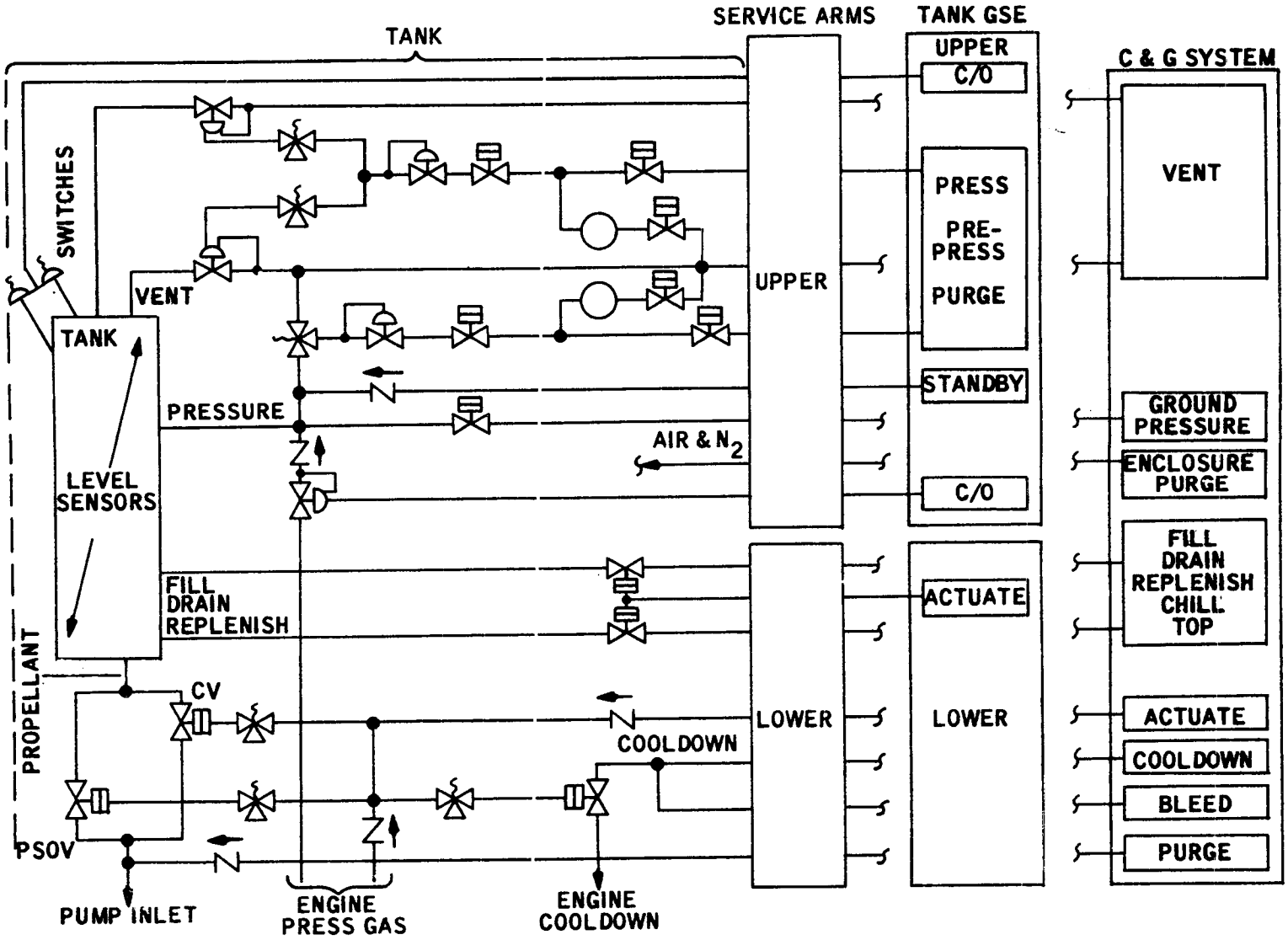


Figure 133 - TCSS-Integrated Fluid Controls

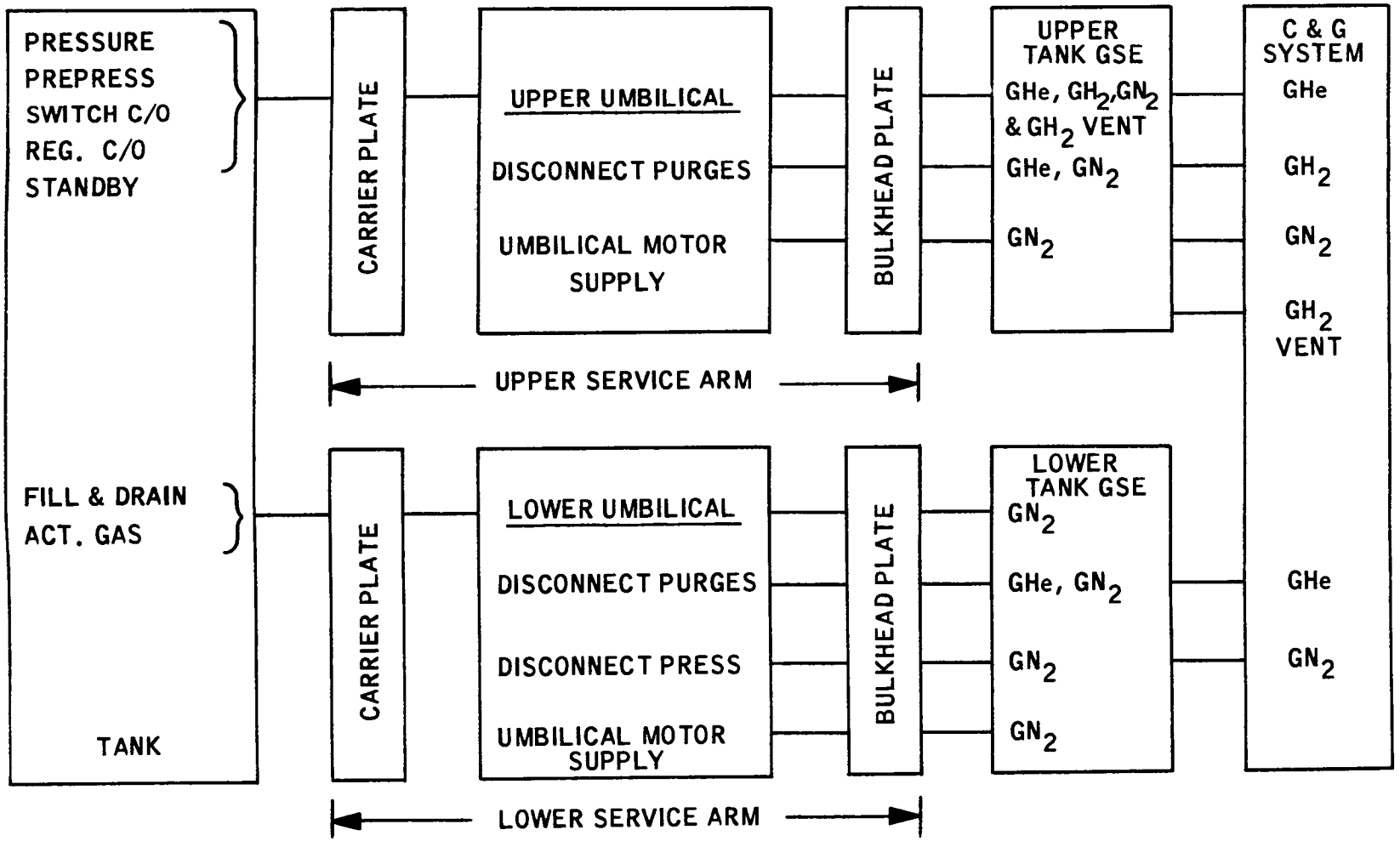


Figure 134 - TCSS-Tank GSE Control

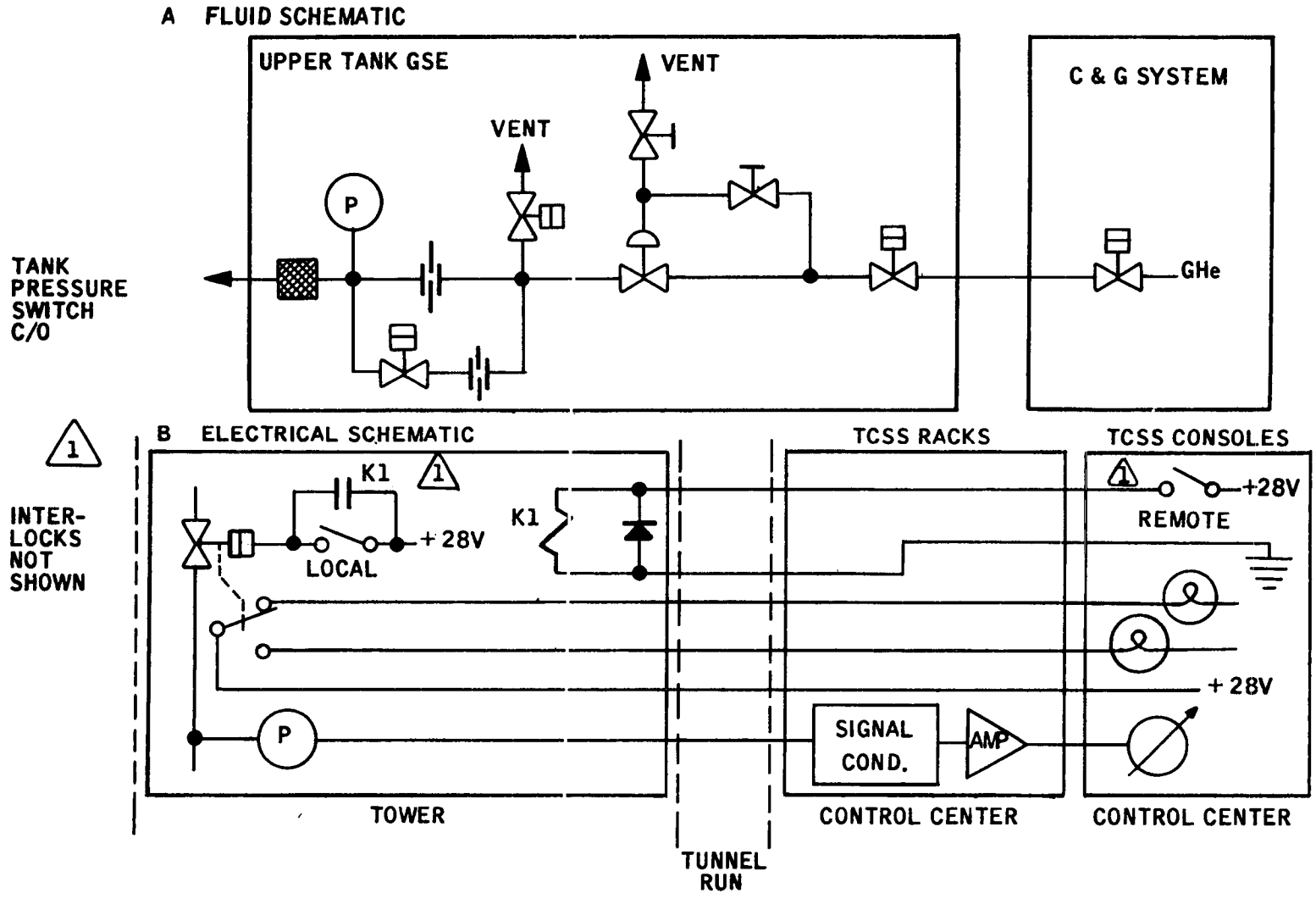


Figure 135 - TCSS/Tank GSE, Typical Control Circuits

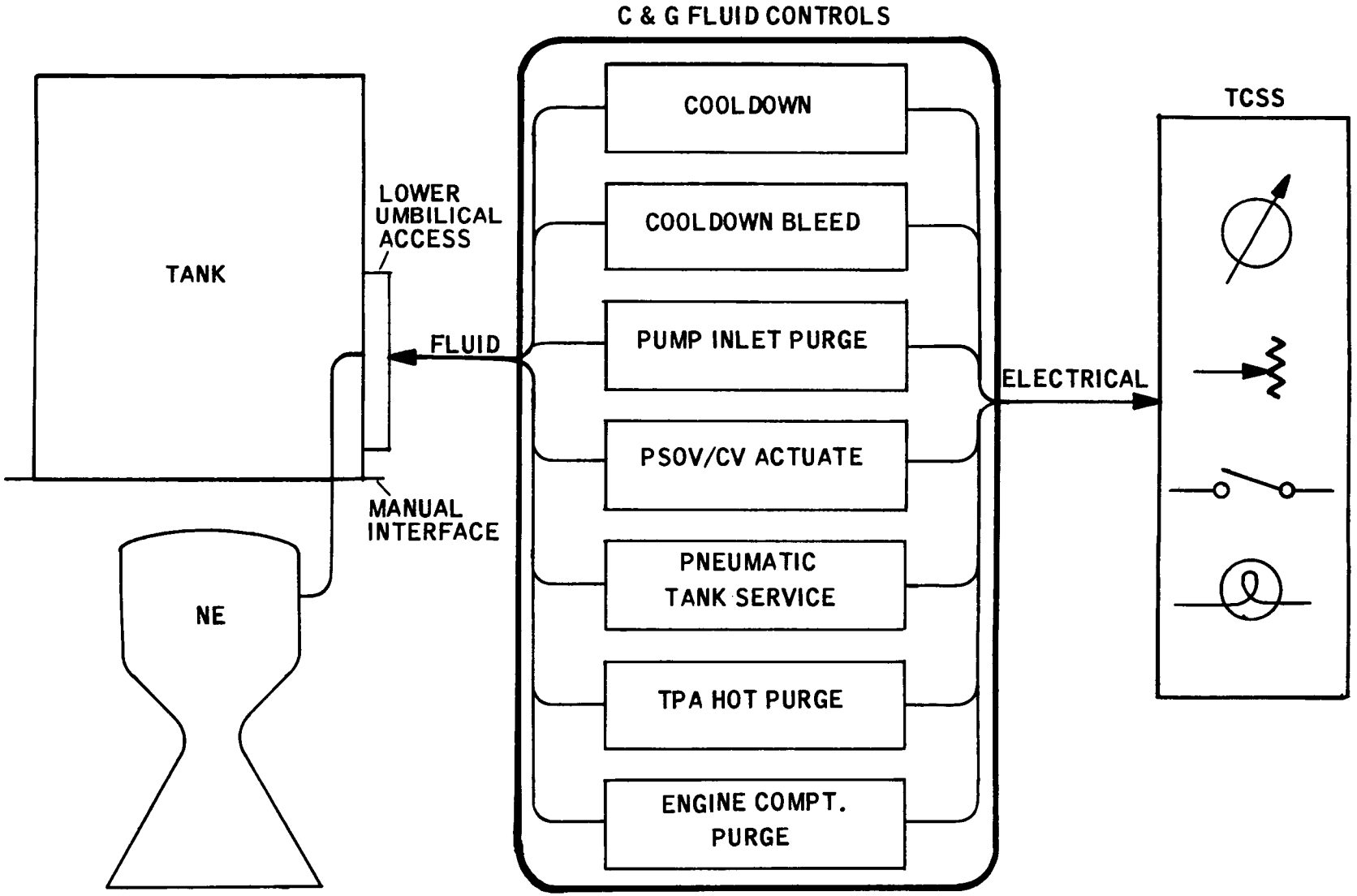


Figure 136 - TCSS-C and G Engine Controls

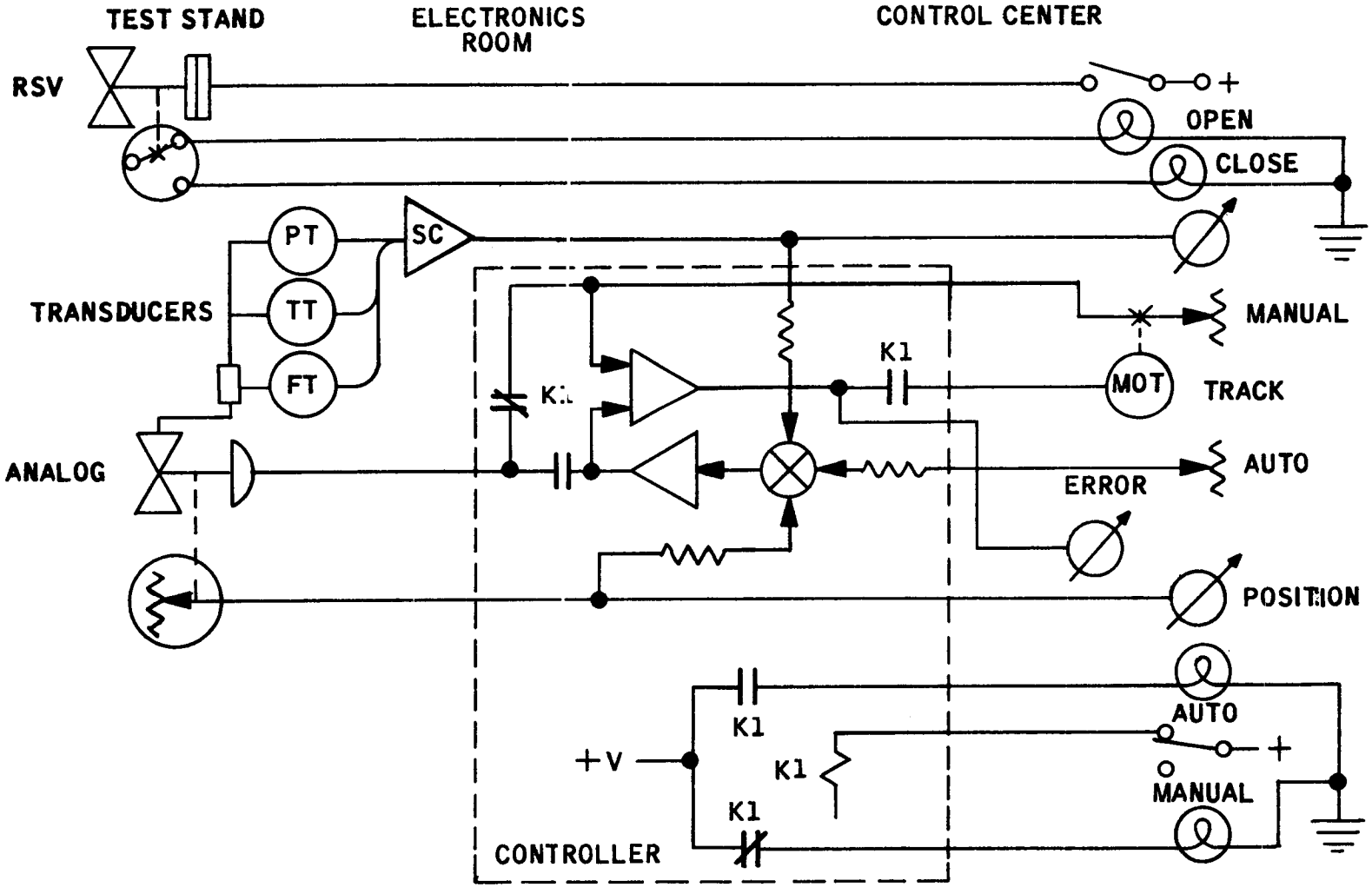


Figure 137 - TCSS-C and G System (Typical Controls)

INTEGRATION

- SINGLE INTERFACE
- STANDARDIZATION
- CONFIGURATION CONTROL
- SINGLE CONTROL SYSTEM
- SINGLE SAFETY SYSTEM

FLEXIBILITY

- ALTERNATE MODES
- INTEGRATED SYSTEM CHANGES

TRANSITION

- FLIGHT SYSTEM COMPATIBILITY
- SYSTEM ANALYSIS

Figure 138 - TCSS Summary

In the last quarter major support was provided for SNPO at Kaiser Engineers, Oakland relative to the E/STS 2-3 I&C system design. The effort included engineering consultation, review of interim designs, specifications and drawings, and of coordination requirements with SNPO. A grounding concept for the entire facility I&C System was provided and was reviewed with Kaiser Engineers prior to submittal as the proposed technique.

Meetings were conducted at MSFC to further define TCSS-to-NGTM system electrical interfaces. Conceptual design were developed for system power control, MGE/ESE/TCSS signal interchange, and the TCSS/TM ground station interfaces.

Subsequently, work was started on detailed TCSS cable routing concepts and signal conditioning and amplifier requirements. Final engineering drawings will be available in CY 68.

Final analog hydraulic valve and transducer specifications generated at the request of SNPO-C were released for use by Kaiser Engineers in the C&G system valve procurement.

b. E/STS 2-3 Facility and Duct Support (3.0.2)

(1) E/STS 2-3 NES Analytical and Experimental Studies

In early 1965 various diffuser concepts were considered for the E/STS 2-3 facilities. A scaled-up ETS-1-type exhaust system was used as the reference point and various configurations to reduce the overall height were evaluated. This led to a scale model test program designed to evaluate various diffuser L/D's, contraction ratios, contraction angles, elbow configurations, film cooling, preliminary water penetration, and water mixing tests. Some significant findings of this program were included in the CY 66 summary report (RN-A-0008). However, most of the testing and analysis was completed and reported on early in this contract year. As a direct result

of this experimental and analytical effort and Aerojet recommendations, a diffuser system was selected by SNPO in January 1967. This configuration consisted of an entrance diameter of 126 in., an L/D = 4, ψ = 1.9, α = 4°, a wet elbow, centerbody ejector nozzles, and a turning deflector. A scale model of this selected diffuser was tested in February 1967. Further testing on stream penetration has been completed at NASA's 6- x 9-ft wind tunnel at Lewis Research Center.

The overall efforts completed during this contract year are as follows.

(a) Wet- and Dry-Elbow Diffuser Evaluation Studies

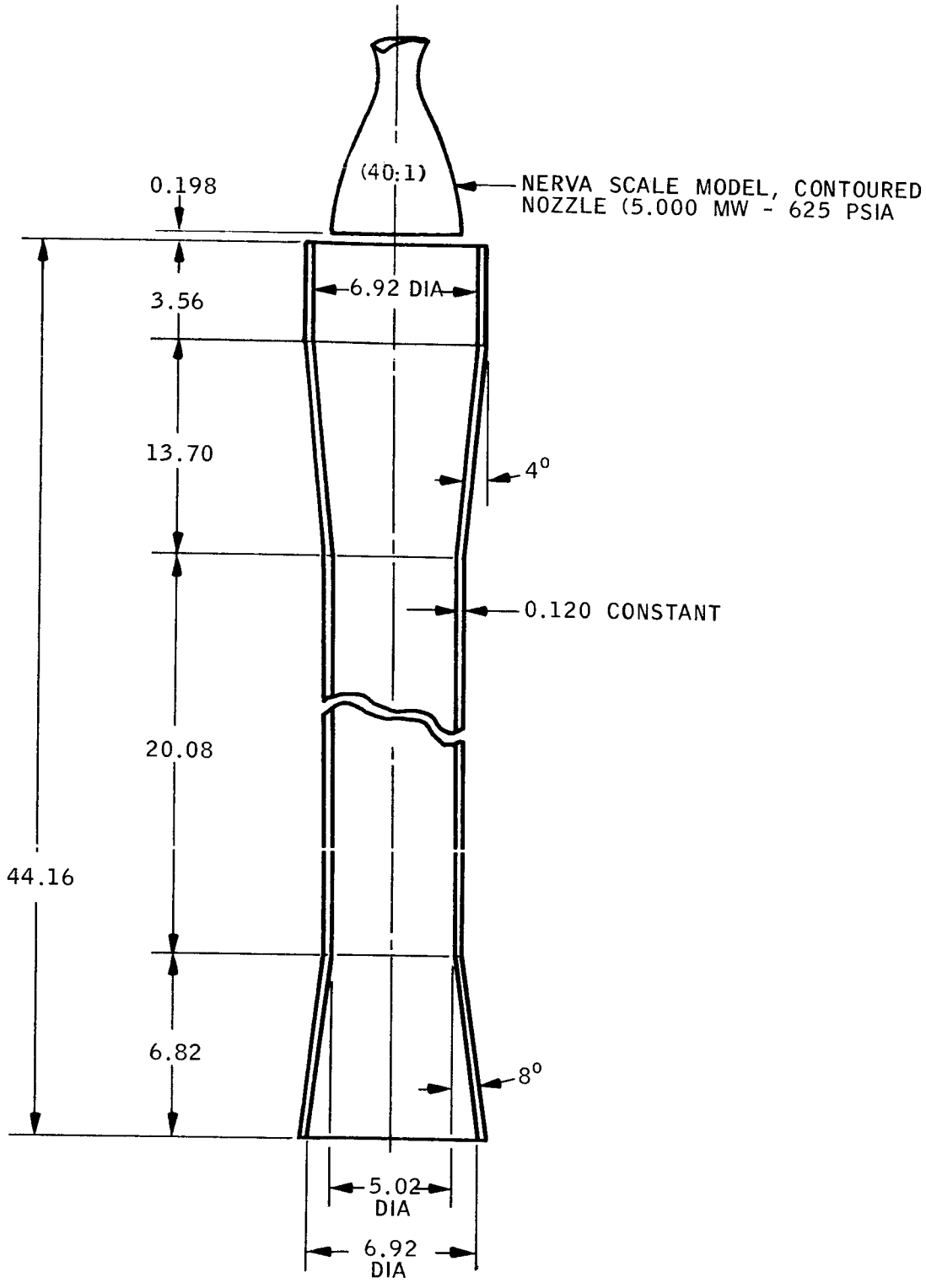
Scale-model testing and the analysis of data were essentially completed and presented in CY 66 Summary Technical Report (RN-A-0008). Final reports, however, were prepared and issued during this reporting period and are as follows:

1 RN-S-0379, Evaluation of E/STS 2-3 Scale-Model Diffuser-Ejector (Dry-Elbow System), January 1967

This study led to the general conclusion that elbow cooling by internal (wet) means is feasible; however, further testing is required before quantitative values can be predicted with sufficient confidence for design of the full-scale hardware.

(b) Selected Diffuser Studies (Evaluation Tests)

A final configuration of the E/STS 2-3 diffuser was chosen by SNPO personnel. A 1:20 scale model of this diffuser configuration was fabricated (Figure 139), and system-evaluation tests were completed. Heat-transfer and aerodynamic tests and analysis with both nitrogen and hydrogen gas at 1500°R have been accomplished. Figures 140, 141, and



NOTE:

ALL ARE INSIDE
DIMENSIONS
SCALE FACTOR 20.22:1

Figure 139 - Dimensions of E/STS 2-3 Selected Diffuser

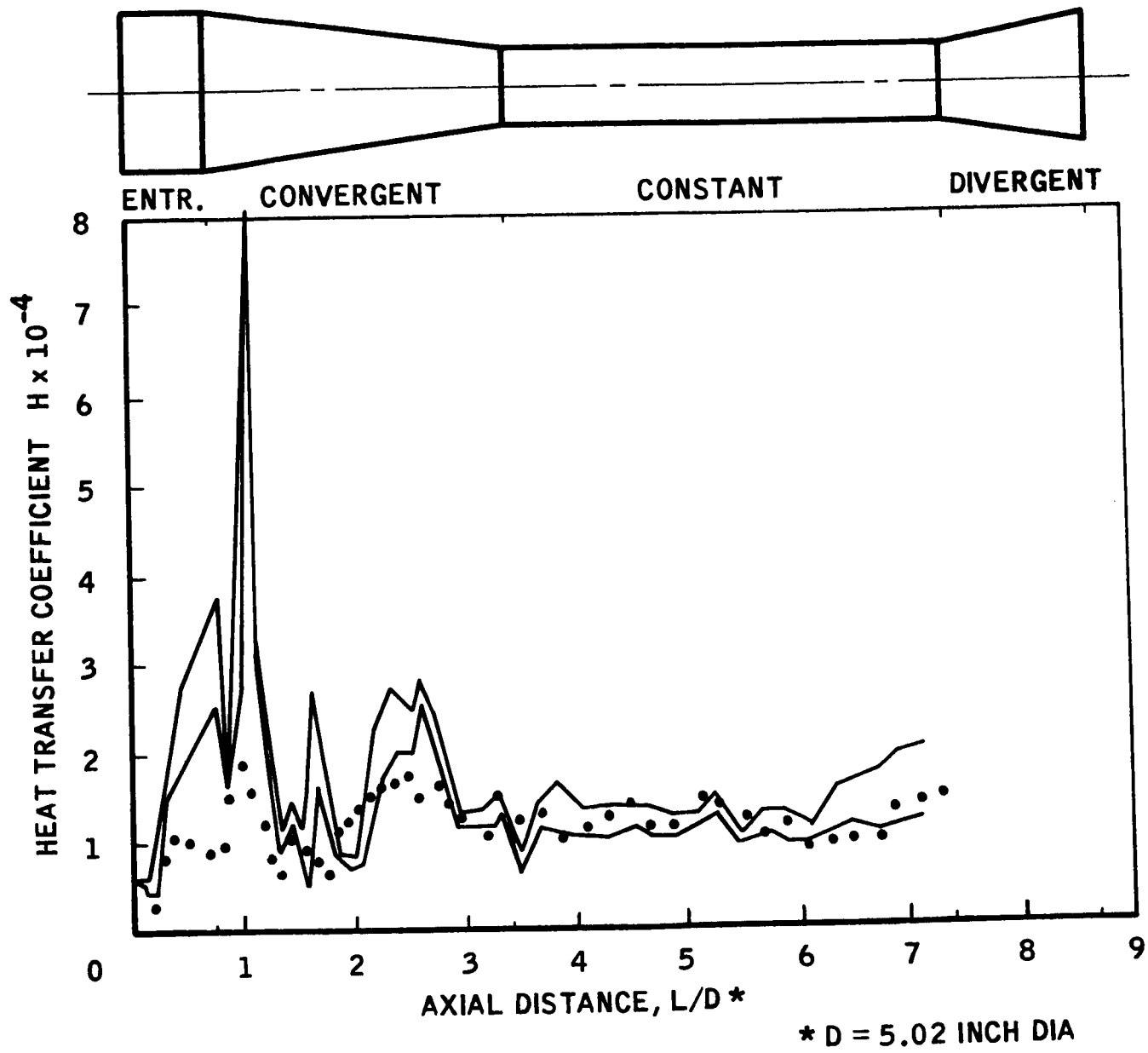


Figure 140 - E/STS 2-3 Diffuser Performance-Selected Diffuser System

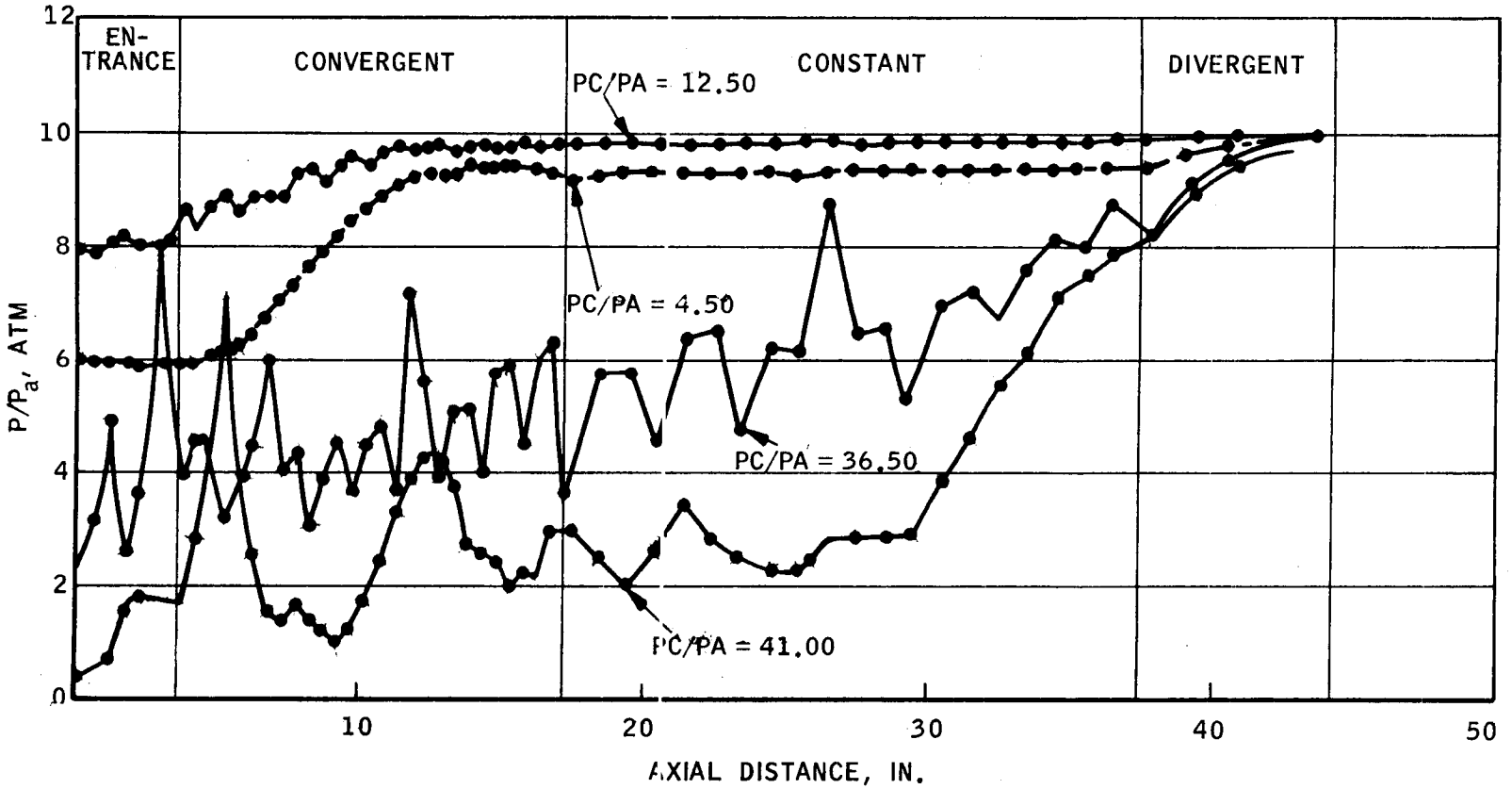


Figure 141 - Axial Static-Pressure Profiles for Various Back Pressures, Selected System, Hydrogen

142 show examples of the test data. Further testing included gimbaled-nozzle tests and reverse diffuser flow tests. Also completed during this period was a 1:20 scale model of the selected elbow configuration (Figure 143). Testing of this system was accomplished under sub-subtask 3.1.1 and is discussed in detail in that section.

(c) Stream-Penetration Studies

A test program to investigate water-jet penetration into a high-velocity gas flow field was completed at the 6- by 9-ft wind tunnel at NASA's Lewis Research Center (LRC) in Cleveland under joint Aerojet and SNPO-C cognizance. This program is an extension of a series of jet-penetration tests conducted at Aerojet's Von Karman Center (VKC) under the E/STS 2-3 NES scale-model test program, reported in RN-S-0380. Limitation on the size of water nozzles that could be adequately tested at the VKC facility (1/2-in. dia) necessitated use of a larger facility, such as LRC's 6- by 9-ft tunnel. This wind tunnel enables water-jet tests of nozzles up to 1 1/2 in. in diameter.

Water-jet penetration data obtained in tests conducted at Lewis Research Center were analyzed. The tests were made with four fire-fighting nozzles and three Aerojet-fabricated nozzles in the 6- by 9-ft icing-research tunnel (IRT) with air at 35°F as the working fluid flowing at nominal velocities of 200 and 300 mph. The nozzles were positioned in the floor of the test section to inject water normal to the air flow; the penetration of the water jets was determined by photographs taken from the side and top of the tunnel. The test setup is shown schematically in Figure 144.

The recorded data included wind-tunnel gas temperature and total and static pressures and the total and static pressures of the water. Photographs of the water jet were made to determine the penetration and the jet spread. The results were reported for camera locations at axial stations 7 and 22 in. downstream from the point of injection.

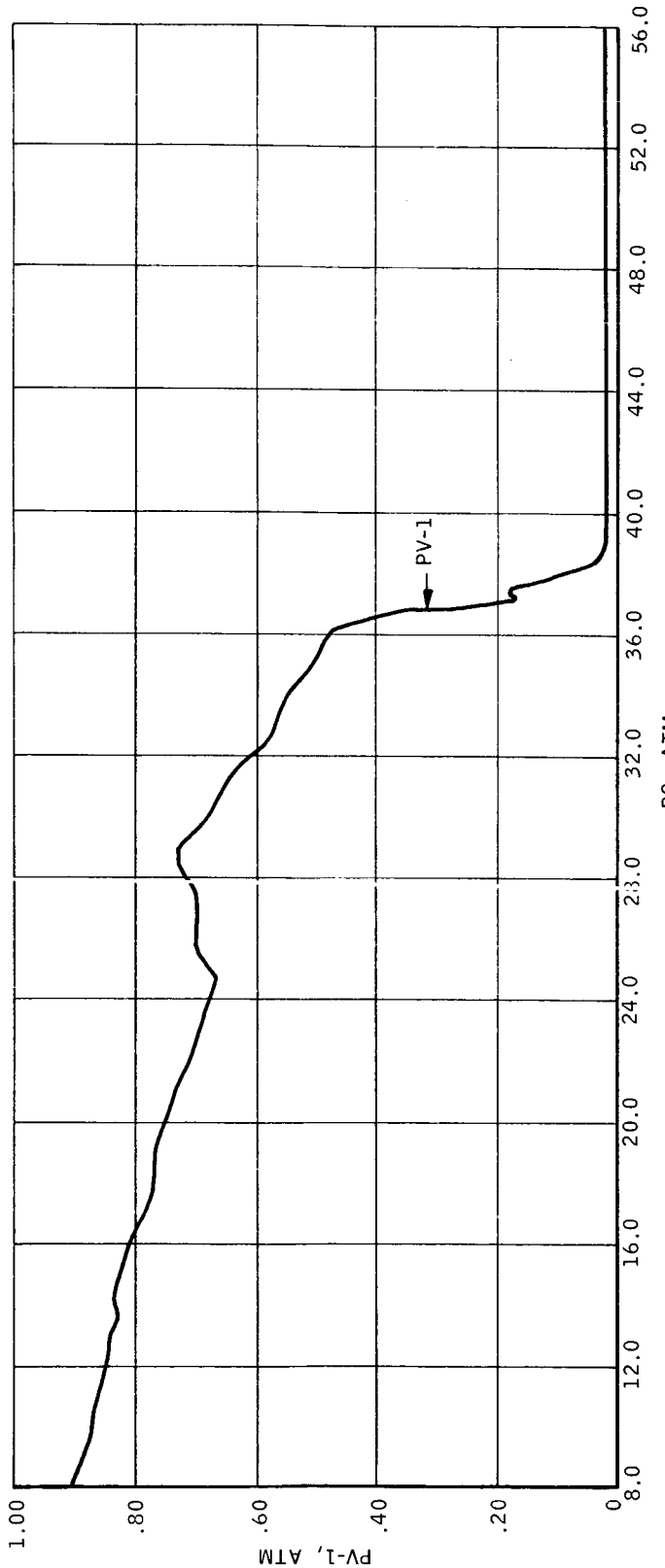


Figure 142 - Diffuser Performance, Selected System, Hydrogen

NOTES:

⊕ MATERIAL TO BE 0.125-IN. THICK

△ MATERIAL TO BE 0.375-IN. THICK

C.S.-CARBON STEEL

S.S.-STAINLESS STEEL

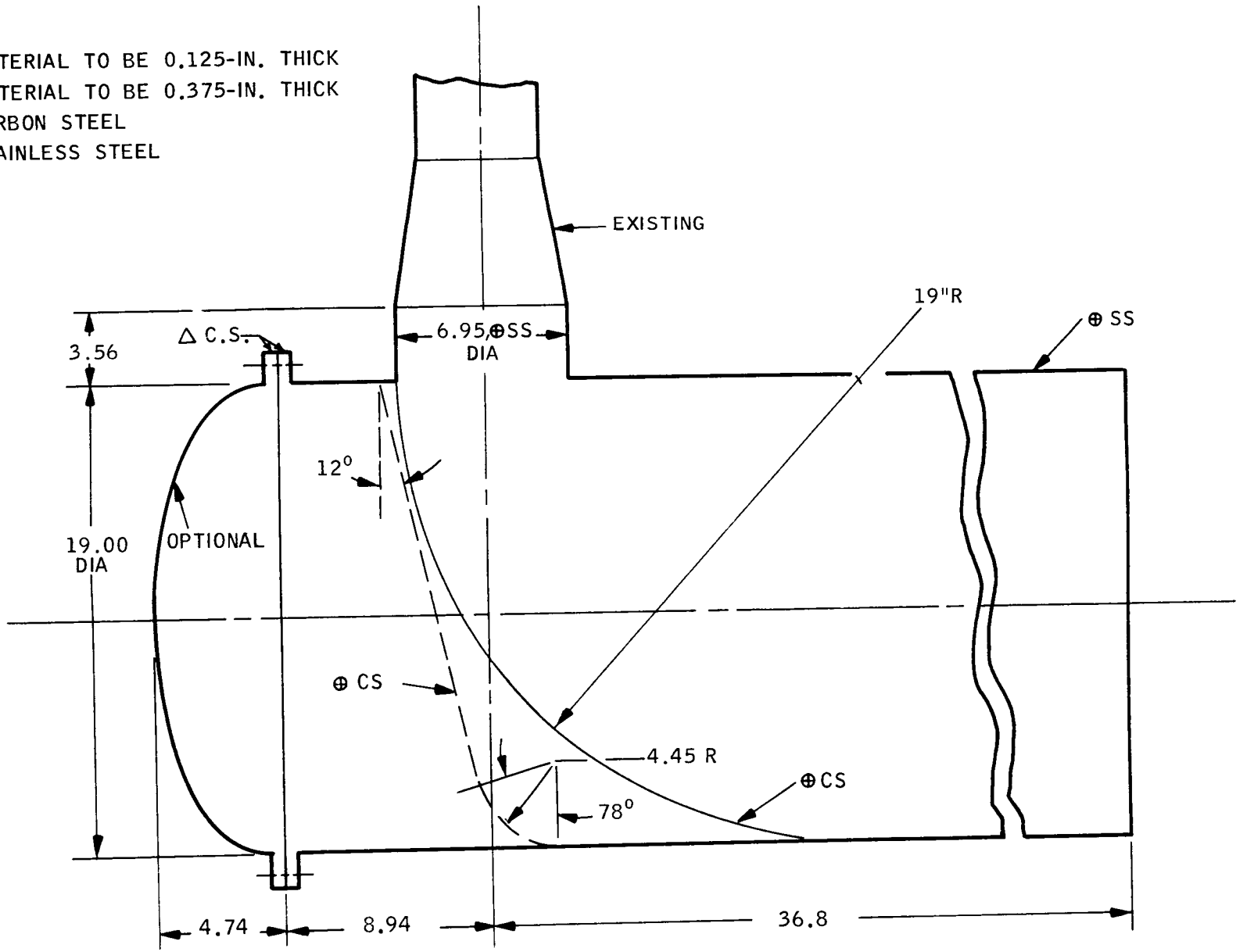


Figure 143 - E/STS 2-3 Subscale-Elbow Configuration

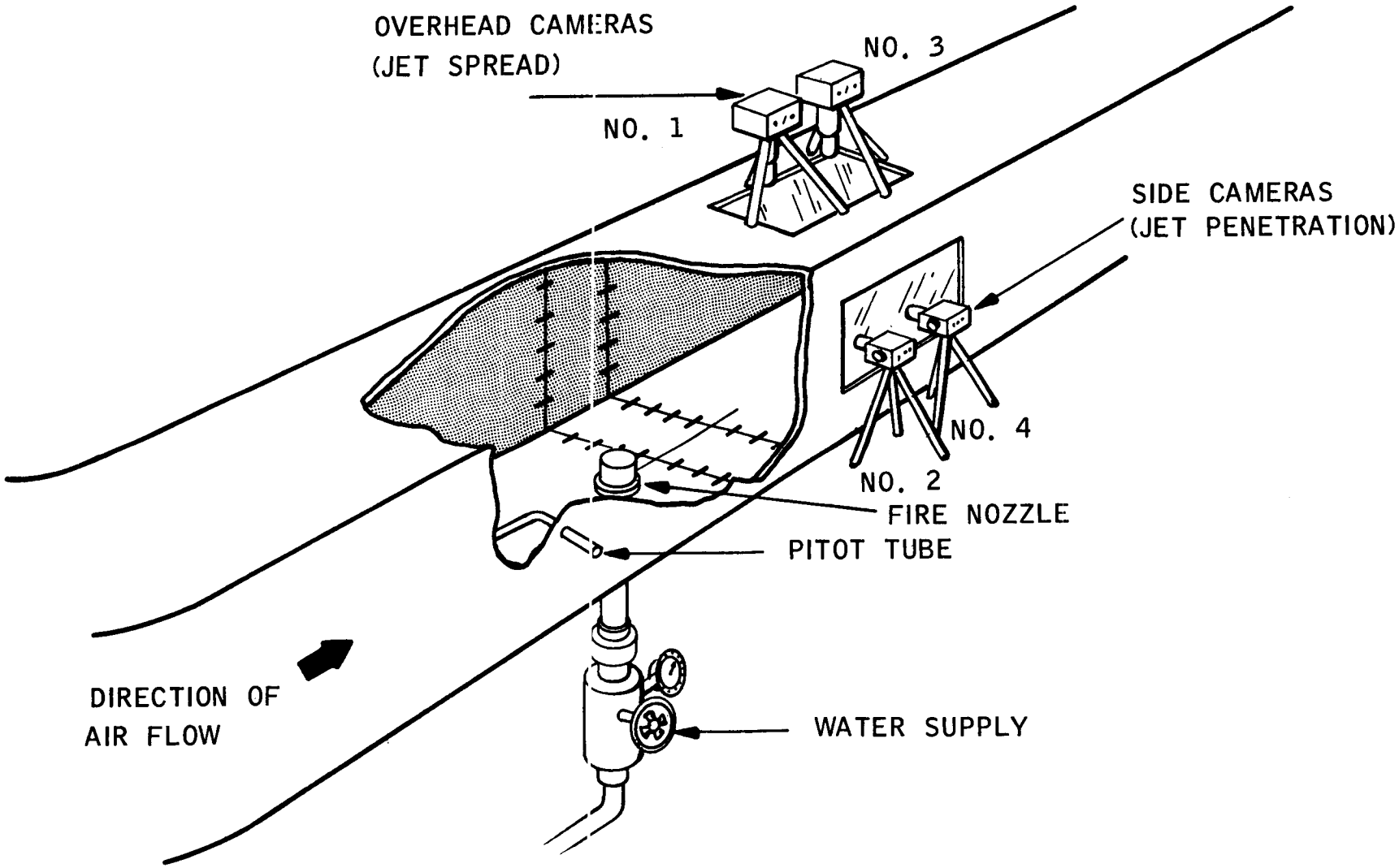


Figure 144 - Test Installation, Lewis Research Center Wind Tunnel

Penetration measurements were based on grids located on the back wall and on the floor of the tunnel. The determination of jet penetrations from photographs showing these grids in the background of the jet required a correction to account for parallax. The reported penetration values have been corrected by preparing a special scale for reading the photographs. Interpretation of the jet spread requires knowledge of the distance from the nozzle exit to the point of maximum jet spread. It was assumed that the approximate point of maximum jet width corresponds to the point on the photograph where the jet is most dense. The parallax in the top-camera reading was corrected by using this estimated point of maximum jet spread.

The analysis, considering the two types of nozzles (Aerojet and fire-fighting nozzles) and the data generated in the original test section at Von Karman Center (Figure 145) give the following empirical relation:

$$Z/_d = 2.0\ (q_j/q_g)^{0.5}\ (X/d)^{0.27},$$

where Z = penetration depth in in.
d = water-jet-nozzle orifice diameter in in.
q_j = dynamic head of water jet $(p_j v_j^2/2)$
q_g = dynamic head of gas flow field $(p_g V_g^2/2)$
X = distance in direction of gas flow in in.

Figures 146 and 147 summarize the LRC data and the VKC data, respectively. More scatter is seen in the VKC data and is believed to be the effect of test-facility limitations. In Figure 148 the effect of Mach number on water penetration is illustrated. Figure 149 compares the two types of water nozzles, and Figure 150 shows an overall comparison of all data. The water-nozzle arrangement for scale-model tests mentioned in this section was designed by using the above correlation. The effect of a varying-Mach-number flow field was also taken into account.

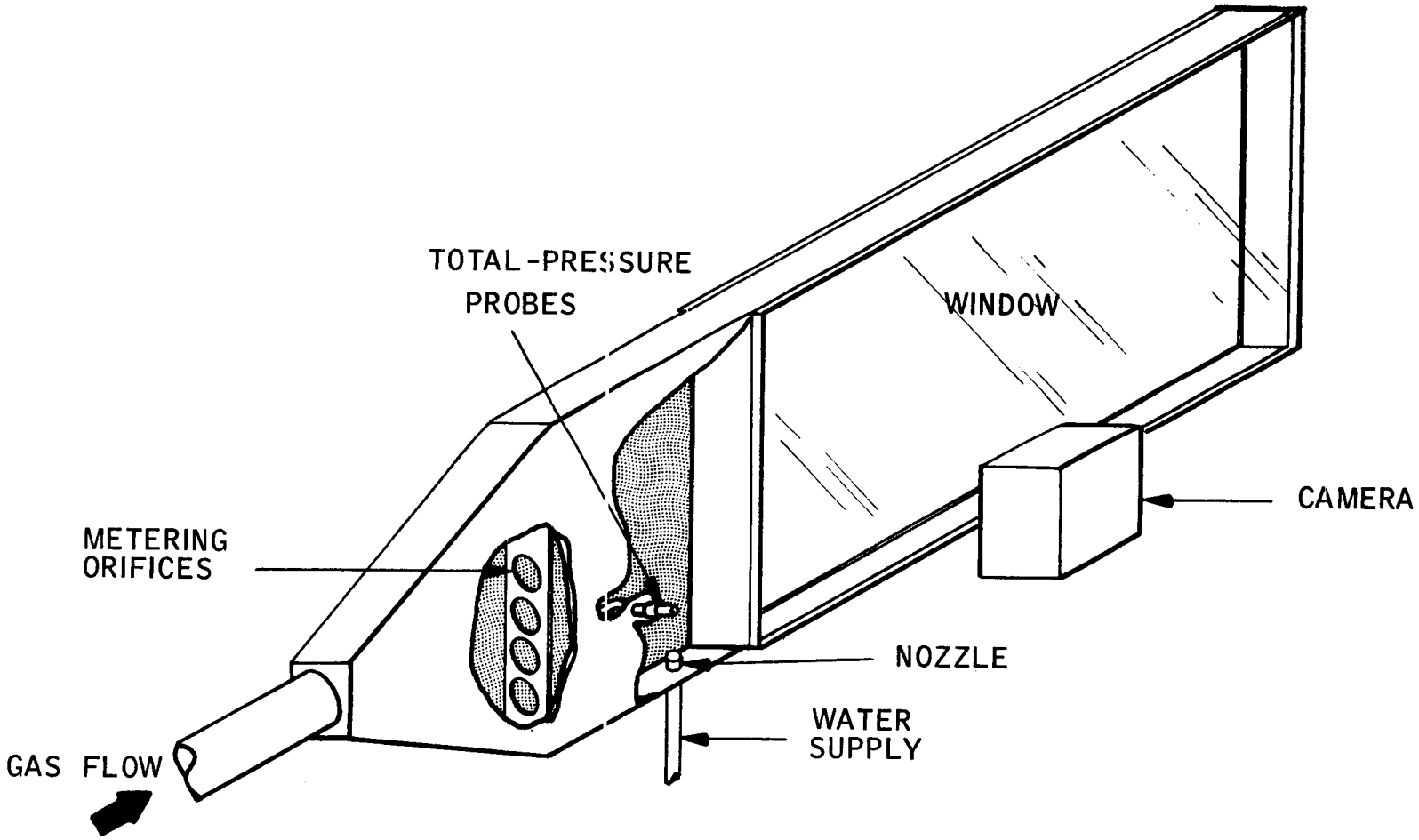


Figure 145 - VKC Test Installation

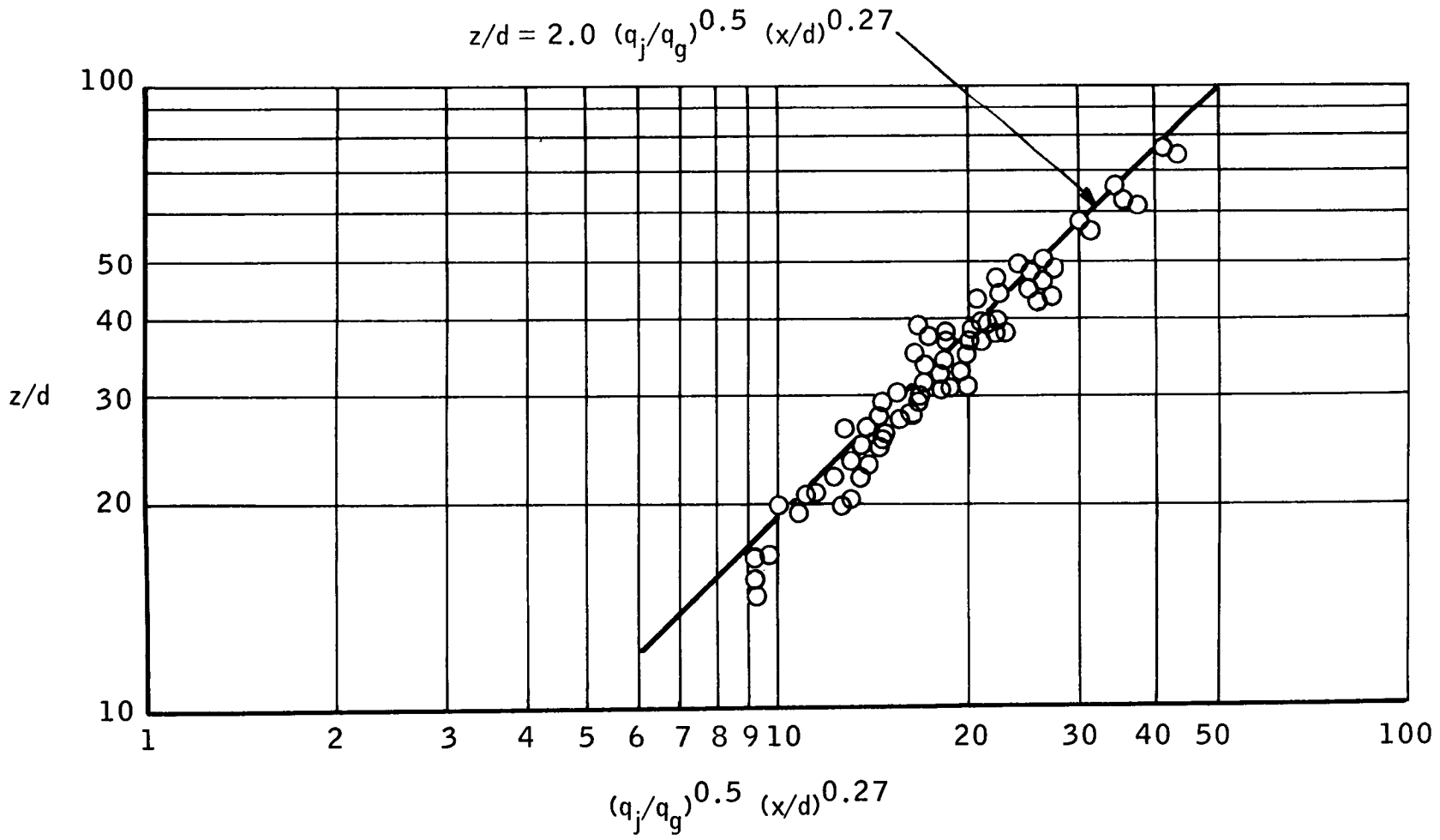


Figure 146 - Water-Jet-Penetration Data, Lewis Research Center

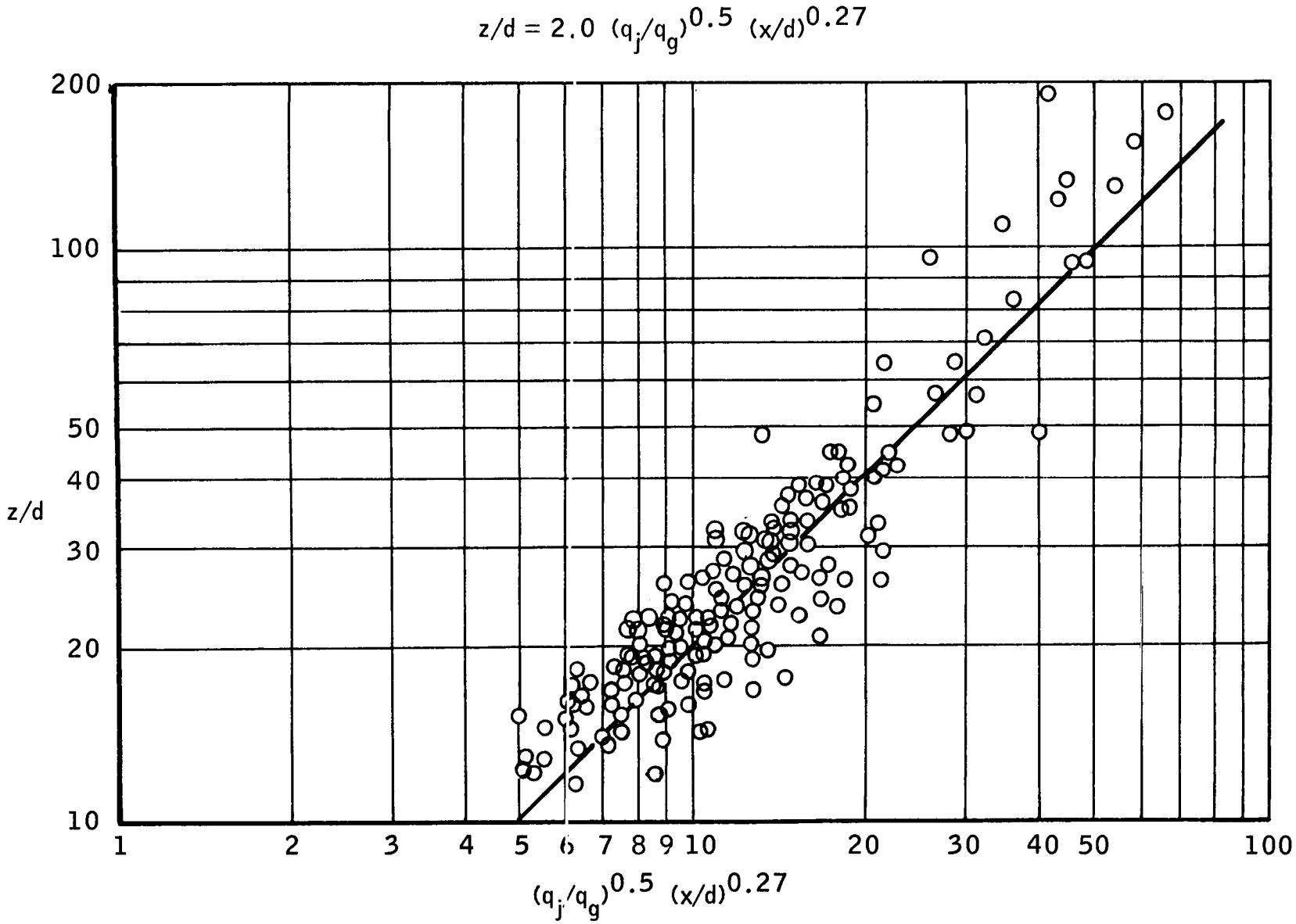


Figure 147 - Water-Jet-Penetration Data, VKC

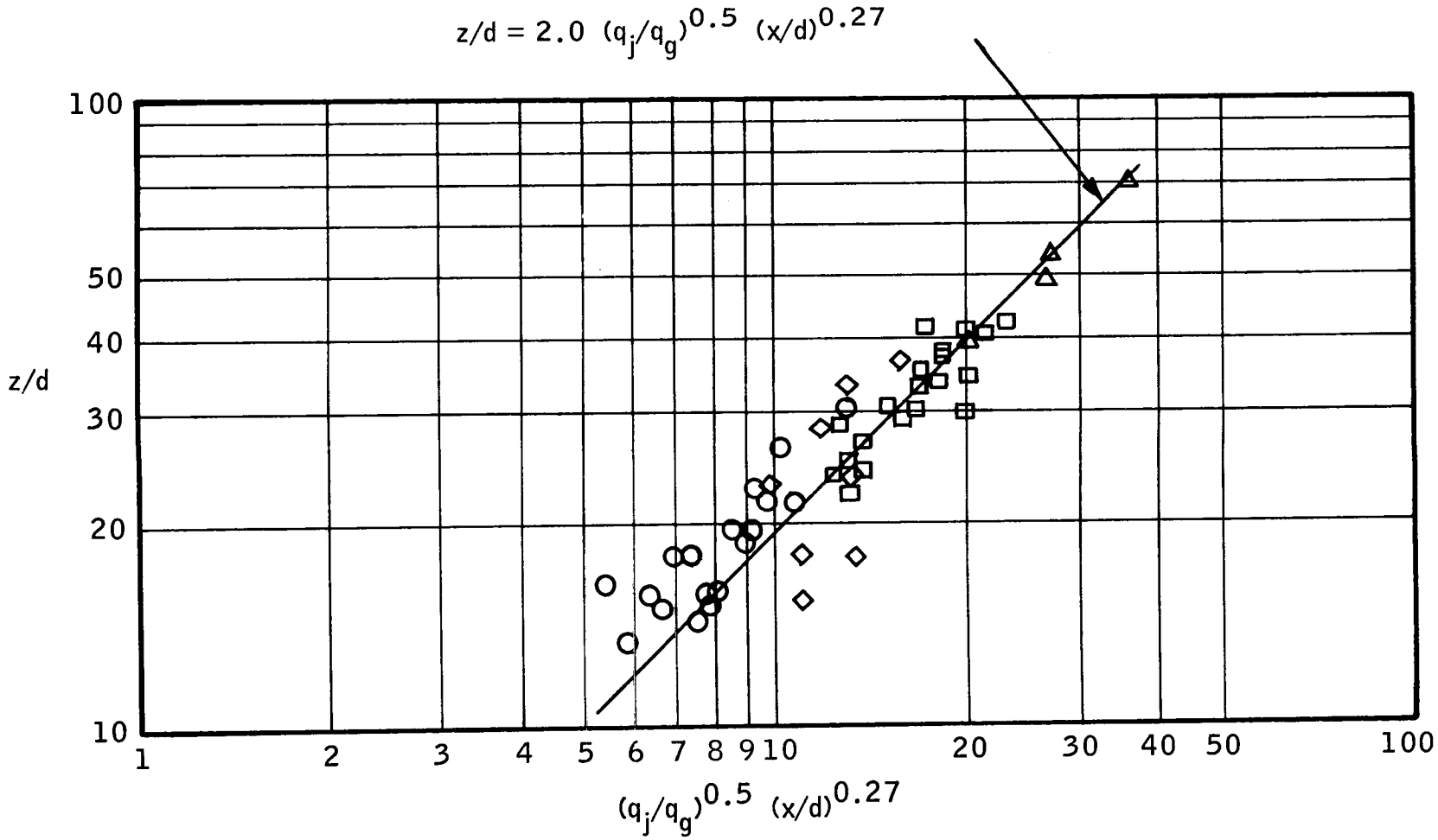


Figure 148 - Effect of Mach Number on Water-Jet Penetration

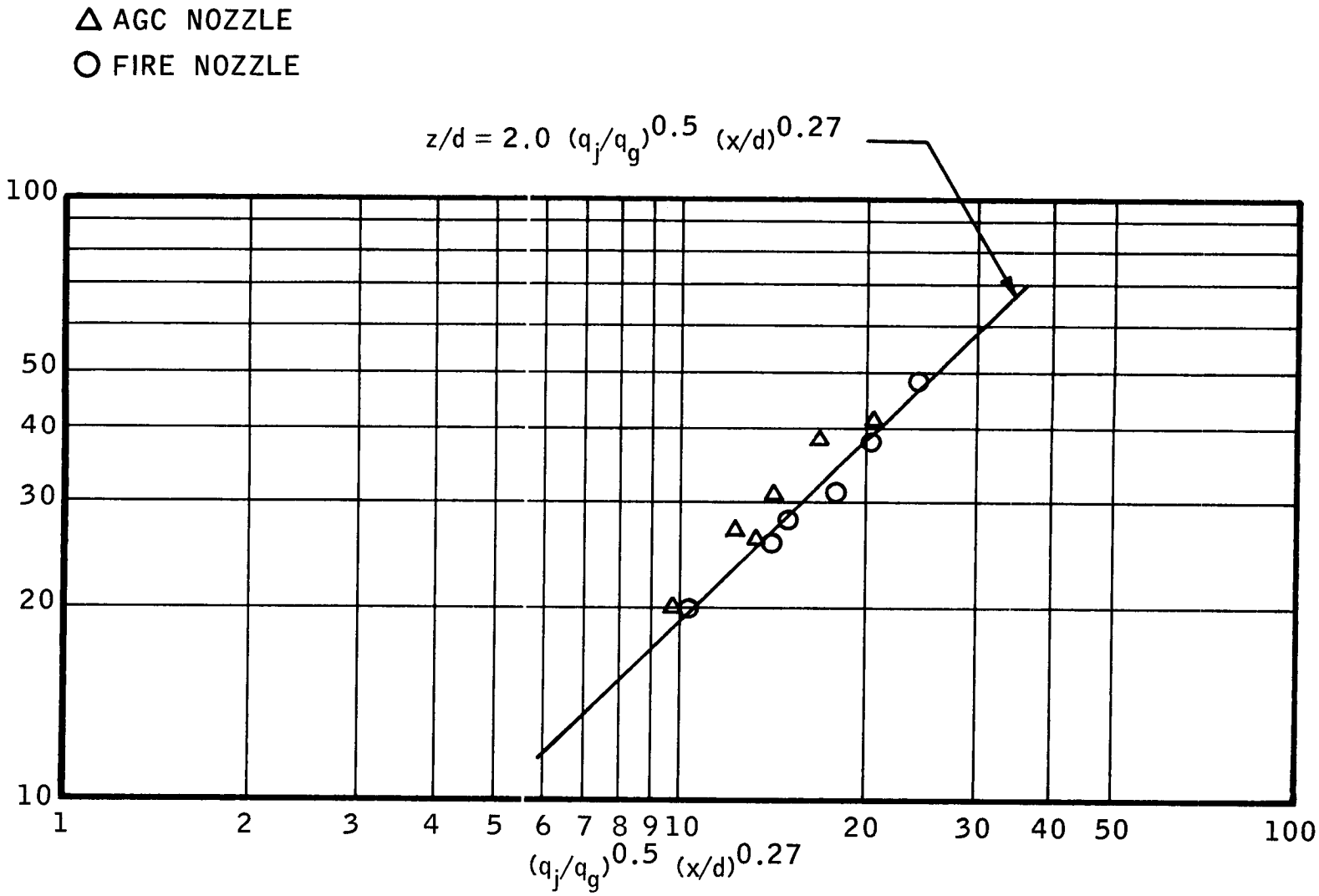


Figure 149 - Water-Jet-Penetration Data, 3/4-in.-dia Nozzle

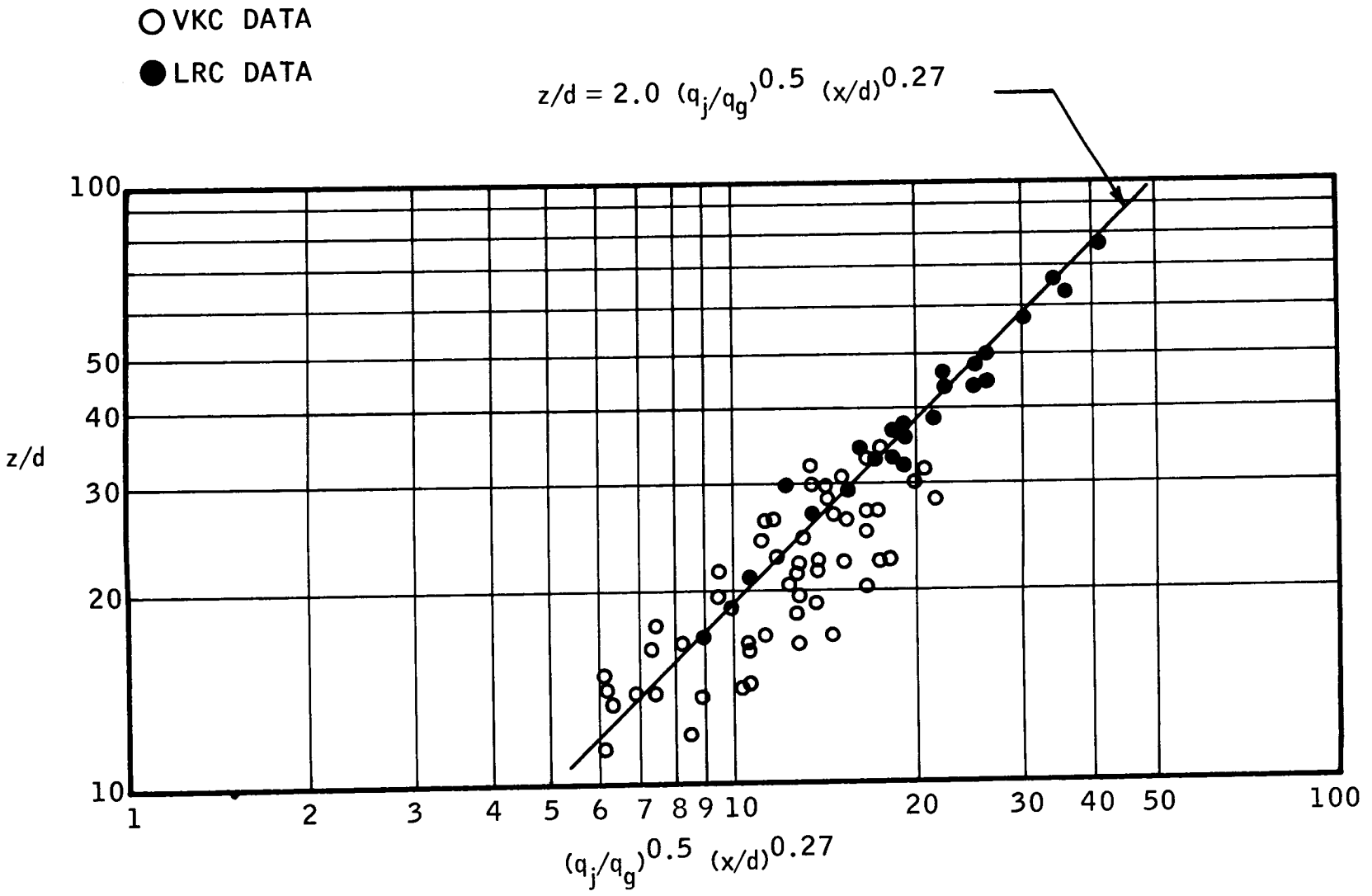


Figure 150 - Water-Jet-Penetration Data, 1/4- and 1/2-in.-dia Nozzles

Scale-model tests were conducted to develop a minimum-length diffuser-ejector design for use in testing 5000- and 10,000-Mw NERVA engines in a simulated space environment. The experiments simulated component parts of the E/STS 2-3 and E/STS-3 test-stand systems in approximately 1:20 scale and were conducted at the Aerojet-Azusa facilities from February through September 1966. The component designs were altered systematically to determine the effects of various diffuser contraction angles, contraction ratios, throat lengths, turning-elbow radii, and downstream constriction ratios on starting conditions and operating efficiency. The system was evaluated by taking pressure measurements and determining wall-heating effects. The study resulted in design recommendations for a diffuser system to be used in a full-scale test facility.

2 RN-S-0380, Evaluation of E/STS 2-3 Scale Model Diffuser-Ejector (Wet-Elbow System), January 1967

Together with the dry-elbow studies, auxiliary test series were conducted to derive preliminary information relative to methods of cooling the walls of the flow-turning elbow in the subsonic portion of the exhaust diffuser system. The methods investigated were:

a Film cooling, which consists of cooling the flow boundary by injecting water through discrete ports in the elbow wall

b Stream saturation, which was investigated to determine the effectiveness of cooling by injecting water directly (both axially and radially) into the hot-gas flow field

c Stream penetration, which was investigated to determine the depth of penetration of a water jet directed normal to the hot-gas flow field.

c. Engineering Support for NRDS Instrumentation System (3.0.3)

(1) ETS-1 Data Acquisition System Accuracy Tests

(a) Preliminary Accuracy Test

The preliminary data system accuracy tests were conducted during the first quarter in accordance with RN-S-0308 Test Specification requirements. Analysis of the preliminary test data was started during the first quarter and continued into the second quarter. A summary report of the preliminary test data analysis was prepared, and an oral presentation was made for SNPO and WANL representatives. The formal report (RN-S-0389) was released during the third quarter.

(b) Final Accuracy Test

The original test specification, RN-S-0308, was revised to incorporate the findings and recommendations of the preliminary report. Revision, RN-S-0308A was coordinated with SNPO-C and WANL prior to initiating final accuracy tests. Arrangements were made with Sacramento Test Division to borrow three precision transducer simulators to be used for the final accuracy tests. NTO test procedures were reviewed and approved prior to the start of testing. Test Scheduling was coordinated with NTO personnel. The final accuracy test was performed during the third quarter under NRO supervision. Testing included the digital data system (narrow band), wideband data system (magnetic tape), and quick-look recorders (oscillographs, strip charts). The data were reduced and analyzed during the fourth quarter. A draft copy of

the final report was reviewed with SNPO-C. The analysis shows that ETS-1 has an excellent narrow-band data system. A formal test report will be released during the first quarter of contract year 1968.

(c) Addendum Test

An addendum proposal, RN-S-0308B, to test the ETS-1 cable, junction boses, and engine/facility interface connectors was started during the third quarter and was released in the fourth quarter. This additional testing was intended to verify the quality and integrity of the diagnostic data channels from the ETS-1 north terminal room out to the UTS/TSA interface.

The addendum test was performed during the fourth quarter. Data analysis was started during this period and should be completed in first quarter of contract year 1968.

(2) ETS-1 Test Diagnostic Center, Design Criteria

A preliminary design criteria document, RN-S-0395, was completed during the third quarter and was distributed for review and comment. Revisions and recommendations were incorporated and a final version of the TDC criteria was issued.

The TDC criteria document defined the methods for obtaining on-line data availability for interpretation and evaluation of the performance of the X-engine and its major components.

(3) UTS Closed Circuit Television

(a) Plug 39

Support activity was provided for procurement, transmittal, and delivery of special plugs (P-39) to NTO for use in satisfying UTS television requirements. Cable- and plug-mating buildup problems were coordinated with NTO personnel.

(b) Power Supply

The requirements for a 110 vdc power supply to be used for UTS television lighting purposes were coordinated with NTO. The power supply was procured, tested, and delivered to NTO on schedule.

(4) NES Instrumentation Activities Support

(a) Vibration Isolation

NES duct vibration during flow testing identified transducer mounting problems. A study of data resulted in the design of a vibration damper and the remounting of several transducers for mechanical isolation.

(b) Sound Pressure

Coordination and engineering support for defining requirements for sound-pressure-level measurements in the engine test compartment and near-field locations were provided. Subsequent efforts were extended to delivery, installation, and checkout of the acoustic transducers for ETS-1 use.

(c) Damaged Transducers

Support was provided to NTO in replacement of damaged or out-of-specification duct transducers during the NES test program. Deletion of several parameters was coordinated with NTO.

(d) Stand Heating

Instrumentation for the determination of test stand heating, caused by the exhaust plume was provided. Recommendations of the thermodynamics and structures departments were studied and a measurement list was prepared.

(e) SPEAR Support

Assistance was provided to SPEAR Committee activities throughout the NES test program in reducing and analyzing test data and subsequent followup on instrumentation problem areas.

(f) PCV-449 Reliability

Support to NTO was supplied for resolution of the questionable reliability of the main control valve PCV 449 for NES duct demonstration testing. An analysis of the valve performance was completed and a prediction report was issued.

(5) Additional Facilities Instrumentation Support

(a) Greely Event

Data from the Greely Event, (Nevada Nuclear Tests) were reduced from magnetic tapes and reproduced on IBM cards prior to entry into a digital computer. Cards were forward to John A. Blume

Associates, San Francisco, for power spectral density analysis and other computations.

(b) ETS-1 Grounding System

An analysis of the ETS-1 electrical grounding system relative to lighting protection was conducted in collaboration with NTO personnel. It was concluded that the grounding system is adequate.

2. NERVA Exhaust System; ETS-1 Nuclear Exhaust-System Support (3.1 and 3.1.0)

a. NES Duct Coolant System

(1) Hydrostatic Proof Tests

During preparation of the preceding annual report a failure during proof test occurred in the inner wall of the duct drain tube. This area was strengthened, repaired, and was satisfactorily proof tested to 360 psig. Report No. RN-TM-040, ETS-1 Exhaust Duct Repair, is a detailed discussion of the failure and the repair.

(2) Water Flow Tests

From a common water inlet to the duct, the coolant flow splits three ways to each of the three major sections: the primary, the elbow, and the secondary sections. Further, the lower eight tubes of the secondary section (which also cool the drain pipe) comprise a separate coolant circuit. Orifice plates at the outlet of each separate circuit are used to balance the flow to obtain the proper flow division. The duct as delivered had orifice plates installed (bore diameter based on calculations), but had not been flow tested.

Test Specification No. 101, Duct Coolant System Water Flow Tests was released. Several water flow tests were performed in accordance with the requirements of this specification to demonstrate (1) flow stability, (2) proper flow distribution between the various flow circuits, and (3) required minimum flow rates obtained at minimum feed pressure (low-tank-level) conditions.

To obtain the required minimum flows to each section and the correct flow split, the following changes were necessary during the course of testing:

(a) The orifices were removed entirely from the secondary section.

(b) The orifices downstream of the primary section were replaced with larger (6.0-in. dia) orifices.

(c) The orifice downstream of the lower eight tubes of the secondary section was removed, and the discharge line was disconnected from the discharge manifold. Outlet flow now is directly to atmosphere.

With these changes satisfactory flows were obtained. During early testing high-pressure drop across the orifices of the primary and secondary sections caused vibration due to cavitation. However, changes 1 and 2 above, although made for other reasons, solved this problem.

b. Steam Generator - System Improvement Program

This program was initiated to incorporate improvements indicated by testing during the SGS development test program. Test Specification No. 001, Steam Generator System Improvement Verification Tests was issued, and defines the system modifications and the testing required.

The first test, GEP-IX-1, was a water-flow test to check modifications made in the coolant water circuitry. The test was completed satisfactorily, and no flow anomalies were observed as a result of the water system changes. Test GEP-IX-2 was unsatisfactory in that one module (No. 3) could not be started. This problem was attributed to a malfunctioning LOX

bleed valve and was unrelated to the recent system modifications. The delay, however, led to the decision to incorporate the GEP-IX-2 and 3 tests into the later NES Phase I tests. Subsequent SGS operation was satisfactory and all GEP-IX test objectives, including generator switching, were met.

c. NES Design Demonstration Tests - Phase I

Phase I tests were those conducted with the Temporary Engine Compartment (TEC). Test Specification No. 201, NES Design Demonstration Tests, Phase I was issued giving the requirements for the test program. Four tests (NEP-I, II, III and IV) were performed.

With GN_2 used to simulate engine-exhaust flow, the engine and duct performed as expected and verified the ability to pump down the engine compartment pressure to simulated altitude conditions of about 1 psia or less. Another important result was the demonstration that the SGS serves its intended function of prohibiting air back flow into the duct in the event of a sudden termination of primary (engine exhaust) flow.

A SPEAR (Systems Performance Evaluation and Review) Committee was formed for data review. The group released in February 1967 a preliminary report titled SPEAR Summary Test Report, Phase I NES Design Demonstration Tests. A final report will be issued after completion of Phase II of the test program.

d. Steam Generator Malfunction Problems

Safety evaluation of the NES, assuming a malfunction shutdown of the SGS during conditions of low H_2 primary flow, indicated two possible problems:

(1) A pressure overshoot above 1 atmosphere during ETC repressurization. This is a problem in that the ETC latches were not designed for positive pressure.

(2) Air entry into the duct and possibly the ETC leading to combustible or explosive air/H_2 mixtures.

During the latter part of the contract year special attention was given to these problems and to possible solutions:

(a) The first tests under Phase II of the NES Design Demonstration Program were made to determine if problems exist. As discussed in subsequent section (5), the tests confirmed that problems exist and improvements and changes are required.

(b) A modes of failure analysis of the SGS, duct, and ETC was completed. Included with the analysis were recommendations for several system improvements, which have since been incorporated to increase system reliability.

(c) Various steam accumulator concepts were investigated for use as a backup system for the SGS. With this system a tank containing either steam or superheated water (flasher tank) floats on the steam line. In the event of SGS failure, the blow-down of the accumulator provides sufficient steam to repressurize the ETC without air intrusion into the duct. A plain steam accumulator concept (as opposed to the flasher system) was selected and design drawings for tank fabrication and installation were completed. Fabrication and installation of this system is being held up, however, pending investigation of the following system.

(d) Another system currently being evaluated introduces helium gas into the ETC for repressurization if an SGS failure occurs. With this system a sensor system detects and analyzes any steam pressure decay, and if an SGS failure occurs a signal causes a fast-acting valve to open, which admits the helium.

e. NES Design Demonstration Tests - Phase II

Phase II tests are being conducted with the permanent Engine Test Compartment (ETC). Test Specification No. 202A NES Design Demonstration Tests, Phase II was issued, which gives the requirements for the test program. Run NEPN-1 was conducted. Although the generators were started only once, they were brought to full steam and returned to idle five separate times during the run, and five separate experiments were performed. These experiments were primarily safety tests designed to evaluate air backflow into the duct or ETC during various types of shutdowns. GN_2 was used to simulate engine primary flow.

One possible adverse effect of air backflow is overpressurization of the ETC. The tests demonstrated that without primary flow no overpressure occurs during SGS shutdown in either a normal or simulated malfunction mode. In the normal shutdown the modules were turned off one at a time, and for the simulated malfunction both modules were turned off at once. However, with the SGS inoperative, some overpressurization occurred in all tests during the termination of primary flow. With rapid termination of primary flow (252 psi per/sec), a condition that might occur due to an engine malfunction, an ETC overpressure of 1.6 psi was measured. Because of this condition the ETC latches, which were not designed for any positive internal pressure, are now being modified for 2.0 psi.

The other possible adverse effect of air backflow is that the air may react with hydrogen in the ETC or duct. The tests showed that with

low primary flow air will back-flow all the way to the ETC if one or two generators malfunction, confirming the use of an SGS safety back-up system.

A preliminary report, SPEAR Report NEPN-1, was issued in July, and a final test report will be issued at the completion of Phase II.

f. Duct Drain Tube Modification

A design was completed and a modification kit was supplied to NTO for the addition of this equipment.

Safety analyses of air intrusion into the duct indicated air entry into the drain tube may occur under conditions of SGS off- and low-GH_2 flow as in pulse cooldown. The condition occurs as a chimney effect, because the GH_2 flowing in the duct draws air up through the drain tube. To resolve this problem a U-tube (manometer) type water trap was designed and fabricated. This trap is attached to the end of the existing drain tube. Any excess water is gravity-drained from the duct as before, but air back-flow is prevented.

3. Duct Analytical and Experimental Support (3.1.1)

Analytical and experimental efforts were directed toward evaluation of the 1:20 scale E/STS 2-3 selected NES system shown in Figure 151. These efforts were mainly concentrated on (1) the diffuser without a plenum elbow; (2) a diffuser with a plenum elbow and no water injection; and (3) a diffuser with plenum elbow and water injection. These wet- and dry-elbow experiments were conducted at the Aerojet Von Karman Center test facilities in June 1967. The purposes of the tests were to obtain additional data relative to the fluid dynamic and heat-transfer processes in a diffuser plenum system such as that planned for E/STS 2-3 and to demonstrate that the plenum would be cooled by the water injection. These duct tests were conducted with 1/20 scale

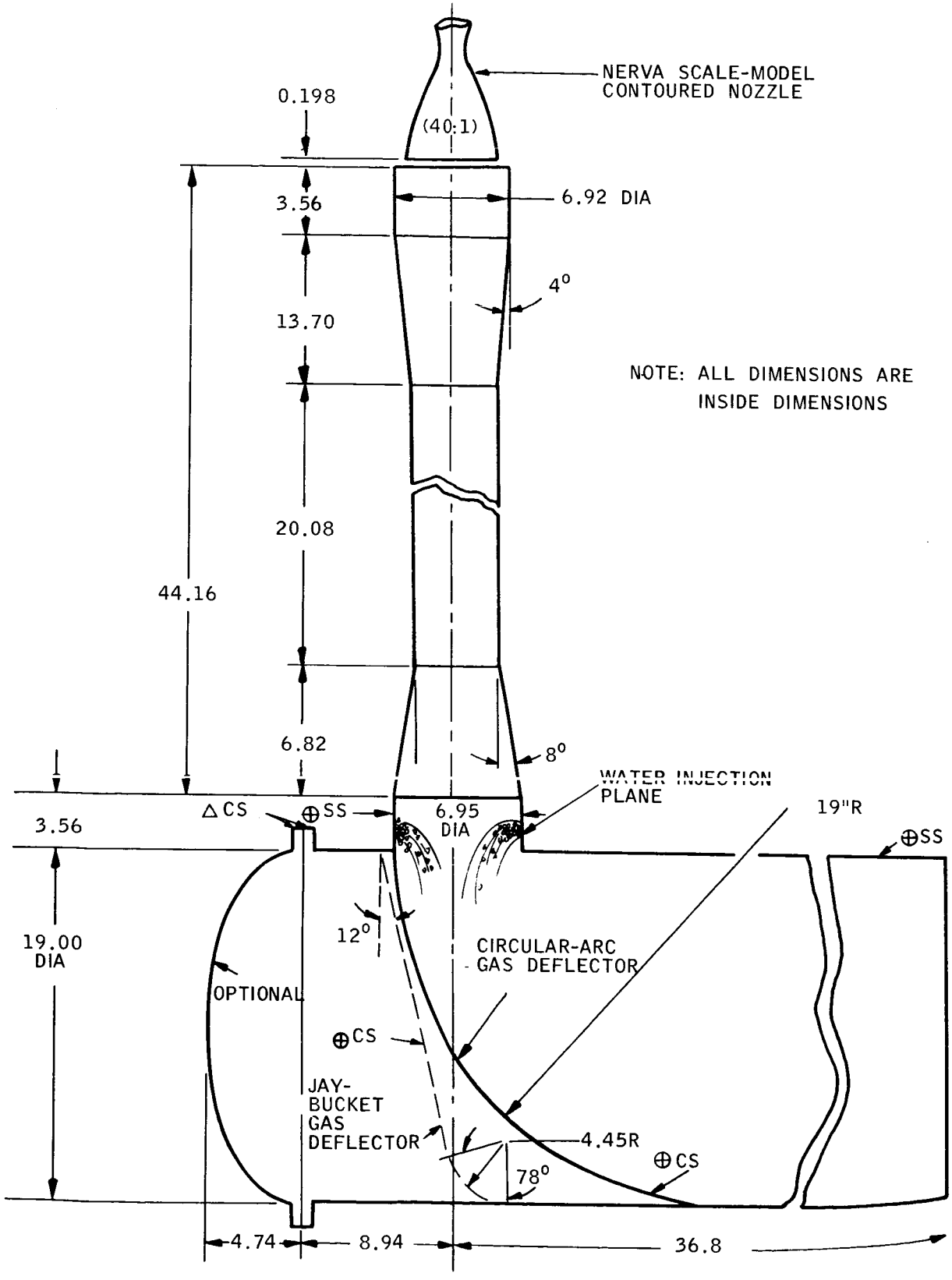


Figure 151 - E/STS 2-3 Subscale Selected NES Configuration

hardware, which was instrumented to determine surface temperatures, static wall pressures, and total pressure of the gas stream, with or without the addition of water. The test equipment consisted of a contoured nozzle with a 40:1 expansion ratio in an air-tight enclosure, a second throat diffuser with a 4:1 length-to-diameter throat section, a water injection system at the exit of the diffuser designed to inject enough water to saturate the gas stream, followed by a plenum that included a deflector plate to aid in turning the exhaust gases. Figure 151 shows the scale-model hardware, indicating the size and arrangement of the various components.

a. Special Hardware Development

(1) Water Injection System

A water-injector ring, which was designed to penetrate the gas stream leaving the diffuser, would produce a uniform distribution of water in the gas stream. Figure 152 shows the complete water injection ring, and Figure 153 shows a closeup of the injector ports.

The penetration profile was calculated using the equation obtained from the previously mentioned (3.0.2) correlation:

$$Z/d = 2.0\ (q_j/q)^{0.5}\ (X/d)^{0.27} \qquad (1)$$

where:

- Z = penetration distance, in.
- d = nozzle diameter, in.
- q_u = dynamic pressure of the water
- q = dynamic pressure of the gas stream
- X = mixing distance, or axial distance along the duct downstream from the point of injection

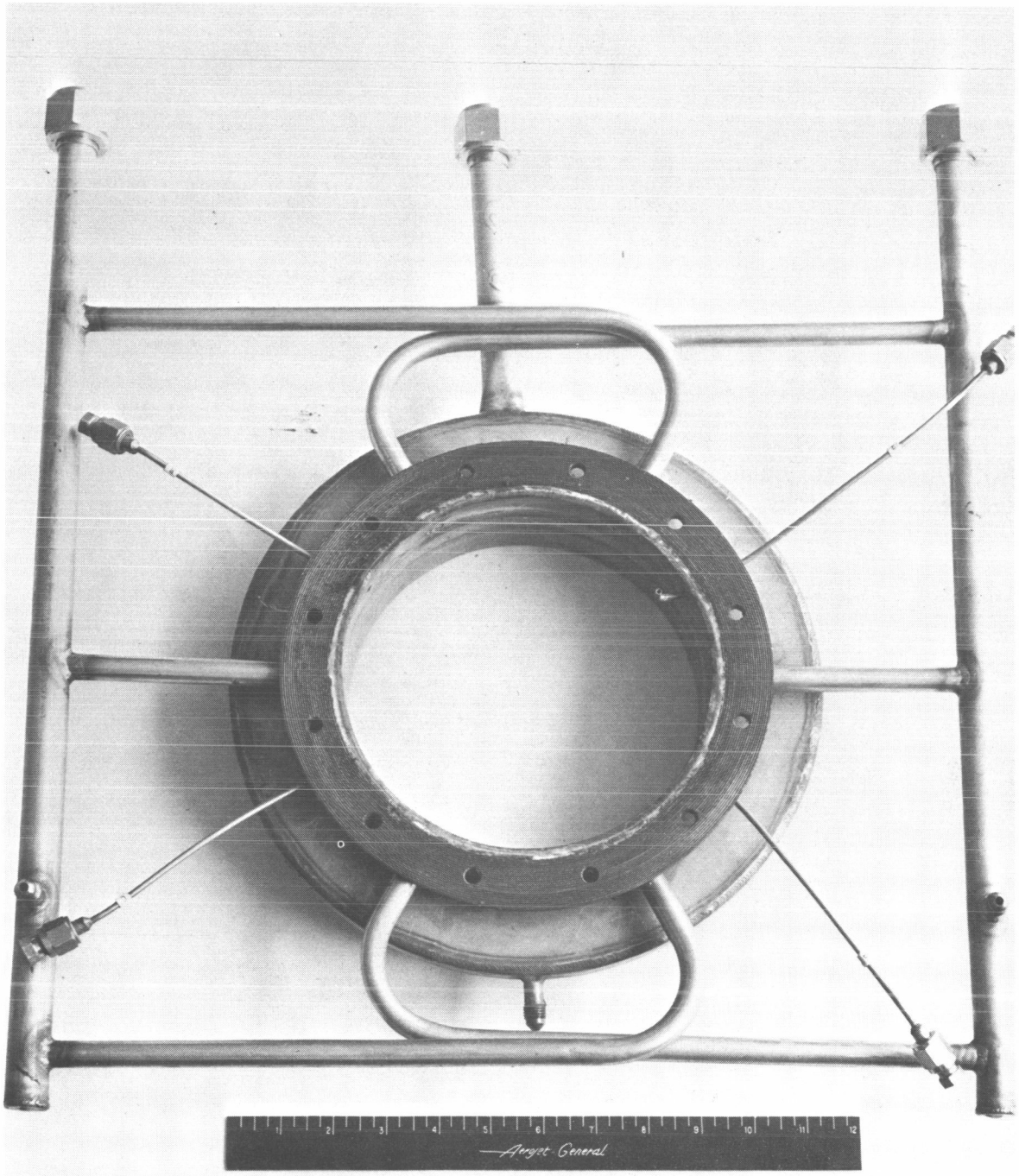


Figure 152 - Water Injector Ring

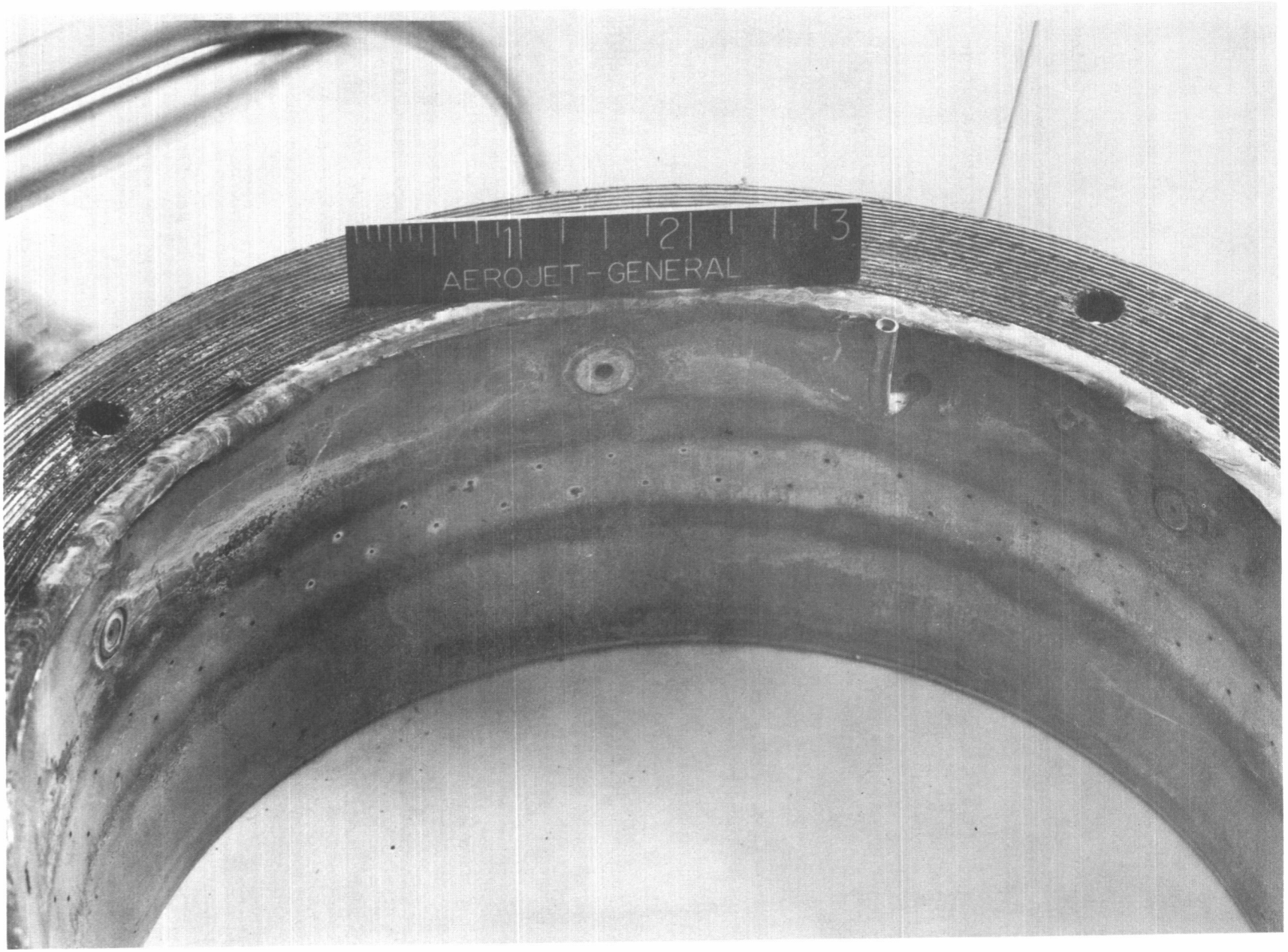


Figure 153 - Closeup of Water Injector Ring Showing Detail of Injector Ports

The gas-flow field at the exit of the diffuser was calculated using the selected diffuser test data. The diffuser-exit Mach number and dynamic pressure profiles were used in calculating water-jet penetration. The nonuniformity of the gas flow field relative to the prediction of jet penetration was assumed to be stepwise, as though the gas was flowing at a constant velocity in each of three concentric rings. The penetration profile for each diameter nozzle was determined with the slopes of the penetration curves matched as the steps in the flow field.

Since the penetration distance at different mixing lengths is known, it was possible to estimate the spread of the jet from the following expression, which is the result of earlier Aerojet experimental effort (S/S/T 3.0.2):

$$Y/D - 2.88\ (X/d)^{0.3} \qquad (2)$$

where:

Y = distance from centerline to edge of jet normal to the axis of the jet

Knowledge of the penetration and spread of the jet made it possible to geometrically arrange the nozzles so that the water spray would fill the duct. Although several geometric arrangements of nozzles will adequately fill the duct with a water spray, another possible restraint is the distribution of water in the duct. Because the mass-flow rate of gas in different regions of the duct is known, it is possible to calculate the mass of water that must be mixed with the gas to cool the gas flow in that region to saturation. For the wet-elbow tests conducted in this test program, the mass addition was essentially uniform or tailored for a uniform gas-flow field. Two other water-injection systems that altered the way the water was distributed across the duct were designed but were not tested.

(2) Deflector Plate

One advantage of the wet-elbow over a dry-elbow system for turning the gas is that it enables decrease in overall stand height. With either system, a 90° turn of the gas flow is necessary, and it is desirable to achieve this turn with the minimum possible loss in pressure. The efficiency of the 90° turn increases with the bend radius; therefore, the minimum turn radius would have the highest pressure drop and the highest heat-transfer coefficient. For a given envelope the optimum design will be a compromise between aerodynamic performance and heat transfer. As shown in Figure 151, two configurations of gas deflector plates were chosen. The circular-arc configuration is the maximum turn-radius deflector plate that can be accommodated in the available space. This appears to be the most efficient design. Since contact between the core of the hot-gas stream and the deflector occurs at a limited distance from the diffuser exit with this deflector, an alternative deflector not having this condition was also tested. The alternative is the J deflector, which has a 12° angle of inclination from the axis of the gas stream and is turned at the end with a minimum radius. The contour of the J-plate deflector approximates the equation $y = x^3$, and reasonably represents the alternate extreme from the circular plate. The heat transfer to the face of this deflector should be minimum due to the small angle of contact, and the point of impingement between the hot core of the gas stream and the deflector occurs at the most extreme point consistent with the envelope dimensions.

b. Diffuser Without Plenum Elbow

Aerodynamic and heat-transfer studies of the scaled selected diffuser have been completed and are discussed in the S/S/T 3.0.2 section of this report.

c. Diffuser With Plenum Elbow (No Water Injection)

Aerodynamic testing of the combined diffuser and plenum-elbow configuration shown in Figure 151 has been accomplished without water injection. Initial data indicate that negligible changes in system performance occur with the addition of the elbow. The duct appears to pull in at approximately the same chamber pressure (38.0 atm) and to pull down to about the same back pressure (0.025 atm) as it does without the elbow. If a restriction were added to the model to simulate the area of the secondary ejectors, the duct performance would probably be altered slightly. Two types of gas deflectors in the plenum elbow were evaluated. The 19-in.-radius circular arc appeared to give the smoother flow of the two types of deflector plates around the 90° turn. The J-bucket gave a more severe turn. The two types are compared in Figures 154 and 155 which present interpretations of oil smears of surface flow patterns. The difference between the two gas deflectors appears to be mainly due to inadequacies in the design of the J-bucket. A different J-bucket deflector design could improve the flow pattern. Further analysis is necessary in this area.

d. Diffuser With Plenum Elbow (Water Injection)

Testing of the combined diffuser and plenum-elbow configuration with water injection is complete, and a detailed analysis has been started. A water-injection-nozzle arrangement injects various amounts of water normal to the gas-flow field. Preliminary analysis indicates that (1) water droplets entrained in the gas-flow field (those not evaporated) follow the gas flow and are not wrung out, as previously believed, and (2) the problem of cooling objects downstream of the gas deflector (because the water droplets remain entrained in the gas flow) appears to be significantly diminished if sufficient water is added to saturate the mixture. Further studies and analysis are necessary.

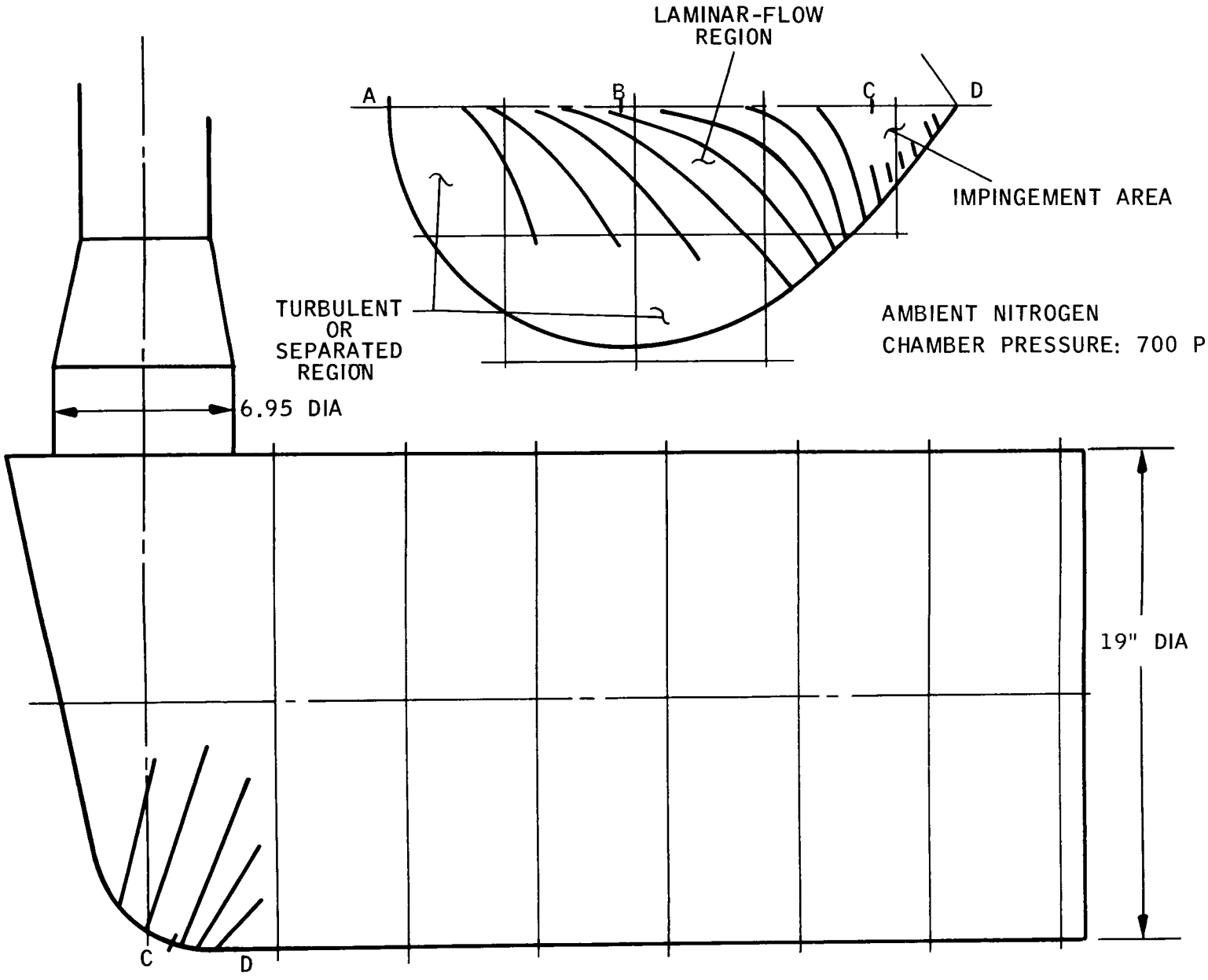


Figure 154 - Surface Flow Patterns, E/STS 2-3, Deflector A, J-Bucket

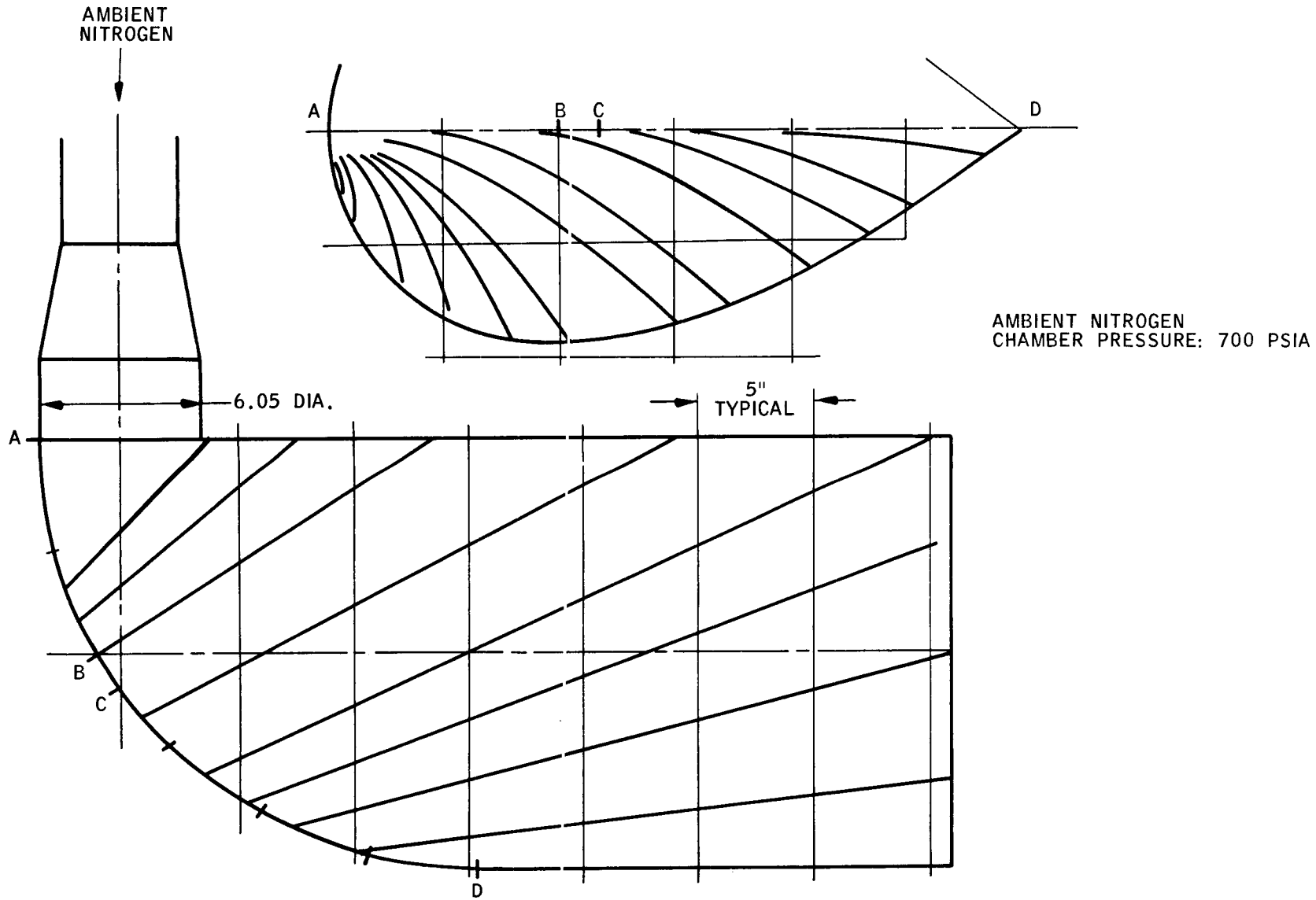


Figure 155 - Surface Flow Patterns, E/STS 2-3, Deflector B, (19-in.-Radius), Circular Arc

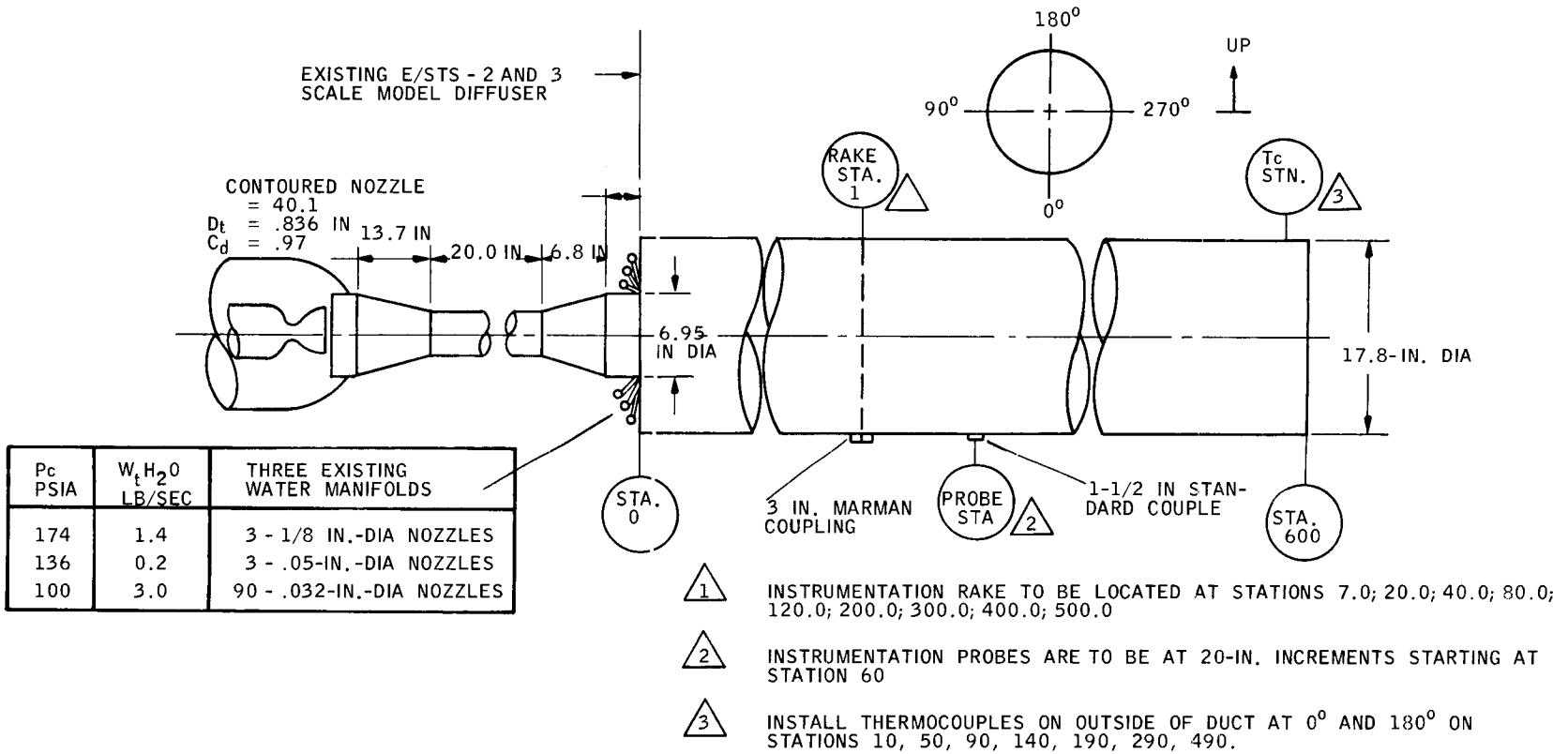
These tests also demonstrated the ability to predict water penetration or water coverage of the gas-deflector plate on the scale model. The nozzle arrangement designed to accomplish this purpose apparently performs satisfactorily. Test results indicate that the system worked better than expected. The amounts of water used in these tests did not appear to affect duct performance significantly.

e. Other areas of effort during the contract year included the following:

(1) Mixing and Evaporation Studies

A study is being made to investigate the cooling effectiveness of a flow field similar to the one that exists downstream of the water injection plane of the E/STS 2-3 subscale duct. Water was injected into the hot-gas stream at the exit of the E/STS 2-3 subscale diffuser. The diffuser effluent was exited into a large duct to evaluate the evaporation characteristics under controlled flow conditions. As shown in Figure 156, total pressure rakes and total temperature rakes were used throughout the duct to determine the flow field and the effective cooling characteristics established by the water-injection cooling system. Special rakes built to measure moisture in the hot gas were expected to establish the point at which the droplets are completely evaporated.

Although this program was started, complete testing and analysis was deferred to CY 68 due to testing of the reduced-inlet-diameter-diffuser already discussed.



Pc PSIA	$W_t H_2O$ LB/SEC	THREE EXISTING WATER MANIFOLDS
174	1.4	3 - 1/8 IN.-DIA NOZZLES
136	0.2	3 - .05-IN.-DIA NOZZLES
100	3.0	90 - .032-IN.-DIA NOZZLES

Figure 156 - Water-Hydrogen Mixing and Evaporation Test Setup

(2) Experimental and Analytical Evaluation of the E/STS 2-3 Reduced-Inlet-Diameter Diffuser

Initiation of the experimental and analytical evaluation of a diffuser configuration different from that selected was directed by SNPO in July 1967. The purpose to investigate a diffuser with a smaller inlet diameter (smaller than the selected system) relative to the following items:

1 Effect of purge flow and turbine-exhaust flow on diffuser performance

2 Define the location of first shocks and the effect on performance of a 70- and 120-in. diffuser entrance height

Fabrication of hardware necessary for the test program has been completed (Figures 157 and 158) and testing has been started. As of this report the only significant finding is that the 120-in. collar height will not pull down to the desired pressures due to the existence of a nearly normal shock in the long cylindrical entrance section and to excessive total pressure losses. Future testing and analysis are continuing.

(3) E/STS 2-3 Steam Requirement Effort

The steam requirements and ejector sizing were determined and will be presented as a REON technical memorandum. These requirements include those of the standby, safety, and pumping conditions and are as follows:

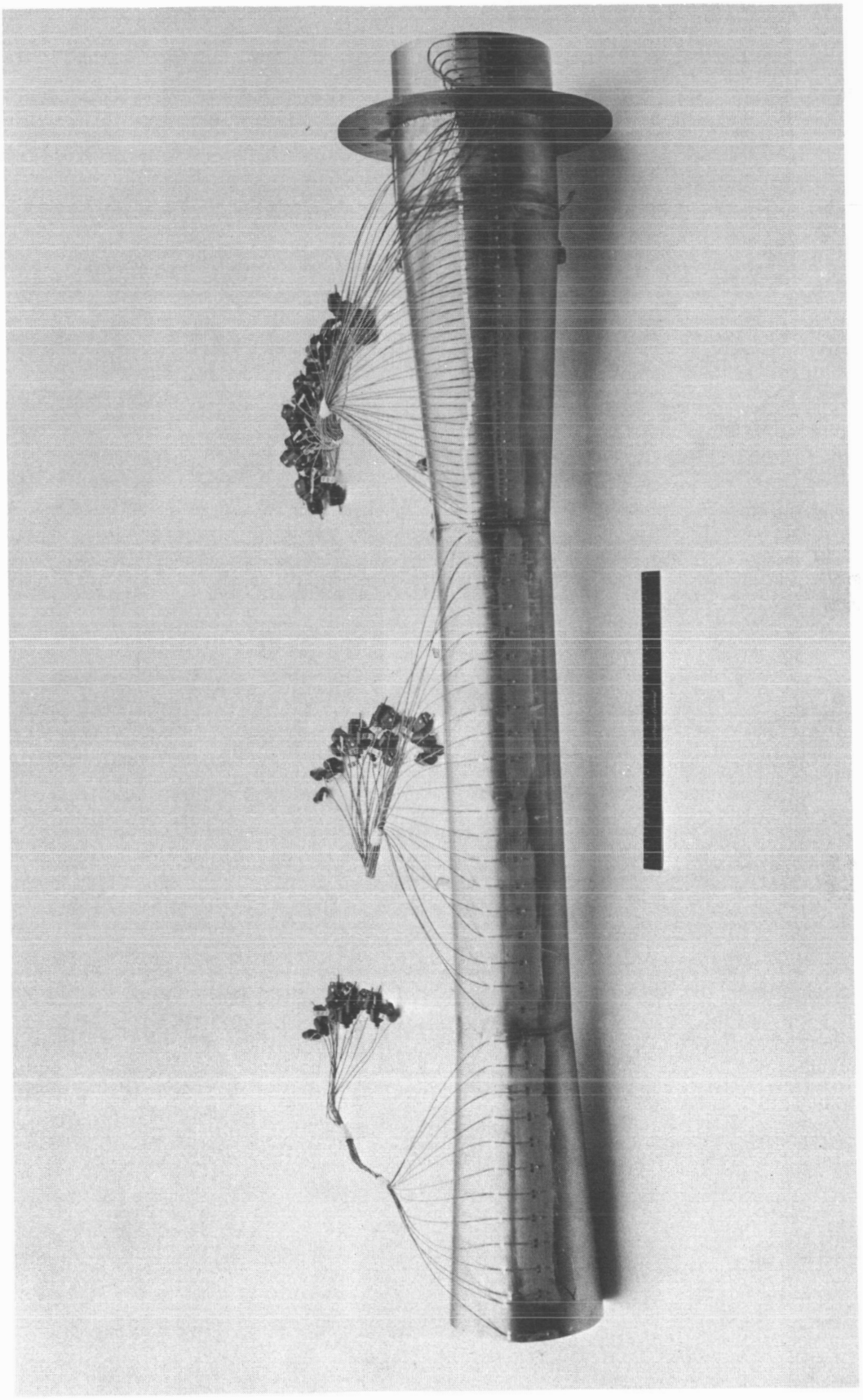


Figure 157 - Diffuser with Reduced Inlet Diameter

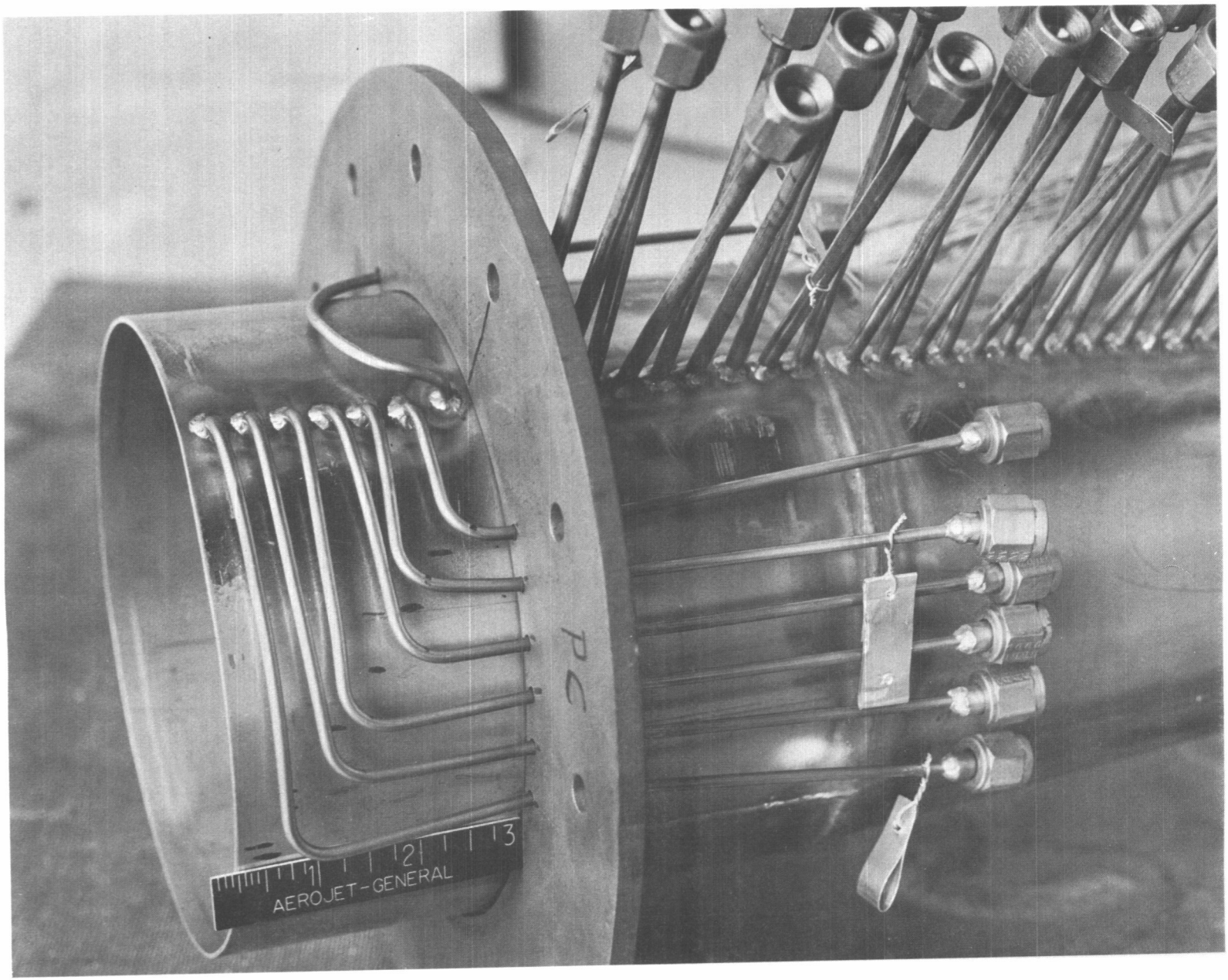


Figure 158 - Closeup of Diffuser with Reduced Inlet Diameter

Duct-Facility Interface Parameters	Standby	Safety	Pumping
1. Pressure, psia	27	45	113
2. Temperature, °F	350° + 150 - 0	350° + 150 - 0	350° + 150 - 0
3. Molecular Weight	18 ± 4	18 ± 4	18 ± 4
4. Ejector Throat Area, ft^2	17.9	17.9	17.9
5. Flow Rate, lb/sec	227 + 20 - 0	850 + 100 - 0	3700 + 200 - 0

Use of a FORTRAN computer program assisted in the optimization of the duct and ejector dimensions and determination of the minimum flow requirements for design operation.

4. E/STS 2-3 Duct System Design (3.1.2)

a. Design

On 23 March 1967 NRO was directed to provide the necessary engineering effort for the initiation of a functional design of the E/STS 2-3 NERVA Exhaust System Duct. NRO used the conceptual design defined in NERVA Exhaust Duct Specification Termination Report, data 7 March 1967 (The Marquardt Corporation), as a starting reference. The basic duct configuration having the diffuser wet-elbow concept was continued; however, the duct was resized to accommodate a 4200 Mw NERVA engine in accordance with direction from SNPO .

Several review meetings were conducted at Oakland to provide design review and close coordination and interface control with the facility A&E. The A&E defined specific design information requirements

pertaining primarily to interfacing and steam requirements. A chronological due-date listing of design requirements is shown in Table 21. All of the requirements were provided on schedule.

Twenty-six drawings and sketches (Table 22) were made during this design period, all of which were transmitted for review to the SNPO and Kaiser Engineers for review and comment.

The drawings show the preliminary duct dimensions (Figure 159), facility-duct interfaces (Figure 162), and design progress including such items as the diffuser, diffuser collar, elbow plenum and deflector plate, water flow schematics, and piping and line routing.

On 13 July 1967 NRO received direction that terminated the duct design effort. In its place NRO was directed to prepare the technical part of a functional specification for the procurement of the detailed design and the fabrication and installation of the NES duct. In addition the scale-model program was redirected to test a selected duct configuration to determine the combined effects of purge, turbine exhaust, gimbal, and collar-height variations.

A formal technical review and status presentation meeting was conducted at Sacramento for NRO and SNPO on 19 and 20 July 1967 to evaluate the progress of the duct design and scale-model program. This presentation was the last review prior to program redirection. The drawings and analyses that were in various stages of completion at that date were transmitted to SNPO.

A presentation was made to SNPO-C at Cleveland on 18 May 1967 to define the total NES design requirements of the E/STS 2-3 duct design, to review the critical areas, and to provide comparative data based on the ETS-1 effort. A similar presentation was made to the SNPO Headquarters, Washington D.C. on 8 June 1967.

TABLE 21

CHRONOLOGICAL LISTING OF NES DUCT-DESIGN INFORMATION REQUIREMENTS

Item	Date
Duct Configuration Drawing	8 May 1967
Duct General Arrangement	8 May 1967
Duct Loads	8 May 1967
Instrumentation and Controls Requirements	12 May 1967
Bellows Attachment to Bottom Shield	15 May 1967
Water Treatment Requirements	15 May 1967
Duct Collar O.D. and Concentricity	22 May 1967
Amount and Location of Duct Drain Water	1 June 1967
Duct Diffuser O.D.	1 July 1967
Location and Size of Vault Penetrations	1 July 1967
Type and Number of Instrumentation Circuits	1 July 1967
Interface Definitions on Elbow Support	1 July 1967
Steam Requirements and Duty Cycle	15 July 1967
Interface Definitions on Vault Closure	1 August 1967

TABLE 22

E/STS 2-3 NES DUCT
PRELIMINARY DRAWING AND SKETCH LIST

Drawing/ Sketch No.	Title
1134044 B	E/STS 2-3 NES Duct Configuration Control
1134045 B	E/STS 2-3 NES Duct Installation and Connection Interfaces
1134256	E/STS 2-3 NES Duct Process Water Flow Diagram
1134257	E/STS 2-3 NES Duct Diffuser
1134259	E/STS 2-3 NES Diffuser Collar
1134254 A	E/STS 2-3 NES Duct Diffuser Collar to Diffuser
1134253	E/STS 2-3 NES Duct Diffuser to Facilty Lower Shield
1134258 A	E/STS 2-3 NES Duct Elbow Plenum
1134260	E/STS 2-3 NES Duct Elbow Plenum Details
1134261 A	E/STS 2-3 NES Duct Ejector and Barometric Drain
1134255	E/STS 2-3 NES Duct Diffuser Collar to Diffuser
7780-67-0185	E/STS 2-3 NES Duct Elbow Plenum Ejector Ring
7780-67-0193	E/STS 2-3 NES Duct Upper Truss-Diffuser Section Concept No. 1
7780-67-0194	E/STS 2-3 NES Duct Upper Truss-Diffuser Section Concept No. 2
7780-67-0195	E/STS 2-3 NES Piping Plenum Collar Area
7780-67-0196	E/STS 2-3 NES Elbow Plenum Deflector Plate Concept No. 1
7780-67-0197	E/STS 2-3 NES Elbow Plenum Deflector Plate Concept No. 2
7780-67-0198	E/STS 2-3 NES Plenum Elbow Deflector Plate Concept No. 3
7780-67-0199	E/STS 2-3 NES Ejector to Facility Seal

TABLE 22 (cont.)

E/STS 2-3 NES DUCT
PRELIMINARY DRAWING AND SKETCH LIST

Drawing/ Sketch No.	Title
7780-67-0200	E/STS 2-3 NES Duct Diffuser Stabilizing Struts
7780-67-0201	E/STS 2-3 NES Duct Inlet Piping Layout
1134262	E/STS 2-3 NES Duct Elbow Plenum Injector Nozzles
1134263	E/STS 2-3 NES Duct (Isometric)
1134264	E/STS 2-3 NES Duct Facility Vault Closure Concept
1134265 A	E/STS 2-3 NES Duct Facility Interface Control
1134266 A	E/STS 2-3 NES Duct Configuration

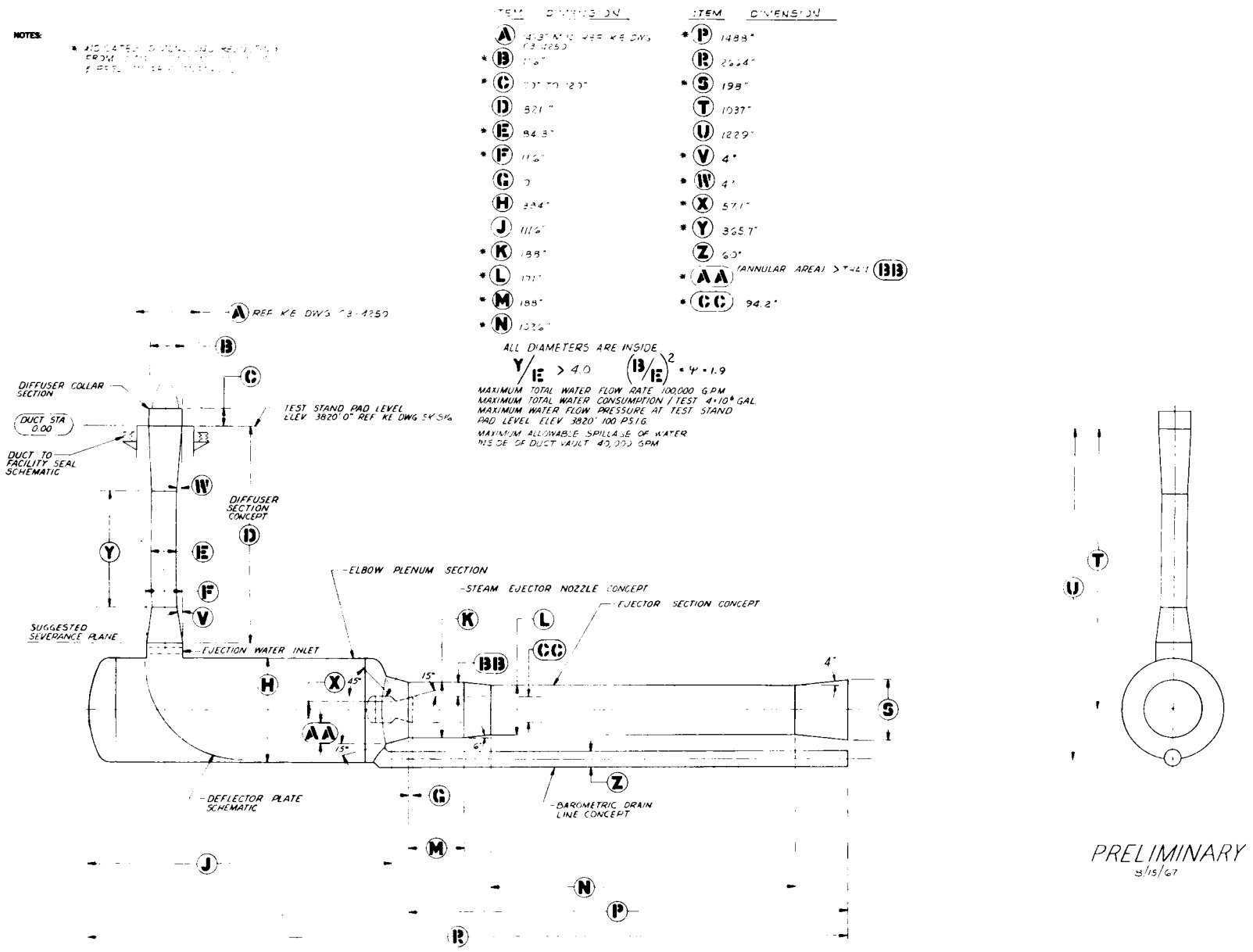


Figure 159 - E/STS 2-3 Duct Configuration Control (Preliminary)

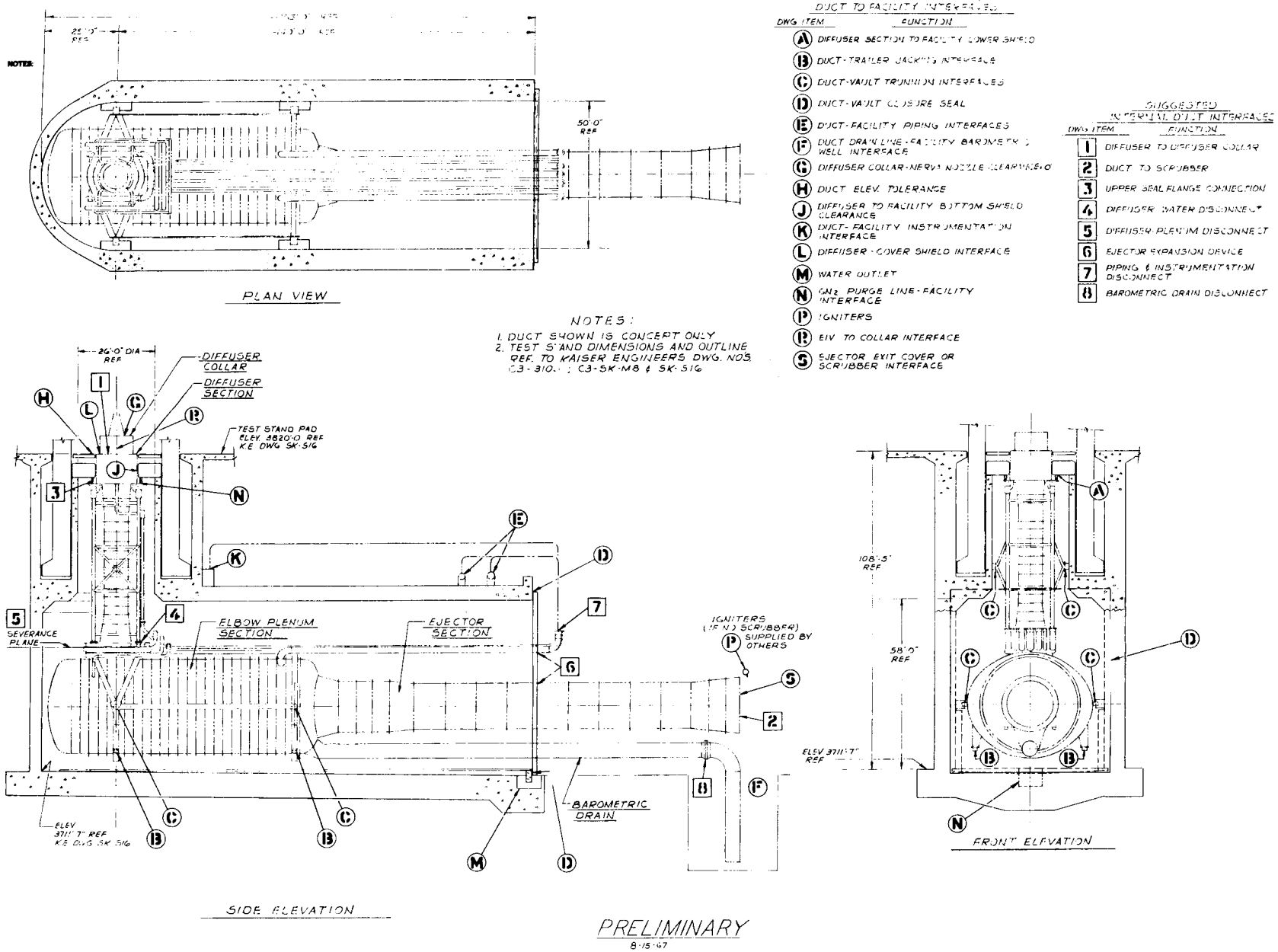


Figure 160 - E/STS 2-3 Duct Installation and Connection Interface

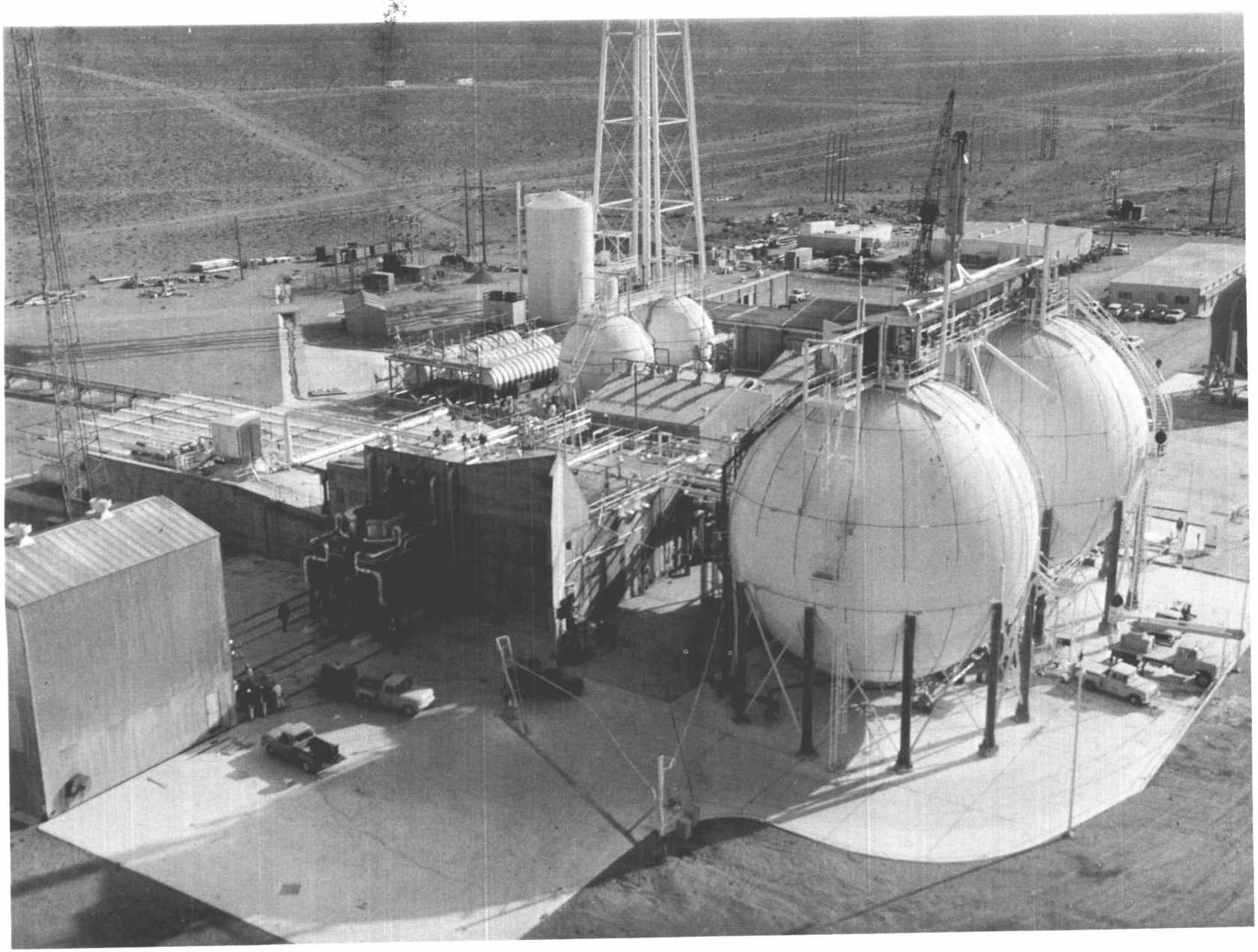


Figure 161 - Test Cell C Showing Side Shields

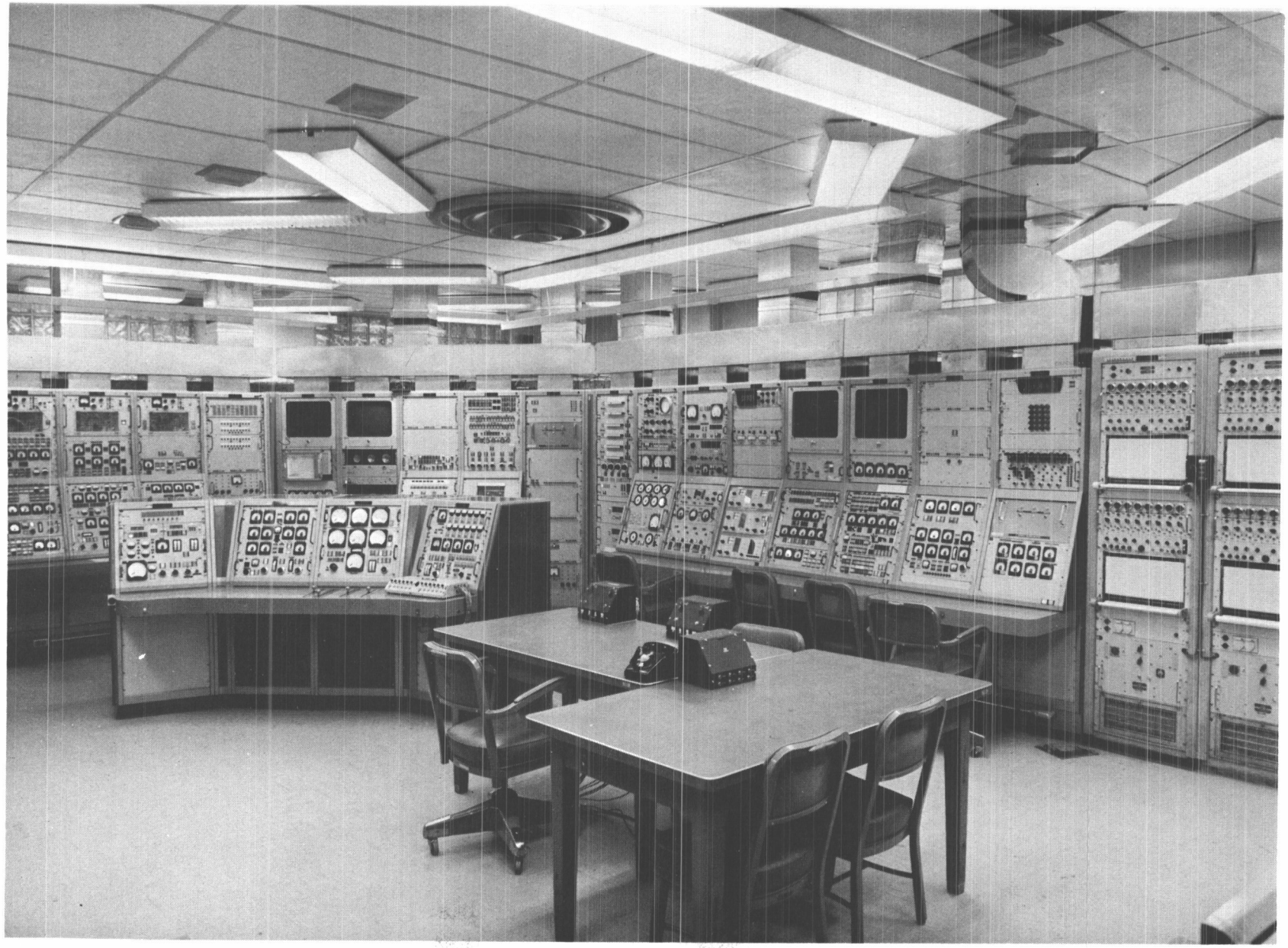


Figure 162 - Test Cell C Control Room

The technical section of the E/STS 2-3 NES duct functional specification was completed on schedule and transmitted to the SNPO-C on 15 August 1967. NRO also assisted in preparing a similar technical specification for the E/STS 2-3 Steam Generator and Delivery System.

b. Stress

A preliminary stress analysis was initiated wherein preliminary loads were prepared for the duct. The various loading conditions were identified and evaluated accordingly in the analysis. Table 23 presents a preliminary summary of the duct reactions. Furthermore, a preliminary dynamic model of the duct for seismic evaluation was prepared. The various duct-handling concepts and the effects of the duct loading were evaluated.

c. Process Water Requirements

The preliminary water requirements for the NES duct were defined and considered as the maximum upper limit. The estimated maximum flow rates are defined as: diffuser collar 10,000 gpm; diffuser 40,000 gpm; plenum deflector 10,000 gpm; water injection system 40,000 gpm.

Acceptable mineral content for the duct coolant water was investigated. A study indicated that scale-forming tendencies exist when the saturation pH is less than the actual water pH. The saturation pH increases with dissolved solids content or increases with temperature to the normal boiling point and decreases with the hardeness and alkalinity. Tests are still being conducted to determine the scale-forming tendency of the NRDS well water.

d. Steam Requirements

The total steam requirements for the duct were defined based on a 30-min full-power NERVA run profile. The ejector pumping fluid (steam) was based on the following nominal requirements at the duct facility interface:

TABLE 23

SUMMARY OF ALLOWABLE MAXIMUM DUCT SUPPORT REACTIONS

Component	Reaction	
Av=	2,683,240 lb	
Ah=	1,734,804 lb	(Along Plenum Centerline)
Ah^1=	250,040 lb	(At Right Angles to Plenum Centerline)
Bv=	854,625 lb	(Vertically)
Bh^1 =	51,225 lb	(Horizontally at Right Angles to Plenum Centerline)
Cv=	543,940 lb	(Vertically)
Ch^1 =	33,540 lb	(Horizontally at Right Angles to Plenum Centerline)

Item	Standby	Safety	Pumping
Pressure, psia	27	45	113
Flow Rate, lb/sec	210	850	3700
Time, sec	1500	1620	720

These rates were based on the delivery of steam with a molecular weight of 18 and a temperature of 810°R with a steam nozzle throat area of 17.9 sq. ft. The molecular weight may range from 14 to 22 and temperatures may range from 810° to 960°R, in which case the required flow rates would be derived from the following equations:

Standby $\dot{W} = 210\ x^{\sqrt{\frac{M118}{T1810}}}$

Safety $\dot{W} = 850\ x^{\sqrt{\frac{M118}{T1810}}}$

Pumping $\dot{W} = 3700\ x^{\sqrt{\frac{M118}{T1810}}}$

Where:

$\dot{W}$ = flow rate lb/sec

M = molecular weight

T = temperature, °Rankin

The standby steam flow rate is defined as the required amount of steam that will prevent engine compartment overpressurization if there should be a cessation of engine exhaust flow prior to reinitiation of full steam flow. The standby flow rate is defined as the amount of steam required to prevent air from entering the duct exit due to the bouyancy effect during any period that hydrogen is on-stand and there is no engine flow.

e. Materials

The duct environmental and design requirements dictate the use of materials with an optimum balance of corrosion resistance, strength and ductility in the operational temperature range, weldability, fabricability, availability and cost, cyclic strength, minimal crack sensitivity, and radiation resistance. The prospective alloys considered included ferrous

aluminum base and nickel-base metals. The ferrous groups with desirable characteristics are the AISI 300 series austenitic stainless steels and the low-carbon or low-alloy (Cr-Mo) steels. Prospective aluminum alloys are the non-heat treatable, strain-hardenable types of the 5000 series; prospective nickel-base materials include the austenitic solid-solution strengthened alloys of the Hastelloy family. Table 24 shows some of the materials reviewed for the duct.

TABLE 24

MATERIAL SPECIFICATIONS AND SUPPLIERS OF CANDIDATE MATERIALS FOR E/STS 2-3

MATERIAL	MATERIAL FORM AND SPECIFICATION						
	PLATE SHEET OR STRIP	BARS AND FORGINGS	TUBING WELDED	TUBING SEAMLESS	WELDING WIRE	WELDING ELECTRODE COATED	SUPPLIERS
Hastelloy C	Mil-N-18088 AMS 5530 ASTM B 334	AMS 5750			ASTM B 304 CL ERN 7C	Mil-E-22200/3 ASTM B295 C1 E3NIC	Stellite Div of Union Carbide Corp.
Hastelloy X	AMS 5536	AMS 5754	AMS 5588	AMS 5587	AMS 5798	AMS 5799	Stellite Div of Union Carbide Corp. Universal Cyclops Steel Corporation
AISI 347	Mil-S-6721 QQ-S-766 AMS 5512	QQS 763 AMS 5646	Mil-T-6737 AMS 5575	Mil-T-8606 AMS 5571	Mil-R-5031 AMS 5680	Mil-E-22200/2 Mil-E-16715 AMS 5681	Allegheny-Ludlum Steel Crucible Steel Co. Republic Steel Co. U. S. Steel Co.
AISI 304L	QQS 766 AMS 5511	AMS 5647	AMS 5647	AGC 44197	Mil-R-5031	Mil-E022200/2 Mil-E-16715	Allegheny Ludlum Steel Crucible Steel Co. Republic Steel Co. U. S. Steel Co.
AISI 321	Mil-S-6721 QQS-766 AMS 5510	QQ-S-763 AMS 5645	Mil-T-6737	Mil-T-8606 AMS 5570	Mil-R-5031	Mil-E-22200/2 Mil-E-16715	Allegheny-Ludlum Steel Crucible Steel Co. Republic Steel Co. U. S. Steel Co.

TABLE 24 (cont.)

MATERIAL SPECIFICATIONS AND SUPPLIERS OF CANDIDATE MATERIALS FOR E/STS 2-3

MATERIAL	PLATE SHEET OR STRIP	BARS AND FORGINGS	TUBING WELDED	TUBING SEAMLESS	WELDING WIRE	WELDING ELECTRODE COATED	SUPPLIERS
AISI 316L	QQS 766 AMS 5511	AMS 5653			Mil-R-5031	Mil-E-22200/2	Allegheny Ludlum Steel Crucible Steel Co. Republic Steel Co. U. S. Steel Co.
5083A1	QQ-A-250/6D Mil-A-17358	QQ-A-200/4A	Mil-A-52234	QQA-225/4	5556 QQ-R 5356 566		Aluminum Co. of America Reynolds Aluminum Kaiser Aluminum
5454A1	QQ-A-250/10B Mil-A-21598	QQ-A-200/6B		QQ-A-225/6	5356 QQ-R- 5554(Best) 566 5556		Aluminum Co. of America Reynolds Aluminum Kaiser Aluminum
5456A1	QQ-A-250/9D Mil-A-19842	QQ-A-200/7B	Mil-P-25995	QQ-225/7	5356 QQ-R 5556 566		Aluminum Co. of America Reynolds Aluminum Kaiser Aluminum

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D. PROGRAM MANAGEMENT (TASK 4)

1. Program Planning and Control (4.1.0)

Program Planning and Control activities associated with the CY 67 work program and evaluations of program status were conducted on a continuing basis.

The routine biweekly updating, evaluation, and reporting of the active Management Planning networks were also continued. These included the NRO portion of the NRX-A6, WEMU, MCC/EIV, RADA, XECF, XE-1, XE-2, E-MAD and ETS-1 networks.

The activities of Program Planning and Control personnel at the test site and at subcontractor facilities were monitored and coordinated.

A major effort during this period involved the detail planning, direction, coordination, and preparation of the long range plan. The most significant of these efforts was the detailing and computerizing of the NERVA 8-year program for the end item and component management and the preparation and submittal of the NERVA Engine Development Program Plan, RN-DR-0103 to SNPO-C.

2. Fiscal Control (4.2)

At the beginning of CY 66, a new cost report format was developed in cooperation with SNPO-C and was continued in CY 1967. This format displays budget, actual budget, actual, and variance cost data as well as actual man-hours. During CY 67 special SNPO-C requests for additional cost data on a one-time basis or monthly until completed were complied with and were included in Section V of the cost report.

Throughout the report period, monthly fiscal reports and monthly cost estimates were prepared and submitted in accordance with requirements.

The annual 2-year budget study and an 8-year program plan were prepared and submitted.

3. Technical Reports (4.3 and 4.3.1)

Reports published during the first three quarters of CY 67 are listed in the respective quarterly reports. During the fourth quarter, the following reports were published:

No.	Title	Date Pub.
RN-S-0412	Preliminary NERVA Thrust Vector System Development Plan	9-1
0414	Preliminary NERVA Pressure Vessel Development Plan	9-26
0415	Preliminary NERVA Thrust Structure and Thrust Vector System Design Criteria	9-26
0416	Preliminary NERVA Pressure Vessel Design Criteria	9-26
0417	Calibration Data Log Book NRX-A6	8-1
0420	Final Report on GTR-18 Test of Bearing Cage Materials	8-15
0423	Nuclear Analyses in Support of E/STS 2-3 Preliminary Design	9-26
0426	Final Report - XE Cryogenic Test Program	9-29
0436	Preliminary Design Criteria for NERVA Skirt Assembly	9-28
0437	Preliminary Design Criteria, Major Lines Assemblies	9-30

No.	Title	Date Pub.
RN-TM-0437	XE Engine Dynamic Modal Analysis	6-20
0440	Hybrid Spectral Analysis System	7-26
0442	Longitudinal Dynamic Analyses of ETS-1 and XE-ETS-1	8-24
0444	ETS-1 Side Shield Transfer Car Dynamic Analysis	8-22
RN-DR-0097	NERVA Support Equipment OMI for Functional Valve and Leak Test Set -4400	9-26
0099	NERVA Support Equipment OMI for Electrical Simulator 4409	8-1
0118	NERVA Program Review	7-18
0120	NERVA Support Equipment OMI for Remote Checkout Adapter Kit - 4043	7-6
0127	Proof Pressure Test of Turbine Power Control Valve Actuator	7-7
0309A	NRX/EST Data Analysis Report Fluid Oscillations at Intermediate Pressures	7-14
0347	Radiation Effects Program Plan CY 1967 (Rev. A)	7-18
0367	NERVA Radiation Effects Status Report	9-15
0369	NRX-A5 Qualification Test Report of Engine Mounted Pressure Transducers	7-18
0370	Fast & Thermal Neutron & Proton Effects on Platinum Resistance Transducers at Liquid Hydrogen Temperature	7-26
0378	ETS-1 Facility Safety Report	7-28

No.	Title	Date Pub.
RN-S-0381	Influence of Space Environment on NERVA Engine Design	7-14
0384	Summary Report Phase II of Countermeasures Radiation Effects Program	7-18
0391	Minutes of CY 1967 Instrumentation Development Review Meeting	7-26
0396	Summary of Radiation Effects Information Obtained from NRX/EST	8-3
0397	Summary of Radiation Effects Information Gained from NRX-A5	9-1
0398	Final Report - GTR-18 Test to Determine High Temperature Radiation Effects on Structural Materials	7-31
0400	XE-2 Test Specification Supplement I	9-15
0400	XE-2 Test Specification Supplement II	9-15
0407	NERVA Materials Developments 3rd Quarter, CY 1967 (1 April - 30 June)	8-18
0123	Design Analysis - MK 4 Mod 2 Turbopump	7-5-67
RN-PA-0011	NERVA Configuration Management & MPT/NERVA Engine Interface	8-11
RN-Q-0042	Technical Quarterly	7-28
42A	R & QA Quarterly	7-31
RN-TDI-0011	Test Description for Vibration Survey of XECF in ETS-1	7-25

4. Central Data System (4.4, 4.4.0)

Documentation, storage, and retrieval activities associated with the CY 67 work program have been maintained for NERVA. Engineering and test data were transmitted to agencies and contractors as required.

Indices of drawings, specifications, and standards of all NERVA drawings pertinent to the NERVA Program were updated for monthly distribution to SNPO-C. Thirty-five mm microfilm aperture cards of drawings on the NERVA Program were provided to SNPO-C, WANL, and NTO on a regular weekly basis. Monthly transmittal of parts lists in 16 mm microfilm and specifications on hardcopy were forwarded to SNPO-C.

Pertinent Aerojet and WANL technical reports continued to be filmed and duplicated on 4 x 6 Diazo microfiche copies and transmitted to SNPO-C as generated.

The computerized system developed to generate information and retrieval of technical reports, letters, and memorandums has been successfully checked out and corrected for IBM 360/65 production status. Reports in alpha-numerical sequence report number, classification, and Keyword in Context (KWIC) were generated.

This subtask participated in coordinating the disposition of ACFI records related to the NERVA Program.

The Benson-Lehner Cathode Ray Tube Printer/Plotter was ordered and is scheduled for delivery in October 1967.

Test data formatting and plotting continued to be checked out with CDC 3200 tapes through the 360/65 System, which provides magnetic tapes for processing on the B&L CRT Printer/Plotter.

Investigations of test data handling methods are continuing in order to provide rapid turn-around time to support SPEAR team activities. This effort is in preparation for support of the XE Test Program.

Test data processing and support was provided as requested for NEP's, FEP's, and NRX/EST. The processing of wide-band test data in support of the XE test series has been coordinated with NTO. The mechanism of maintaining a microfilm master file of wide-band test data plots has been completed.

Data reduction activities have been coordinated with Aerojet, LASL, WANL, NTO, and SNPO to establish and maintain the most efficient and economical means of processing LASL, XE, and NERVA test data.

5. New-Technology Reporting (4.6, 4.6.0)

Accomplishments during the current contract year are as follows: (1) transmittal of reportable items to SNPO-C increased 28% over 1966; (2) 49 backup packages for technology utilization reports were prepared; 12 computer programs were submitted as reportable items; a number of promotional activities were undertaken to stimulate interest, including initiation of the Technology Utilization Award-of-the-Month, with nine award presentations during the contract year, and a NASA-sponsored Technology Utilization/Patents Awards Program initiated as an incentive to contractor employees.

As a result of high-quality reports submitted, due partly to the Technology Utilization Award-of-the-Month Award incentive, NRO transmitted 46 reportable items during CY 1967 compared with 36 inputs during the prior contract year. This is an increase of 28%.

AEC-NASA has increased the rate of evaluation and approval of reportable items with subsequent publication of AEC-NASA Tech Briefs, which requires Aerojet to initiate backup information for subsequent transmittal to NASA.

Reporting of computer programs was initiated during the contract year with 12 programs transmitted to SNPO and subsequently to "COSMIC" (Computer Software and Management Information Center) at the University of Georgia. COSMIC has a reciprocal program and NRO requested and received four codes. Aerojet had two computer programs published as NASA Tech Briefs.

Promotional activities included the Technology Utilization Award-of-the-Month, newspaper publicity, film presentations, management briefings, technical coordinator's instructions, and bulletin boards.

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E. SACRAMENTO PLANT SPECIAL TEST EQUIPMENT (TASK 6)

1. Other Test Zones and Laboratories (6.2, 6.2.0)

a. Cryogenics Laboratory - Test Zone A

The test bays of the Cryogenics Laboratory were used for development testing of NERVA components and materials throughout the contract year.

Test Bay A-1 was set up to test the sealing ability of the Omega-type seal. Six of these tests were conducted during the latter part of January 1967.

Test Bay A-4 was used during early November 1966 for a four-test series to evaluate the insulating properties of prefoamed and foamed-in-place insulation on a 5-in.-LH_2 line segment. Subsequently, setup within the bay was modified for cryogenic tests of an XE upper thrust structure/shield segment. A total of 13 tests were conducted to determine the effects of purge gas condensation under LH_2 flow conditions. This test series was conducted from 29 November 1966 to 10 January 1967.

Seven wear tests of various material specimens were conducted in Test Bay A-5 during the contract year. Test Bay A-5 was also used for six subscale bearing tests to evaluate various bearings and bearing retainer configurations and materials. These tests were conducted during the months of June and August 1967.

Acceptance testing of 5-in. check valves was accomplished in Test Bay A-7 during early October 1966. Following these four tests, cycle and acceptance tests of 3/8-in. check valves were conducted in Bay A-7. Eight of these tests were conducted during a period ending on 18 November 1966.

Test Bay A-9 was also used for valve testing. Two 8-in. pressure sequencing valves were acceptance tested. One valve was tested on 4 November 1966 and one on 6 January 1967.

The bearing test setup in Test Bay A-10 was used extensively from late January 1967 through mid-August 1967. The 85 tests conducted were for evaluating the performance of a single-ball bearing.

Test Bay A-11 provided testing capability for 27 tests of 5-in. butterfly valves. The series was conducted during November and December 1966 and included acceptance, cycle, and actuator-torque testing. During February 1967, Bay A-11 was further modified to accommodate a test setup for an XE upper thrust structure. Six tests were conducted on the unit between 21 and 24 February 1967.

Metallic specimens were subjected to tensile testing in an LH_2 environment in the tensile test machine in Test Bay A-13. Seventeen specimens were tested during the second and third quarters of the contract year.

A leakage problem that developed in the high-pressure-gas vessels used by the Cryogenics Laboratory temporarily interrupted testing in January. Tube trailers were used temporarily to provide pressurant gas capability and were subsequently replaced by two vessels relocated from Test Zone E.

b. Transducer Laboratory

A high-sensitivity cryostat received in March 1966 and subsequently rejected has been modified by the vendor and returned. The modified unit has been found to be acceptable for calibration of platinum resistance temperature transducers.

c. Vibration Laboratory-Test Zone G

The vibration facility in Test Zone G was used to determine the effects of LN_2 dripping on On-Mark and other electrical connectors during vibration. Nine tests were conducted during the period from November to January.

2. Test Zone H (6.3, 6.3.0)

NERVA Technology Engine turbopump testing on Test Stand H-6 was successfully completed with a series of four cavitation tests that ended on 1 November. After completion of the H-6 testing, the hot hydrogen system was switched over to Test Stand H-4A for turbine power control valve and turbine block valve testing. Following the switchover, two TPCV and two TBV tests were completed by 29 November. This concluded Technology Engine testing in Test Zone H and the NERVA testing complex was partially deactivated.

Modification of high-pressure GH_2 receivers in Test Zone E by Daco Metal Products continued throughout the contract year. Vessel V-H74 has been completed and successfully leak tested. Vessel V-E6 was completed. Because of leakage during tests, further modification of the vessel was necessary. Modification of V-E6 has been completed and preparations are being made for leak testing that will determine the adequacy of the repairs.

Modification of two other high-pressure GH_2 vessels, V-E7 and V-E8, was initiated by Daco. Installation of manway assemblies in these vessels has been completed and the installation of plug seals is nearing completion. The completion of V-E7 and 8, including final testing, is scheduled for the first quarter of Contract Year 1968.

Following the presentation an evaluation of both heater concepts was made, including cost and technical comparisons. Subsequently, with SNPO-C concurrence, the Twyman Engineering Co. was retained to start design of a hydrogen heater under letter contract, NP-000154, awarded on 13 July 1967. This subcontract was to cover the first 2-1/2 months of an expected 11-month design effort. The remaining design effort would then be funded as a part of work to be accomplished during Contract Year 1968.

During the latter part of September, all design effort related to the E Zone test facility was terminated in accordance with SNPO-C direction. Twyman Engineering Company was notified to discontinue the heater design effort, and all other E Zone activities were abandoned.

3. NRO Laboratory (6.4, 6.4.0)

Testing and system checkout in support of engine controls, instrumentation, and the ETS-1 Test Stand Control and Test Simulation Systems (Subtasks 1.5 and 2.4) were conducted throughout the contract year.

Support during the assembly, checkout, and testing associated with the TPCV actuator life-test fixture in the actuator control laboratory was provided. Details of this effort are discussed in Section 1.5.2.

4. Test Zone E (6.5, 6.5.0)

Design activities related to a test facility for NERVA non-nuclear development centered around the Testing Complex E-1, E-2 and E-3. Because these facilities had previously been used to serve the M-1 Engine Development Program, the piping and support tankage were sized to accommodate flow rates in the range expected for NERVA turbopump testing.

A succession of proposed iterations were made during the contract year as varying hardware requirements were postulated. It was assumed in all cases that initial testing would use ambient hydrogen gas as the turbine-drive fluid, followed by testing with heated hydrogen as the turbine drive. However, due to the variety of assumptions made relative to the other aspects of turbopump development, the facility design effort was in an almost constant state of transition. The factors considered included varying relationships between the overhead run vessel and the pump inlet, extending and compressing test schedules, and varying degrees of flexibility and sophistication in the instrumentation and controls systems.

Due to the lack of firm criteria and hardware definition, initial facility design effort was directed toward areas of a general nature, such as the off-stand structural and piping design, which would be applicable to any of the potential facility concepts.

By the end of the second quarter CY 67, Test Stand E-1 was expected to be the primary test position in the E Zone test complex, with Test Stand E-3 to be used for the initial, short-duration TPA tests. This approach allowed the maximum amount of flexibility in meeting the proposed schedules for construction and testing. Only minor modifications were required to prepare Test Stand E-3 for ambient drive, short-duration testing. This early testing could be accomplished while Test Stand E-1 was being modified to provide a facility with the overhead-run vessel modified and

lowered within the superstructure to enable close coupling with the propellant shut-off valve (PSOV) and with a hydrogen heater that will provide heated hydrogen for driving the turbine.

Subsequently, Test Stand E-3 was eliminated as the proposed site for short-duration, ambient-drive testing and the design effort for that stand was terminated. The E Zone design effort was then directed solely to Test Stand E-1 for heated-hydrogen, extended-duration testing.

As indicated previously, all proposal iterations included the assumption that testing with heated hydrogen as the turbine drive fluid would follow the ambient-hydrogen drive testing. Since current technology related to methods of heating hydrogen is inadequate for meeting the projected NERVA requirements, two contracts were awarded in CY 66 for further study of this problem. One contract was awarded to Twyman Engineering Co. for studying the application of the forced draft, radiant-convective type of heater such as that used in Test Zone H for Technology Engine development. The other contract was awarded to Paul Division of Airco (now Airco Cryogenics) for studying the use of jet aircraft engines as the heat source for a heat exchanger.

Formal presentations were given by Twyman and Paul during mid-October at Aerojet and early January at SNPO-C to receive their findings on methods of heating hydrogen. Due to the significant differences in the relative conservatism of the concepts presented, only gross comparisons could be made of cost and performance. Therefore, both firms were given a base case from which to work together with suggested guidelines and analytical procedures to follow, so that a comparative analysis could be made. This latest iteration culminated in a presentation of both candidate concepts at a meeting held in Sacramento on 24 May 1967. Representatives of SNPO-W, SNPO-C and Aerojet attended this presentation of conceptual design, costing, and scheduling for the candidate concepts.

F. NRDS OPERATIONS (TASK 7)

1. NRDS General Support (7.0 and 7.0.0)

This project covers the activities of NTO Program Planning, Training, Documentation and Reporting, and Site Engineering. These groups support the efforts of all NTO Projects at NRDS on an as-required basis.

a. Program Planning

Program planning activities included the following:

1. Scheduled the procurement of propellants and pressurants commensurate with requirements dictated by test activities of NRX testing and facility testing at ETS-1. Revised the 36-month propellant forecast by commodity and submitted to NRO, Sacramento.

2. Developed and published the 5th annual edition of the Program Requirements Document, Report 2578, for CY 1968, 1969, and 1970. This document was issued 1 July 1967.

Prepared revision 1 of the 5th annual edition of the Program Requirements Document, Report 2578, effective 26 September 1967.

3. Provided the SNP-1 NTO CY 68 Program Planning.

4. Prepared and issued monthly overtime estimates and work authorization documents.

5. Performed SNP-1 NTO budget analysis on a continuing basis.

b. Documentation and Reporting

(1) NRX-A5

The NRX-A5 Posttest Report, NTO-R-0097 and Supplement I were completed and published. These reports summarized the disassembly, postoperative examination, and radiochemistry efforts relative to the NRX-A5 reactor.

(2) NRX-A6

All receiving, assembly, and pretest checkout procedures were completed for the NRX-A6 reactor. Assembly and checkout procedures were also prepared for the side-by-side actuator experiment and dosimetry program.

(3) XECF

The receiving, assembly, transport, and pretest checkout procedures were completed for XECF.

Procedures were prepared for receiving assembly, installation, and checkout of the test stand adapter that was installed at ETS-1 as a part of the XECF program.

A remote removal and reinstallation demonstration at ETS-1 was added to the XECF program to be performed prior to the testing phase. Procedures for the performance of this work were prepared and published.

(4) XE-1

Receiving and assembly procedures were prepared for XE-1.

Review issues of the central poison wire removal and transport procedures were submitted to WANL, NRO and SNPO-C for review.

(5) Test Cell C

NTO personnel were provided to LASL as a part of the JTO organization to support the Test Cell C effort for Phoebus and NRX-A6 testing.

Three-day reports and summary test reports were prepared for LASL Phoebus operations.

Seven standard operating instructions were prepared for use during the NRX-A6 efforts to be performed at Test Cell C.

(6) E-MAD

Twelve Administrative Procedures, fourteen instructions, and three standard operating procedures were prepared to provide the E-MAD Building with the necessary documentation to complete the activation efforts and to provide instructions necessary to perform the NRX and XE assembly and disassembly operations.

A recorder was assigned to the NRX-A6, XECF, and XE-1 Test Specification and Procedures Review Board, who published copies of the procedure changes, prepared minutes for each meeting, and maintained official copies of the test specifications and the assembly procedures.

(7) ETS-1

Twelve administrative procedures and eleven standard operating procedures were published to describe the ETS-1 operations in support of the XE testing program.

Support was provided for ETS-1 personnel in the publication and distribution of the necessary instructions and reports required during the activation phase.

(8) General

Fifteen administrative procedures and two standard operating procedures were prepared or revised to reflect the current systems for control of overall NTO functions.

Support was provided to the product assurance, site engineering, health and safety, training, and administrative services departments in preparation of the necessary procedures and reports.

Progress reports were prepared on a semi-monthly basis to cover overall progress of NTO operations.

c. Site Engineering Group

(1) ETS-1

(a) Pipe Analyses and Stress Analysis

Piping and stress analyses were completed for the following lines to check existing designs to determine the acceptability of required system modifications: 2-LN-4, 1-ST-20, 4-LH-6, NES primary flow line, and 12-in. NES demonstration piping, V-5001 instrumentation pass-through, V-5002 vent tree, 1-ST-20, and simulated thrust test structure.

(b) Facility Modifications

Engineering packages, drawings, and specifications were completed in support of ETS-1. This effort included the following: new boiler building; winterization (Not Used); cooling water drainage system (duct); 1-ST-20 modifications; auxiliary GN_2 header; propane line modification; decontamination surface preparation; short-circuit calculation; V-5001 flowmeter spool; air condition power source; plume heating; deluge/decon water control; XE engine-mounted nuclear detector; XE-1 fast-fission chamber mount; GN_2 bottle addition, LN_2 Dewar; and vaporizer addition.

(2) E-MAD

(a) Stress analyses were completed for the following: Room 120 modification; simulated engine test stand; crane support; outrigger (NRX); door jacking fixture; turntable (WT-2) modifications; CDAE crane support; TSA adapter work platform; cold bay safety pedestal; cold bay ladder.

(b) Facility modifications

Engineering packages, drawings, and specifications were completed in support of E-MAD. Included were the following: interbay radiation shield wall; receiving ramp modification; storage pad; actuator checker gas supply.

(3) Test Cell C General Support

Engineering Support, NTO SEG/LASL-J5, was provided for facility modifications required for NRX-A6, Phoebus IB, and Phoebus II testing items. Included within this category are stress analysis of the nozzle boom; Dewar transfer line, tie-tube cooling system; propellant line filter; NRX-A6 side-by-side experiment; NRX-A6 annulus purge system; NRX-A6 burnstack; effluent cloud marker; NRX-A6 test car LN_2 Dewar fill system (revision);

360° shield/privy roof seal supply system; NRX-A6 nozzle cover; high-pressure accumulator system; NRX-A6 pressure transducer side-by-side experiment; calorimeter-mounting system; and FROG remote plug.

(4) NTO Counting Laboratory

Additional counting equipment was obtained and the counting laboratory space was rearranged to enhance the handling of future larger dosimetry programs.

The laboratory also completed the following activities:

Evaluated in conjunction with NRO, the neutron response of LI_6 thermoluminescent dosimeters.

Supported LASL in Phoebus IB by placing, retrieving, and analyzing dosimetry, and assisted IB power calibration using in-core gold wire.

Performed precalibration runs at WANEF on internal and external NRX-A6 Detectors.

Prepared installation and retrieval for NRX-A6 Dosimetry.

Exposed fire-retardant, strippable paint samples in the sigma pile to determine if the material would become activated. The test indicated very low activity. There was no apparent problem with activation by thermal neutrons.

(5) General

General activities included review of the seismic study made by Blume Associates, and monitoring of the NRDS electric power system design and installation.

d. Training

The majority of NTO personnel received specialized training and traning efforts included the following:

(1) ETS-1

Assisted in the preparation and issuance of the XE operator training and qualification guide.

Published substantial additions and revisions of the ETS-1 Instrumentation and Controls Course for distribution to engineers and technicians assigned to NTO since the last presentation of this course.

Prepared study guides for the ETS-1 Control Point Operator General Indoctrination Course. This one week course was attended by 62 operators.

Preparation and publication of console operations manuals for the traning and qualification of XE-1 Operators, which included those for--

Assistant Stand Engineer
Gas Fill and Service
Facility Engineer Left
Facility Engineer Right
Lead Safety Engineer
Test Stand Engineer

Prepared 50 copies of a selected edition for a three-volume manual ETS-1 Control Point General Indoctrination Course, for use by off-site personnel at NRO associated with engine test operations.

Assisted in XE-1 engine familiarization training given to 36 facilities technicians.

(2) E-MAD

Enrolled 48 technicians in the 5-day soldering course and 60 technicians in the 3-day crimping course at NRDS.

Continued in the administration of the eye proficiency development program.

Completed training in the following courses covering remote handling and special equipment:

(a) Prime Mover Locomotive--12 technicians

(b) Remote Cranes--28 technicians

(c) Master Slave Manipulators--33 technicians

(d) Floor-Mounted Handling System--32 technicians

(e) Overhead Positioning System--8 technicians

(f) Railroad Transport System--5 engineers and 12 technicians

(g) Wall-Mounted Handling System--16 technicians

(h) Rectilinear Manipulator--12 technicians

(3) General

Arranged for six instructors to receive special training given by a manufacturer's representative on the use of eye training equipment at E-MAD.

Revised the text for a 12-hour course in Fundamentals of Radiation Safety. This course was presented twice during the year to a total of 193 NTO Personnel.

Arranged for 12 NTO personnel to attend an instrumentation welding seminar and laboratory welding demonstration at a manufacturers plant.

Arranged for a series of 1-hour First-Aid training classes by the NRDS medical group, which was attended by a total of 81 people from NTO.

2. Test-Cell Operations (7.1 and 7.1.0)

a. General

NTO personnel provided support to the LASL J-17/J-5 Groups for the Phoebus-2 cold-flow test series. In addition, two facility experimental plans were conducted for the NRX-A6 checkout tests.

b. Test Cell C and Control-Point Modifications (Figures 161 and 162)

A major difference in the new system is in the automatic mode switching of the controllers. In the old system, position mode and closed

commands to the controllers were not generated until the reset button was actuated. The new system generates these commands immediately upon shutdown; thus, the controllers should be in a safe condition before the reset command is given. The old system depended entirely on the inhibit feature to prevent an unsafe reset.

(1) A new power-controller chassis for NRX-A6 has been installed and is being checked out. It will be tested with the new temperature controller before the NRX-A6 test series is conducted. The NRX controller provides a full-range temperature control instead of the temperature trim on rod position control and provides a programed control of log power instead of programed control of rod position. A limiter chassis was installed in rack 15B to provide log power and Station-26 temperature limiting for the NRX test series. The limiters will compare a measured variable to a predetermined level or limit and will demand an inward movement of the control rods at a rate proportional to the amount by which the measured parameter exceeds the limit set point.

(2) The control-drum circuitry rack has been installed in the vault in Test Cell C, and checkout is in progress. The rod-system transfer from "local" to "CP" was redesigned, and the required changes were completed. The rod hydraulics and air and the rod rack are all controlled by MCS-20, which is mounted in the rod rack. When the switch is in "local," both hydraulic pumps and both hydraulic bypass valves can be controlled from a console in the MER near the pumps. In the "vault" position, the hydraulic system, lock-pin air solenoid valve 2251, and the rod control can be operated from the rack in the vault. All controls transfer to the "CP" when so switched.

(3) The gas-scrubber controls necessary to operate the analog and binary valves, the shutdown chain, and the pressure-control loop were installed, checked out, and operated satisfactorily. Frequency-response data were recorded on the first experimental plan. These data indicate that the pressure-controller gain could be increased to obtain better control. However,

if the area of the orifice upstream of the control valve is increased (to obtain higher flows), additional response data will be taken before any change is made.

(4) The following system prints for Test Cell C were requested by GSE WANL/Large. These prints were converted to the configuration that will be used for NRX-A6 testing.

Mixing-chamber control
LN_2 reference Dewar
Turbine energy source
Dual-pump specific-speed control
Dewar 1 and 2 pressure control
Emergency shutdown system
Reactor control system
High-pressure Dewar 3
Neutronics log system
Dual-turbopump control
Drum-control system

(5) The design was completed for a high-pressure gas-accumulator system that will maintain uninterrupted propellant-line liquid flow after emergency shutdown. The NRX-A6 design was modified to comply with criteria developed by LASL N-Division for Phoebus 2A so that the overall system would be compatible for use with both reactor test series.

The system for NRX-A6 consists of a high-pressure accumulator with an effective volume of 10 cu ft. During emergency shutdown, the accumulator discharges through a check valve into the TES/pump-discharge line. The check-valve flapper was drilled with a 1/8-in.-dia hole to provide pressure equilization between the propellant line and the accumulators. The TES upstream of the check valve (HC-2043) will supply the pressurization gas through a 3-in. line to the accumulator.

(6) Design work was completed and material was acquired to modify the existing cart liquid-nitrogen reference-Dewar fill line to meet the requirements generated for the NRX-A6 test series.

c. NRX-A6 Testing

(1) NRX-A6 Local Test No. 1

(a) Objectives

The primary objective of NRX-A6 local test No. 1, conducted on 31 August 1967, was to complete the 1400-psig-pressure-test requirements of the test specification on the NRX-A6 test-car propellant line at cryogenic temperatures. In addition, a 200-psig initial leak check and an 1100-psig working-pressure test were performed to verify the test-car propellant-line pressure integrity. Facility-subsystem checkout tests were planned as a secondary test objective. These tests were to include the LN_2 valve N-30 failure-mode test with loss of pneumatic-actuation supply pressure and were to determine the valve N-430 pressure-setup requirements to supply 30-scfm helium flow to the reactor for its low-flow requirements.

(b) Test Results

Prior to the ambient-pressure test, a leak check of the test-car propellant-line piping was performed. Utilizing GHe from the tank farm, a pressure of approximately 250 psig was established at the burn-stack valve (B-15). At a pressure of 200 psig, inspection disclosed a leak at the burn-stack pressure transducer (BP-15) and several other minor leaks on the test setup and in the hookup room. The pressure was vented, repairs were completed, and two additional repressurizations were completed before a leak-tight joint was obtained.

The ambient-pressure test was performed by using GN_2 from the tank farm. The GN_2 header was pressurized to approximately 1150 psig. The pressure was slowly increased to 1125 psig, and during the 5-min hold pressure decay was minimal.

The cryogenic pressure test was performed with the propellant line initially chilled to LN_2 temperature. After a 15-min LN_2 cryogenic soak, the GN_2 header pressure was increased to 1450 psig and the test was successfully completed.

The systems were depressurized and warmed up, and the local test was concluded. The N-30 failure mode test and low pressure helium purge flow tests were not performed as originally planned because of the lack of time.

(2) NRX-A6 FEP-I

(a) Objectives

The objectives of NRX-A6 FEP-I, conducted on 7 September 1967, were to (1) determine the adequacy of the GN_2 accumulator-system pressurization and blowdown characteristics as required for NRX-A6, (2) perform B-15 valve mapping and LH_2 programed startups to simulate NRX-A6 reactor operation, (3) perform frequency-response tests on the LH_2 turbopump control system on the LH_2 flow-system transfer function, (4) investigate the stability of turbopump operation at low flow rates, (5) perform emergency shutdown tests from the intermediate and full-flow program holds with the LH_2 system accumulator and Dewar 3 on the line, (6) perform turbopump stall tests by stepping H-60 fully closed from the intermediate and full-flow program holds with the LH_2 accumulator and Dewar 3 on the line, (7) obtain reactor venturi (BF-13) correlation data with LH_2 and GN_2 flow, and (8) perform a high-flow GN_2 flow test through a simulated reactor impedance.

(b) Test Results

During this experimental plan, the adequacy of the accumulator system to perform as required for NRX-A6 was evaluated by performing the following tests: (1) an emergency shutdown at approximately 55-lb/sec flow rate; (2) an H-60 stall test at 55 lb/sec; (3) an emergency shutdown at 71.3 lb/sec; and (4) two H-60 stall tests at 71.3 lb/sec with different accumulator characteristics. For comparison, an H-60 stall test was also performed at 71.3 lb/sec without the accumulator. The data analysis has shown that the accumulator was effective in reducing the pressure oscillations produced by pump stall. In addition, the gas bubble from the accumulator, which displaces the liquid in the propellant line, was shown to not expand beyond the throttle valve, L-11, before L-11 closes upon shutdown. The operating mode of the accumulator in both the static and dynamic phases will be further evaluated to ensure that the operation of the accumulator is satisfactory with regard to reactor constraints.

The existence of a limit cycle while operating in the flow-control mode and, to a lesser extent, in the speed-control mode prevented the complete achievement of items (2) and (3) above. An analysis of the data has indicated that the specific-speed loop was directly involved in the observed instability. As a result, further tests on the turbopump control systems, including investigation of turbopump operating stability at low flow rates, are necessary.

The LH_2 programed startups to simulate NRX-A6 reactor operation and the mapping of valve B-15 were not attempted during this experimental plan because of the limit cycle in the turbopump control systems. However, investigation of the programed startups was planned for NRX-A6 FEP II.

Calibration of the test-car venturi, BF-13, was achieved by using LH_2 and GN_2. BF-13 and LF-10, the main propellant-line venturi, agreed within the experimental accuracy of the data. There is also good agreement between the turbopump flowmeter (HF-691) and the two downstream venturi. In the GN_2 high-flow test, the flow rate at BF-13 agreed well with the flow rate at GF-4. Although the maximum flow rate obtained during this test was only 95 lb/sec of GN_2, analysis of the data has shown that the GN_2 flow system and gas bottles do have the capability to achieve 100 lb/sec of GN_2, a requirement for one of the NRX-A6 reactor tests.

(3) NRX-A6 FEP II

(a) Objectives

The objectives of NRX-A6 FEP-II, conducted on 21 September 1967, were to (1) perform frequency-response tests on the turbopump rpm and LH_2 flow-control systems; (2) perform B-15 valve mapping and programed LH_2 startups to simulate NRX-A6 operation; (3) investigate system stability during low-flow operation of the turbopump; (4) investigate further the GH_2 accumulator effectiveness in attenuating pressure oscillations that accompany emergency shutdown and stall of the turbopump; (5) perform an NRX-A6 profile run and simulated reactor cooldown operation by using Dewar 3, the mixing chamber, and LN_2 systems; (6) obtain open-loop transfer-function measurements on the propellant feed system; (7) perform Mark 25 turbopump mapping at 32,000 and 25,000 rpm; and (8) provide further operator training.

(b) Test Results

The scope of the FEP-II experimental plan was to combine incompleted test objectives carried forward from FEP-I with remaining objectives required to be completed before NRX-A6 reactor testing. FEP-II consisted of ten runs, which can be categorized into turbopump control-system investigations, programed simulated reactor startups, additional GN_2 accumulator operating data during emergency shutdowns, NRX-A6 profile tests with simulated

reactor cooldown, and mapping tests on the Mark 25 turbopump for vibration data. Also, the new B-15 discharge impedance valve installed on the test car was mapped.

The test configuration of FEP-II employed all the flow systems required for NRX-A6: the LH_2, Dewar 3, LN_2, the mixing chamber the gaseous-propellants system, and the associated auxiliary systems. Pump No. 2 was used for FEP-II, as in FEP-I. The test car (T-1) was installed at the test-cell face for a flow-system discharge impedance. The test car is equipped with an analog hydraulic valve, B-15, that can be programed for simulating reactor operation.

Control-system experiments were performed to identify and correct the limit-cycle oscillation observed in the FEP-I test. Frequency-response data were obtained on the Ns, Speed, and LH_2 flow-control loops.

Simulated reactor startups were programed by using NRX-A6 operating characteristics. Shutdowns were performed from the NRX-A6 full-power hold conditions to investigate the effectiveness of high-specific-speed operation to reduce pressure ringing, which accompanies pump stall and emergency shutdown commands.

An NRX-A6 profile run was performed in conjunction with a simulated reactor cooldown to simulate, as closely as possible, the operation for a reactor power test. Simulated cooldown began with the 2500°R emergency shutdown and was followed by the Dewar-3 blowdown, mixing chamber, and LN_2-cooldown phases.

The Mark 25 turbopump was mapped to obtain vibration data during low-specific-speed operation.

d. Test Cell C Operations

The test cell was utilized during CY 1967 for Phoebus 2 cold-flow test series EP-I through EP-IV, NRX-A6 local test No. 1, and NRX-A6 FEP-I and FEP-II. The following table summarizes the fluids used in performing these tests.

Fluid	Total Used
Liquid hydrogen	1,365,000 gal
Gaseous nitrogen	10,900,000 scf
Liquid nitrogen	70,000 gal
Gaseous helium	2,528,000 scf
Propane	15,000 gal

3. MAD Operations (7.3)

a. Reactor Operations (7.3.1)

NTO efforts included the completion of NRX-A5 radiochemistry work and final reports, technical support for completing the Phoebus 1B assembly operations, and backup support for posttest retrieval and disassembly opeations. The assembly and cold-flow testing of Phoebus 2A and the preparations for NRX-A6 Test Car T-7 and cold flow were also supported.

(1) NRX-A5

During the entire disassembly operations, WANL, AGC, and SNPO observers were present and requested special examinations of components as deemed necessary. Changes to existing procedures were documented and approved, where applicable, by the NRX-A5 Test Specifications and Procedure Review Board.

After disassembly operations at R-MAD were completed, cleanup of the disassembly bay and decontamination were completed. Routine maintenance of equipment was also performed.

The following postoperative examinations for NRX-A5 components were completed:

Special fracture tests
Manual measurements
Epoxy filler-strip and element replicas

The following were shipped to LASL for metallography, microscope examinations, and physical testing in the CMB-14 hot cells:

117 elements

250 metallurgical samples

21 support blocks

30 filler strips

Miscellaneous hardware, tie rods, etc.

NTO technicians were assigned to LASL to complete the following:

Warm laboratory metallography;

54 samples were polished, examined, and photographed - 380 prints were distributed.

Hot-cell metallography on fuel samples;

169 samples were polished and examined, with 458 macro- and microphotographs taken and 1832 prints distributed.

Six fuel specimens were cut into 24 1-in. pieces and analyzed for niobium. Several small sections cut from the NRX-A5 nozzle were analyzed for six fission products.

An electrolytic etching technique was used to determine the depth of penetration of the fission products into the nozzle tubing surfaces. Results of the NRX-A5 core analyses were included in the NRX-A5 chemical and radiochemical measurements report (NTO-R-0093).

Electrolytic etching of the NRX-A5 nozzle thermocouple probe was completed. Etch solutions were analyzed for Y-91, Zr-95, Te-129m, Ce-144, and Ta-182. The final report (NTO-R-0104) was completed and published.

The NRX-A2 pressure-vessel forward closure was removed from the R-MAD complex, the remaining guide tubes were removed, and the closure was prepared for shipment. The contact radiation reading was 4 to 5 mr/hr.

(2) Phoebus 1B

Technician support was provided to complete the assembly testing, posttest retrieval, disassembly operations, and postoperative examinations of Phoebus 1B at the R-MAD facility.

(3) Phoebus 2A

Technician support was provided for the decontamination operations at the R-MAD facility, for the assembly and transfer of Phoebus 2A to Test Cell C for cold-flow testing, and for assembly operations of KIVA 2A/Phoebus 2A.

(4) KIVA 2A

Technician support was provided by NTO for the assembly, test, and disassembly of KIVA 2A. Gamma counting and preparation of KIVA 2A for shipment to NRDS were completed.

(5) NRX-A6

The outfitting of NRX-A6 test car T-7 was completed at E-MAD to accommodate the NRX-A6 cold-flow tests. The assembly of the car was completed after cold-flow tests in preparation for NRX-A6 reactor.

Analyses were performed on iodine standards, and irradiated samples were prepared at the Westinghouse Reactor Evaluation Center (WREC) to obtain factors to be used in measuring the concentration of I-131, I-133, I-134, and I-135 in ground-collected air samples. Such samples were taken and analyzed in Phoebus reactor tests in cooperation with Pan Am rad-safe personnel. Portions of the WREC samples were distributed to Pan Am, USPHS, and EG&G so the various groups could intercalibrate and compare the different techniques to be used on future air samples.

Subsequent work was performed in connection with the analysis of reactor debris collected by Pan Am after the Pheobus tests. Particles were measured for size and were photographed. Selected particles were analyzed for I-131 content. In preparing for this work, a germanium-diode gamma-detecting system was calibrated for measuring I-131 on particles without prior chemical separation from other fission products present. Also, a microscope with camera attachment was set up and checked out for doing particle-size determinations.

Radiochemical Laboratory work in preparation of NRX-A6 included:

Radio chemical methods for ND^{147} using Ge counting checkout of the behavior of chemical forms of iodine under conditions expected in handling "elephant-gun" samples.

Checkout for the use of colored film for photographing effluent particulates.

Development of method for determining less than 0.5 mg of uranium in airplane and "elephant-gun" samples.

Results were received from ten laboratories participating in an ASTM round-robin cesium-137 methods-testing program. A statistical analysis of the results was prepared for the mext ASTM E-10 Sub I Committee meeting.

Four radioisotopes were received at E-MAD for calibration of the axial gamma scanner.

Dissolution studies on coating materials are in process. An analysis of reactor debris for Nb and U was conducted.

Research studies in the following areas are in process:

Mo - Chronoamperometric
Mo - Thiocyanate Procedure
Gravimetric analysis of Ti
Qualitative Pb analysis in various materials

The NRX-A6 disassembly and postoperative-examination data-reduction programs are being revised and rewritten. The new system will provide daily data listings that include standard-deviation values on weight loss and total-surface-damage values as a function of radial increment and coating numbers.

b. Engine Operations (7.3.2)

Engineering and technician labor was provided, along with materials and equipment as required to perform assembly, transport, integration, and checkout of test-article assemblies and to recover, maintain, disassemble, and perform postmortem operations on the test hardware.

(1) XECF

The XECF PVARA and lower-engine-assembly (LEA) components were received at NRDS and unloaded in the E-MAD facility on 20 March 1967. Figure 163 shows the XECF PVARA arriving at Las Vegas.

The XECF parts and components were received, inspected, and assembled; and all electrical, hydrostatic, and leak checks were performed. At the end of the contract year, the test article was complete and was subsequently transferred to ETS-1 on 2 October 1967 (Figures 164 and 165).

(2) XE-1

RADA-hardware and disassembly-tool design changes were monitored for their effects on XE-1.

Receiving-inspection procedures were prepared for the XE-1 PVARA, engine components, actuators, and instrumentation.

The procedures for disassembly of XE-1 are in process.



Figure 163 - Receipt of XECF at Las Vegas

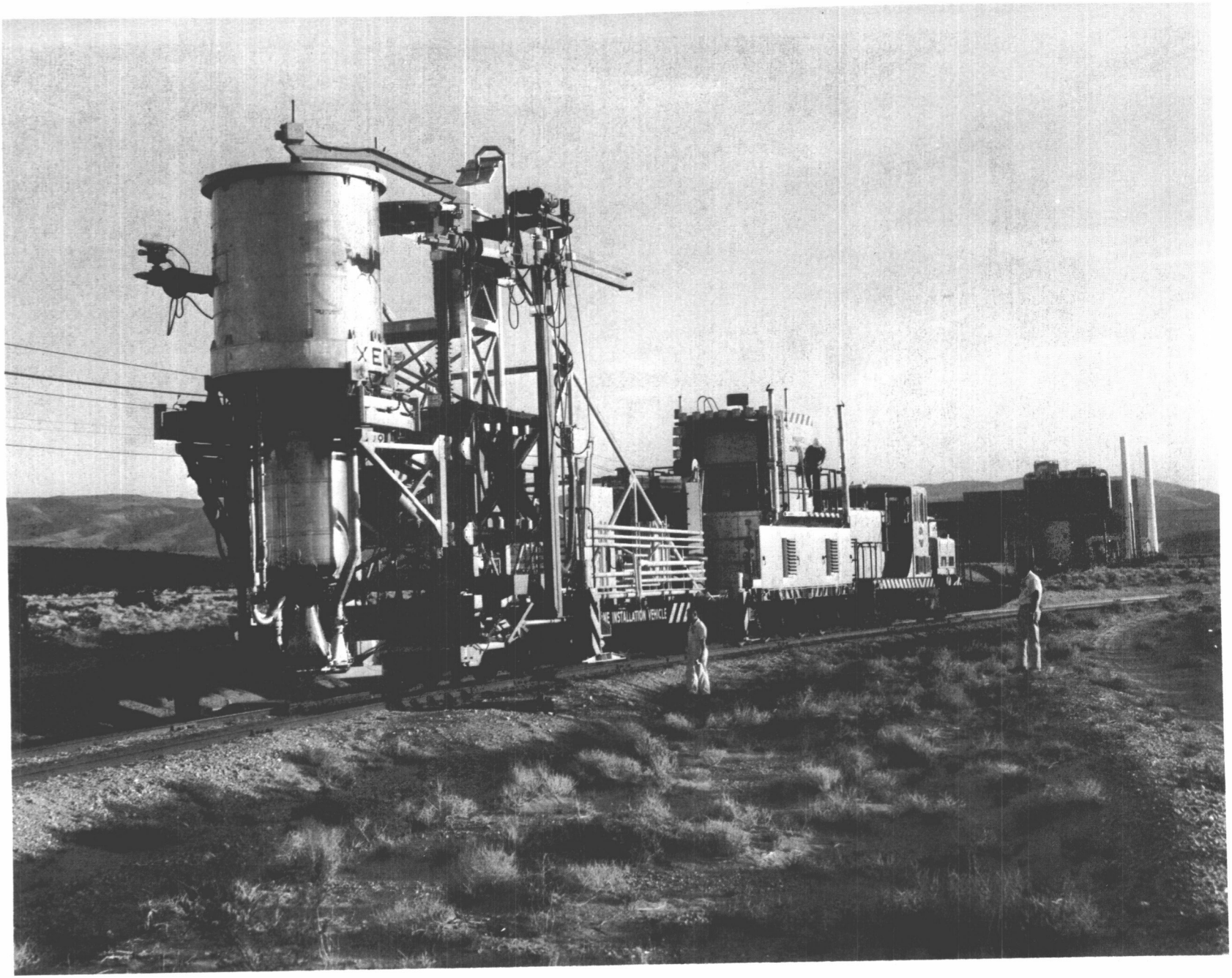


Figure 164 - XECF Transport to ETS-1, October 2, 1967

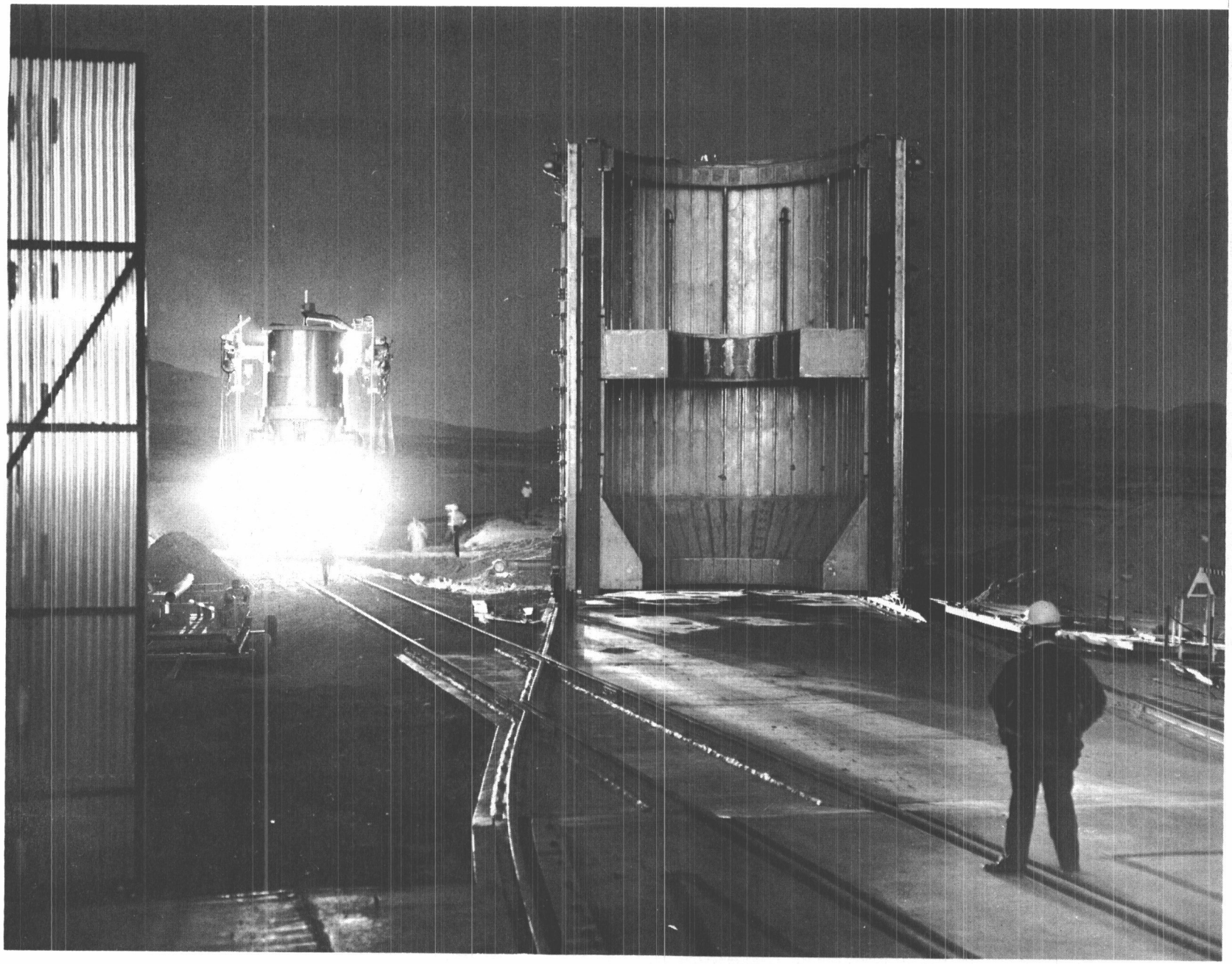


Figure 165 - Receipt of XECF at ETS-1

Tentative plans were made for fission-product plate-out studies to be performed on the XE-1 duct and turbine samples.

The XE-1 assembly (Figure 166) progressed to the point of pulling the peripheral poison wires. Foreign material was found in the nozzle area of the PVARA. Assembly operations were stopped at this point. A photographic survey was conducted, and procedures were prepared for the investigation of foreign material.

All visual foreign material was removed from the nozzle end of the PVARA. Preliminary planning has been initiated to partially disassemble the hardware and investigate possible foreign-material problems in the forward-closure end of the PVARA.

Investigations are being conducted to examine clusters and coolant channels for foreign materials.

(3) RADA/WEMU

The remote assembly and disassembly aid (RADA) and weight-envelope mockup (WEMU) activities during this period included the following:

The WEMU was utilized in checkout of the RTS and SETS facility and was instrumented for shock and vibration tests with the RTS over the applicable NRDS railroad system (Figure 167). The instrumented WEMU was also used for completion of shock and vibration testing with the OPS.

The modification to the alignment fixtures for RADA were completed for the upper-thrust-structure (UTS) shield attachment.

The installation of modified bellows in the upper thrust structure (UTS) and the connections of the modified pump discharge line to the nozzle torus were completed for the remote assembly-disassembly cycling for RADA.

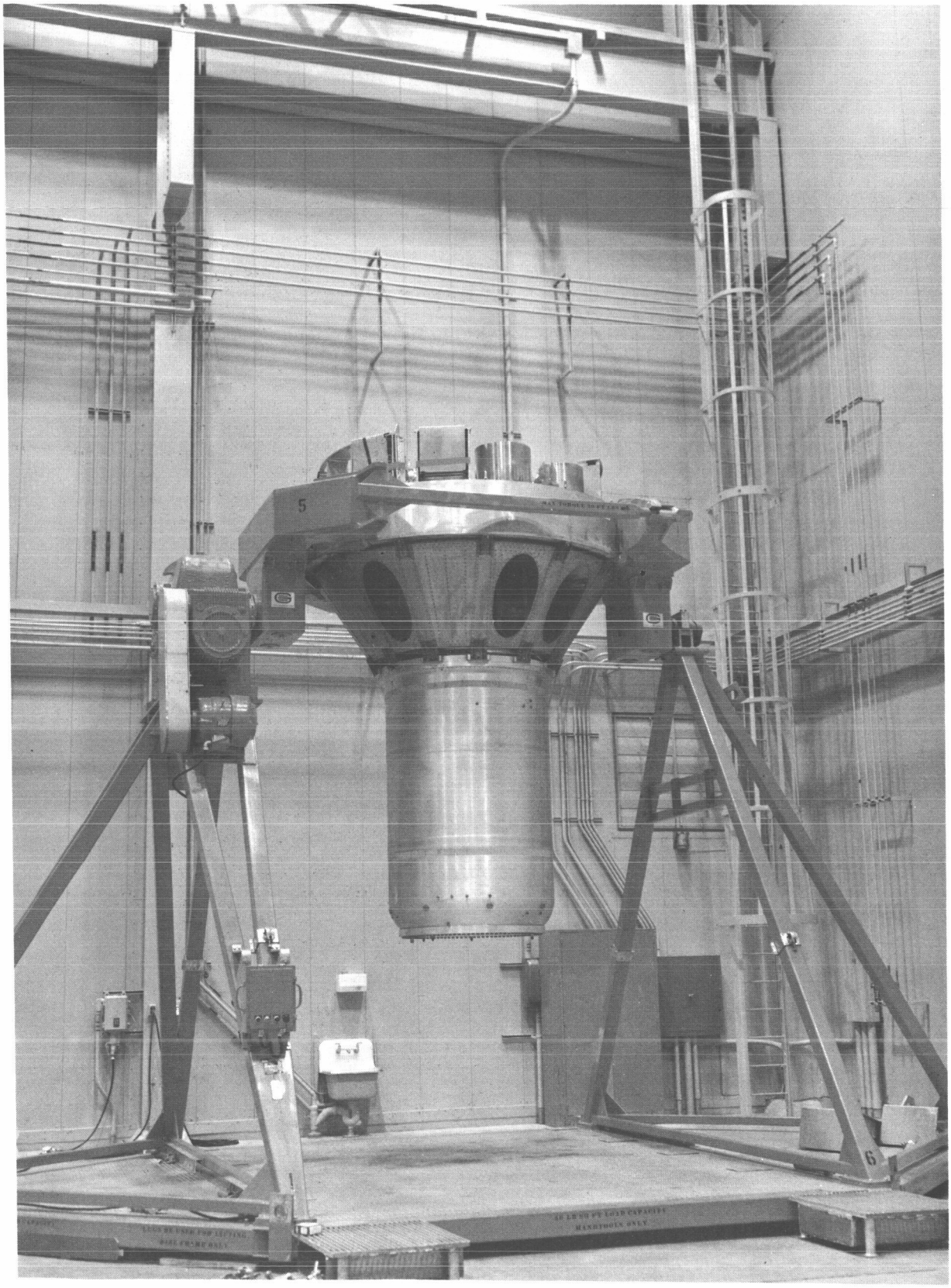


Figure 166 - XE-1 PVARA and LTS Shield

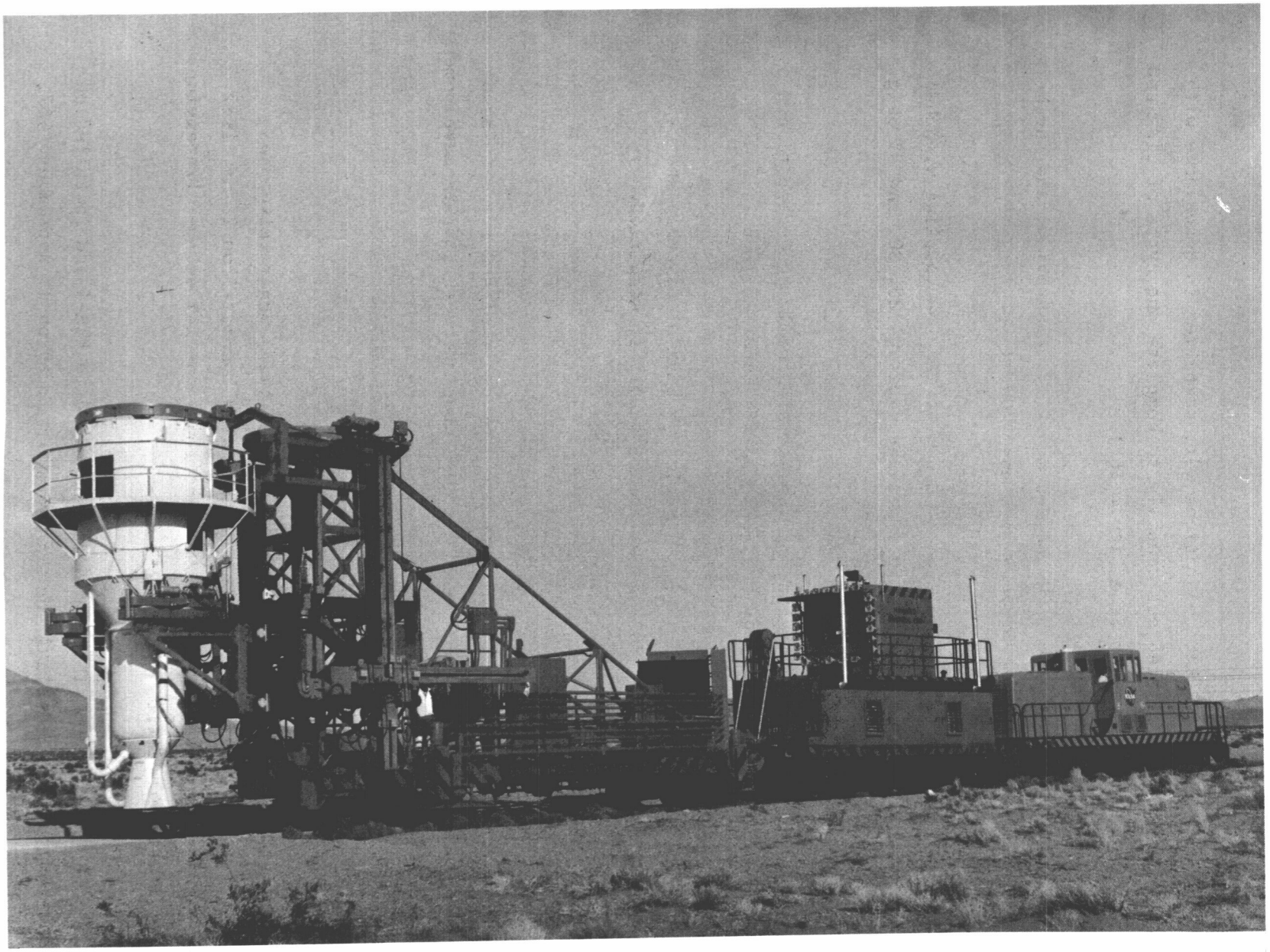


Figure 167 - WEMU on Rail Transport System

RADA operations were completed in accordance with procedure P-3 and were checked out manually to complete one cycle of UTSM and LEA disassembly and reassembly (see Figure 168).

The UTSM-LEA was manually reassembled, and the Marman clamps manually torqued in accordance with specifications.

Torque checks were performed on coupling wrenches PL 4117, PL 4118, and PL 4119 at supply pressures of 20, 25, 30, and 35 psig to verify torque-input-pressure curves.

A leak check was satisfactorily conducted to confirm that seal surfaces were free of scratches and imperfections.

Three remote cycles of RADA disassembly and reassembly were initiated on 17 August 1967 and were satisfactorily completed.

(4) SETS/TSA

The SETS facility was completed and the simulated TSA was installed for functional checkout in support of the WEMU/RTS development program.

(5) ETS-1/TSA

The test-stand adapter (TSA) was received and inspected, and all electrical and leak checks were completed on 22 May 1967. Modifications to procedures NTO-I-0328 (functional checks) and P-7 (receiving inspection) were completed.

The TSA was transported to ETS-1 and installed on 25 August 1967. The electrical checkout was completed on 18 September 1967, and checkout of the operating system was initiated.

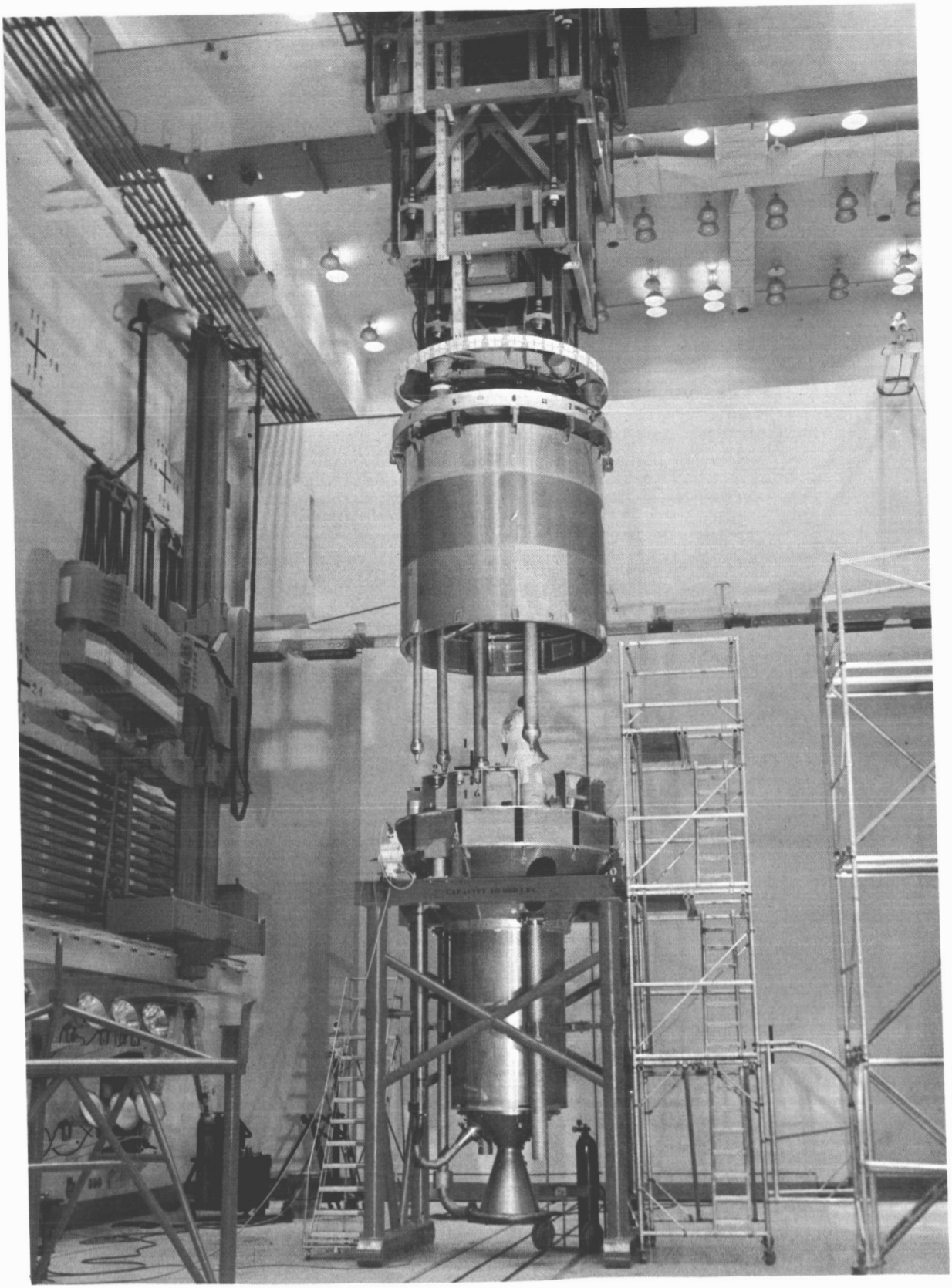


Figure 168 - Installation of RADA-UTSM in E-MAD Hot Bay with OPS

c. Activation (7.3.2) Facilities, Systems, and Equipment

Engineering and technician labor and materials and equipment required to manage and activate, maintain, and modify the E-MAD complex in accordance with the NERVA program plan were provided.

(1) Heating, Ventilating, and Air-Conditioning System (HVAC)

The HVAC water balance (water flow and temperature change through the preheat, reheat, and chiller coils) was completed on 5 November 1966. Approximately 93 discrepancies were noted and corrected.

The dynamic-balance operations of the HVAC system were constrained pending completion of the pneumatic-seals installation. The seals were received at E-MAD on 8 June; installation and checkout were completed on 30 June 1967; dynamic-balance tests of the HVAC were completed on 18 August 1967.

The design and specifications for the procurement, fabrication, and installation of a condenser-water acid-treatment system for the HVAC system operation were completed.

(2) Postmortem Cell and Add-On Equipment

Functional checkouts of the postmortem-cell add-on equipment were satisfactorily completed. This equipment consists of such items as the cutoff machine, element slitting saw, mounting press, grinders, polishers, and the vacuum oven. The functional testing of the Lennox stereomicroscope was also completed.

The design efforts, the fabrication drawings and specifications for the core drilling of holes for the periscopes for the

fuel-element processing system (FEPS), and the Gross gamma scanner in the core disassembly and examination cell (CDAE) were completed. The drilling operations were completed on 28 May 1967.

The preparation of the postmortem area for activation was completed, including the installation of in-cell tables, enclosure plates, repairs to POCMTS cars, the installation of POCMTS enclosures, and the setup of the equipment required for black-light installation. Installation of the gamma scanner and redesign efforts for the stage for the Tukon hardness tester were also completed.

New shear pins were installed in the postmortem-cell plug-door drive mechanisms.

Cell-door rework in the cell service area was completed.

The installation of shielding intercell walls in the postmortem-cell area was completed.

Modifications and repairs to the cell-service-area rectilinear manipulator and the crane-travel limit switches were completed.

The postmortem-cell service-area loading-dock 25-ton monorail hoist was installed, checked out, and acceptance-tested.

Performance of the Phase-IV portion of the shielding-integrity-check (SIC) tests of the postmortem-cell intercell-shielding walls was completed on 4 April 1967. Four shielding violations were revealed. Contractor-type fixes were satisfactorily completed for three of the violations, and administrative control will be maintained for the fourth.

Activation of the postmortem area was completed, with exceptions, on 8 June 1967.

The existing postoperative examination equipment was reviewed to determine modifications and maintenance required.

Engineering, supervision, and design efforts were provided for the installation and proof testing of the bridge crane and rectilinear-manipulator limit stops; the completion of drawings and a design package for postoperative wall-plug assemblies; the completion of drawings and a design package for I&C pneumatic remote-connector fabrication; the completion of the design for the gamma-scanner tamping tool; the fabrication and relocation of the ITS car and mobile-table limit-switch triggers; the design details required for the fuel-element processing system (FEPS); the design layout of a turntable for the stereomicroscope; the design layout of a transfer tray for the metallography specimens; installation of pneumatic controls for the microhardness tester; modification of the FEPS penetration shield by cutting a 23-in. hole inadvertently omitted by the vendor; fabrication and installation of in-cell tables; modification of ITS enclosures and fabrication of spare parts, gears, and periscope liners; complete design package for postmortem trackage; complete fabrication of a grinding fixture and complete track measurement and grinding; the rework and modification of the replication mold master; and a checkout of the electrical motors and controls of POCMTS in the postmortem area.

The designs and modifications required for the four electrically operated, personnel elevating platforms were completed and implemented; and the platforms were proof- and load-tested to 1500 lb.

(3) Wall-Mounted Handling System (WMHS)

The correction of malfunctions in the WMHS were completed. The Class-A manipulator hands were straightened and ground smooth to correct for damage to the clutching surfaces that resulted in low grip force. Broken control cables were replaced. The control cables in the cable drape section between the upper trolley junction box and the clevis junction box for each unit were also repaired.

The grip drive units for the Class-A manipulators were received on 19 May 1967, and installation was completed on 24 May 1967.

The electrical hookup of the WMHS inputs to the master-control-room (MCR) malfunction-annunciator panel was completed.

Electrical repairs were made to the controls for the wall-mounted handling system (WMHS) to correct for loss of motion in the manipulator, damaged control cables were repaired, and the normal preventive-maintenance inspections were made.

(4) Manned Control Car (MCC), Engine-Installation Vehicle (EIV), Prime Mover (LOCO)

Acceptance testing of the railroad transport system (RTS) was satisfactorily completed on 30 June 1967.

Insufficient clearance under the 69-kv electrical transmission lines to ETS-1 at their crossover of the RTS rails at spur A was corrected by raising the lines to a height of 56 ft.

The assembly of the engine-installation vehicle (EIV) was completed, and the functional checkout in the hot bay was accomplished on 19 October 1966.

A deflection study of the EIV suspension system was completed. A redesigned suspension system was installed on the EIV and tested with the WEMU in position. Test results indicated that the new suspension system was satisfactory within the design limits of the shock and vibration track mapping.

The RTS trackage network was inspected by PAA personnel and found to require reballast and realignment, especially at switches and track turns. The sand ballast initially installed was not holding satisfactorily, so a gravel ballast was installed.

The railroad trackage repair was completed and accepted by SNPO-N on 10 May 1967.

The Hovair system installed in the lateral and azimuth carriage of the RTS-EIV was completed.

The engineering, design, preparation of drawings and specifications, and installation and checkout of the redesigned CCTV system in the MCC-EIV was completed; and as-built drawings of the system were documented. Pan and tilt units were installed, camera-control units were mounted, cabling was rerouted and terminated, and the monitor and control package in the MCC cab was completed.

The design and installation of a modified RTS-EIV holding brake for increased reliability was completed.

Modifications to the RTS public-address (PA) system were completed.

A dioctyl-phthalate (DOP) test of the MCC air-conditioning absolute filter system was successfully completed on 5 May 1967.

The DOP test consisted of using 0.3-micron particulate matter in smoke to check the filtering system. Evaluation of the data accumulated indicated that the filters were 99.975% effective.

(5) Engine-Transport-System Maintenance Building (ETSMB), Radioactive-Material Storage Facility (RMSF), and Interconnecting Railroad System

The material-control station for the engine-transport-system maintenance building (ETSMB) was completed on 2 December 1966.

The operational and preventive-maintenance procedures for the radioactive-material storage facility (RMSF) and the NTO RMSF operational-interface procedures were completed.

The design and construction package for the fabrication and installation of the ETSMB exhaust-removal system was completed. On-site installation was completed on 30 June 1967.

Test Cars T-2 and T-6 and miscellaneous radioactive components were transferred from the R-MAD facility to the radioactive-materials storage facility (RMSF) for indefinite storage.

(6) Overhead Positioning System (OPS)

The proof-load testing of the OPS was completed. During proof-loading tests, deficiencies were corrected as encountered. The upper-mast mechanical-override shaft was whipping, and the middle-mast brake failed to release electrically. These items were corrected.

(7) Floor-Mounted Handling System (FMHS)

The installation of the mechanical and electrical hardware required to modify and check out the ST-2 turntable was completed.

Modification of the ST-1 turntable control system by installing permissive switches in the MCR was completed, and load testing of the ST-1 and ST-2 turntables was satisfactorily completed in accordance with specification, and the tables were certified for use.

The WT-1 turntable was rectified on 6 October 1966 after modifications by NTO were completed.

The FMHS carriage and remote dolly were modified to accommodate the existing track gauge by removing 1/4-in. from each wheel flange.

Broken harmonic-drive-shaft mounting feet were discovered during wheel removal on the FMHS carriage and remote dolly. The design, fabrication, installation, and load testing of new steel mounting feet were completed.

(8) Construction-Package Items

The following construction packages were completed during Contract Year 1967:

Air-Sampling-System Installation - Completed 7 October 1966.
Crane-Rail-Support Modifications - Completed 11 November 1966.
Railroad-System Trackage Repair - Completed 10 May 1967.
Material Control Station (ETSMB) - Completed 2 December 1966.
Simulated-Engine Test Stand (SETS) - Completed 28 October 1966.
Postoperative-Cell Intercell-Walls Installation - Completed 15 March 1967.
Repair work of the Postmortem Intercell Walls Installed by Contractor - Completed 17 April 1967.

Controlled-Assembly-Area Construction - Completed 15 March 1967.

The engineering design, procurement, fabrication, and installation packages were prepared for the E-MAD emergency power system. The generator was received at NRDS on 19 June 1967.

Permanent Emergency-Power-System Installation - Completed 15 August 1967.

The Postmortem-Cell Service-Area Loading-Dock 25-ton Monorail-Hoist Installation - Completed 3 March 1967.

The Core Disassembly and Examination (CDAE) Cell Equipment Installation - Completed 29 June 1967.

The Engine-Transport-System Maintenance-Building (ETSMB) Exhaust-System Installation - Completed 29 June 1967.

The Ceiling-Modification Contract of the Hot-Change Room No. 120 - Completed 28 April 1967.

(9) Designs, Review, and Engineering

The design efforts completed in support of E-MAD activation included the following:

A study for relocation of the core disassembly-and-examination cell (CDAE) shield-door drive motor to provide backup capability.

Travel-limit stop mechanisms for the 7-1/2-ton crane and the rectilinear manipulator.

Postmortem-cells intercell-walls construction package.

Final design package for an air-tight ceiling in the hot change room No. 120.

Redesign of panels and electrical circuitry and the preparation of as-built electrical drawings for shielding doors 122-3 and 122-4, for operational safety.

Design of an improved radiation-monitoring criticality-alarm circuit.

Design and drawing changes for the replication mold master.

Design and fabrication of standoff supports for the PVARA stand and reactor handling dolly.

Design, detailed drawings, fabrication, and installation of dust pans for the V-2 10-ton and 40-ton cranes.

Design and installation of pneumatic door seals, plumbing flow diagrams, and electrical control systems for shielding doors 122-1, 122-2, 127, 128, 130, and 173.

Review of the design criteria for the cluster-disassembly fixture, PL 6183.

Design and detailed drawings for the hydraulic actuator.

Equipment design and buildup for the drum-actuator checkout.

Design and detailing requirements and the fabrication and installation of a load-indicating system for the engine-installation vehicle (EIV).

Design drawings for the master-control-room (MCR) modifications concerning power-up, power-down, and improved permissive switching.

As-built drawings of the overhead-positioning-system (OPS) electrical circuitry.

Electrical drawings for installation of additional control wiring between the electrical equipment room (EER) and the master control room (MCR).

Modification package for the OPS floating-head readout package to overcome inconsistent operation and relay activity.

Reviews of existing postoperative examination equipment to determine maintenance, rework, and modifications required for use in the NRX-A6 disassembly operations.

Design and equipment layout for a metallography laboratory.

Design drawings and a fabrication package for the E-MAD postoperative wall plugs and for I&C pneumatic remote connectors.

Design for a gamma-scanner tamping tool, a storage rack, and details for the fuel-element processing system (FEPS).

Design layout of a transfer tray for metallography specimens.

Design layout for a stereomicroscope turntable.

Development and design for a master-slave-manipulator (MSM) removal fixture.

Designs for the prefilter gate modifications in the postmortem cells.

Equipment design layouts for the metallography-specimen storage cabinet and the specimen-holder handling fixture.

Shielding-door electrical-control circuit designs.

Design and modification of the Locomotive L-2 throttle controls.

Design of a fixture to remove liner from the channels of axially slit fuel elements.

Design of RTS spacer-car coupler-position indicator system.

(10) Miscellaneous

The E-MAD hot-area activation was completed, with exceptions, on 8 June 1967.

The E-MAD facility, equipment, and test-article hardware, after preparation by such means as bracing and tying, satisfactorily withstood the shock of several seismic events conducted at NTS. No apparent facility damage was noted. Preparation included concrete-block-wall bracing between Rooms 112 and 114 and between 112 and 115; securing of facility equipment, test-article assemblies, and associated accessories; and installation of instrumentation for the recording of shock and vibration imposed on XE-1, XECF, and NRX test articles, facility equipment, and building doors and walls.

(11) Planning and Documentation

The preparation of spare-parts lists and accumulation of vendor-recommended spare-parts data for all major items of equipment at E-MAD were completed.

Machine-equipment history cards were established for use in programing preventive maintenance for E-MAD equipment, and as a basis for establishing a required spare-parts inventory.

(12) Support-Service Contract Activities

(a) Pan American

NTO direction and supervision were provided for the normal facility maintenance, housekeeping services, and minor modifications performed by the support-services contractor (SSC), Pan American World Airways.

Additional office space (office-trailer installation) was completed and occupied. Piped water, telephones, and electrical circuits were installed.

(b) EG&G

EG&G is providing support services in the instrumentation and controls area at E-MAD under the negotiated memorandum of understanding.

The electronic shop and equipment and the work being performed by EG&G are under the technical direction of NTO personnel. The following items of work were completed:

Factory-recommended modifications on all Tektronic test equipment.
Replacement of an output transformer on a Stromberg Carlson amplifier.
Modification and checkout of E-MAD intercom system.
A survey balance and phasing of the PA-system speakers.
Installation of radios on Nets 21, 22, and 24 and provision of mobile radio units to operate on 115 v.
Checkout of CCTV-vidicon protection-circuitry performance.
Installation and checkout of neutron detection system.
Modification of HP strip-chart recorders and multifunction meters.
Fabrication of alarm panels.
Modification of two Scott Air Pak face masks to provide microphone service with GE PortaMobile Radios.

A tape player was installed for the rad-safe alarm system, and a relay system was provided to disable the audible alarm to the neutron system in the event of power failure.

An input transformer was installed at the input circuit of the PA amplifiers.

In addition to the above items, numerous calibrations, rework, repairs, and modifications are being made.

4. ETS-1 Operations (7.4, 7.4.0)

a. Introduction

Efforts at ETS-1 were concentrated on the installation, modification, and activation of the facility systems. Experimental plans (EPs) were conducted to the extent possible on various systems and components in preparation for the XECF test program.

b. Facility Checkout and Activation

(1) Steam-Generator System

The propane venturi-meter calibration test, GEP-VIII, was completed on 2 November 1966 and consisted of obtaining propane flow data on eight meters.

Modifications to the steam-generator coolant water piping and electrical control system were completed in accordance with the product-improvement test plan, (Report RN-DR-0087). The basic purpose of modifications to the electrical control system was to permit a return to idle operation from fullsteam conditions without a shutdown and restart sequence. The basic purpose of the piping modification was to improve system operational reliability and to reduce water consumption.

The steam-generator water-flow test, GEP-IX-1, was successfully conducted on 14 December 1966. Data analysis indicated that the operational pressures were in the design range.

Full-steam test GEP-IX-2 was conducted on 20 December 1966. Modules No. 1 and 2 performed in a normal manner. Module No. 3, however, could not be brought up to idle steam conditions because of a second-stage cutoff caused by igniter internal burnout.

In an effort to condense the ETS-1 activation schedule, steam-generator GEP-IX switching tests were combined with the NES Phase-I GN_2 experimental plan. These tests were satisfactorily concluded on 2 February 1967.

Modifications to the steam-generator system resulting from the NES mode-of-failure analysis were accomplished and included the following items:

(a) Fail-safe operation of the propane, LO_2, and GN_2 actuation and purge supplies.

(b) Extension of the steam-generator plenum drain line to eliminate the possible release of GH_2 into the top of the pipe vault via the NES-duct steam line.

Modifications to the steam line to reduce shock loads during startup of the steam generator were nearing completion and included the installation of an antivortex dam.

(2) Nuclear Exhaust System (NES)

Repair of the NES duct drain tube and duct primary section, which failed during contractor acceptance tests, was completed on 25 October 1966. A satisfactory duct hydrostatic test was conducted on 26 October 1966. A test pressure of 360 psig was maintained for 15 min, with a total time of 67 min at or above the 240-psig working pressure. Subsequent dye-penetrant checks on the weld repairs indicated no discontinuities.

After the required duct instrumentation was installed, the NES-duct water-flow and leak test, DEP-I-1, was conducted on 16 November 1966. No serious abnormalities were observed. In an effort to obtain the specified flow rates in duct Sections No. 1, 2, and 3, the

flow-control orifices in Sections No. 1 and 3 were removed. Subsequent duct water-flow calibration test DEP-I-2, conducted on 7 December 1966, indicated flow rates were at or near design requirements. The noise and vibration levels were significantly reduced from those observed during DEP-I-1.

Because of late completion of the engine-test-compartment installation, preparations were made for conducting the NES GN_2 design-demonstration tests with the temporary engine compartment (TEC) less the simulated TSA-UTS. Interference with contractor work on the ETC delayed the initiation of the TEC installation until 23 December 1966. Activities associated with the NES design-demonstration tests included the following items:

(a) Installation of the NES temporary controls.

(b) NES-duct instrumentation installation and the evaluation of means for reducing the effects of vibration on differential-pressure transducers.

(c) Installation of the NES temporary gas-analyzing system for monitoring the oxygen concentration at the duct exit and also within the TEC.

(d) Installation of the NES fluid supply.

(e) Installation of the ETC gas-monitoring system.

NEP-II-1 and NEP-II-2 were successfully conducted on 26 January 1967 by using the temporary engine compartment (TEC). The duct was operated at steam supply conditions of 110 psig at 1750°R. The temporary engine compartment was made inert without difficulty, and the TEC pressure decreased to approximately 1 psia during GN_2 flow through the simulated engine thrust chamber operating at a chamber pressure of approximately 200 psia.

NEP-III was conducted on 2 February 1967 with a steam supply condition to the NES duct of 110 psig at 1350°R. The GN_2 NES Phase-I tests were concluded on 7 February 1967 with NEP-IV.

Modifications completed prior to the initiation of NEPN-I with the ETC included the following items:

(a) Installation of automatic drain valves for the duct drain manifold.

(b) Modification of the 20-in.-dia steam line to prevent additional line distortion.

(c) Modification of the duct-drain-snout water-coolant piping to obtain increased water flow capacity.

(d) Installation of pressure switches for cold checkout of the steam-generator system.

(e) Repair of the NES-duct internal surfaces that were nicked during NEP-III.

(f) Engine-test-compartment (ETC) modifications and correction of punch-list items.

NEPN-I was conducted on 13 June 1967 to evaluate the repressurization rate of the engine test compartment (ETC) at various conditions of primary flow when the steam generators were shut off individually and simultaneously. Prior to this test, the ETC was banded circumferentially with steel cable to prevent ETC separation in the event the ETC internal pressure exceeded ambient pressure.

When the steam generators were shut off either individually or simultaneously, with or without primary flow, there was no ETC overpressure. During the steam-generator-system shutdowns without primary flow, however, an increase in the oxygen concentration was indicated at the bottom of the ETC, reaching a maximum value of 6.6%. During the ramp down of the primary flow with the steam-generator system shut down, ETC overpressures occurred that reached a maximum value of 1.6 psi above ambient.

Work was in progress to install a U-tube water seal to prevent air intrusion into the NES duct via the drain tubes.

(3) Engine Test Compartment (ETC)

Field surveillance of ETC construction activities was performed on a continuous basis and included the resolution of problem areas. Installation of the ETC, with the exception of the upper trough assembly, upper-trough cooling system, and upper bellows assembly, was completed by the construction contractor; and beneficial occupancy took place on 20 March 1967. After completion of the remaining installation work, the ETC was accepted by SNPO on 13 April 1967.

Satisfactory water-flow tests were conducted on 28 March 1967 on the top, bottom, and side shields after fill-and-drain modifications to the cooling-water system.

An ETC operational reliability program, as related to engine test requirements and anticipated ETC operational problems, was prepared by NTO and approved by SNPO-C. The three planned pull and remating tests on the current design were conducted without any difficulties.

During the preliminary movement evaluation test, the S-1 car successfully negotiated the curved track with no visible deflections being noted. Sliding of the flangeless wheels on the track was as predicted.

The side-shield reliability test was completed on 31 March 1967 with no significant difficulties. On the basis of results of the reliability tests on the S-1 and S-2 shields, the center-pull-point shield reliability test was not required; thus, the ETC operational reliability program was concluded.

Completed modifications that constrained the initiation of the mechanical-seal and leak test included the installation of trough cooling lines, the installation of valves and tubing for the latch-actuation mechanism, realignment of the latches, and readjustment of 40 temperature controllers for the eutectic-trough heating elements.

The entire ETC mechanical-seal and leak test was satisfactorily completed on 28 April 1967. With the ETC evacuated to 3 psia, the approximate maximum indicated leakage rate of buffer gas into the ETC was 0.2 lb/sec.

ETC purge test, CEP-I, (Figure 169) was satisfactorily conducted on 11 May 1967. GN_2 purge effectiveness through the upper-thrust-structure (UTS) purge line and the ETC purge ring was determined at various flow rates to optimize techniques for making the UTS, ETC, and NES duct inert. Capability of the pressure-relief system for the purge line and adequacy of the alternative purge supply were also investigated.

Punch-list items that were corrected included installation of silicone-rubber gaskets in place of asbestos on the upper bellows assembly, fabrication and installation of stainless-steel trough gates, replacement of bearings and axles on the side-shield transfer cars, repositioning of top-trough heaters and thermocouples, providing convolute seal protectors, rework of the S-1 and S-2 transfer-car drive-cable protectors, and rework of the S-1 curved-track wheel guides to prevent interference with movement of the transfer car.

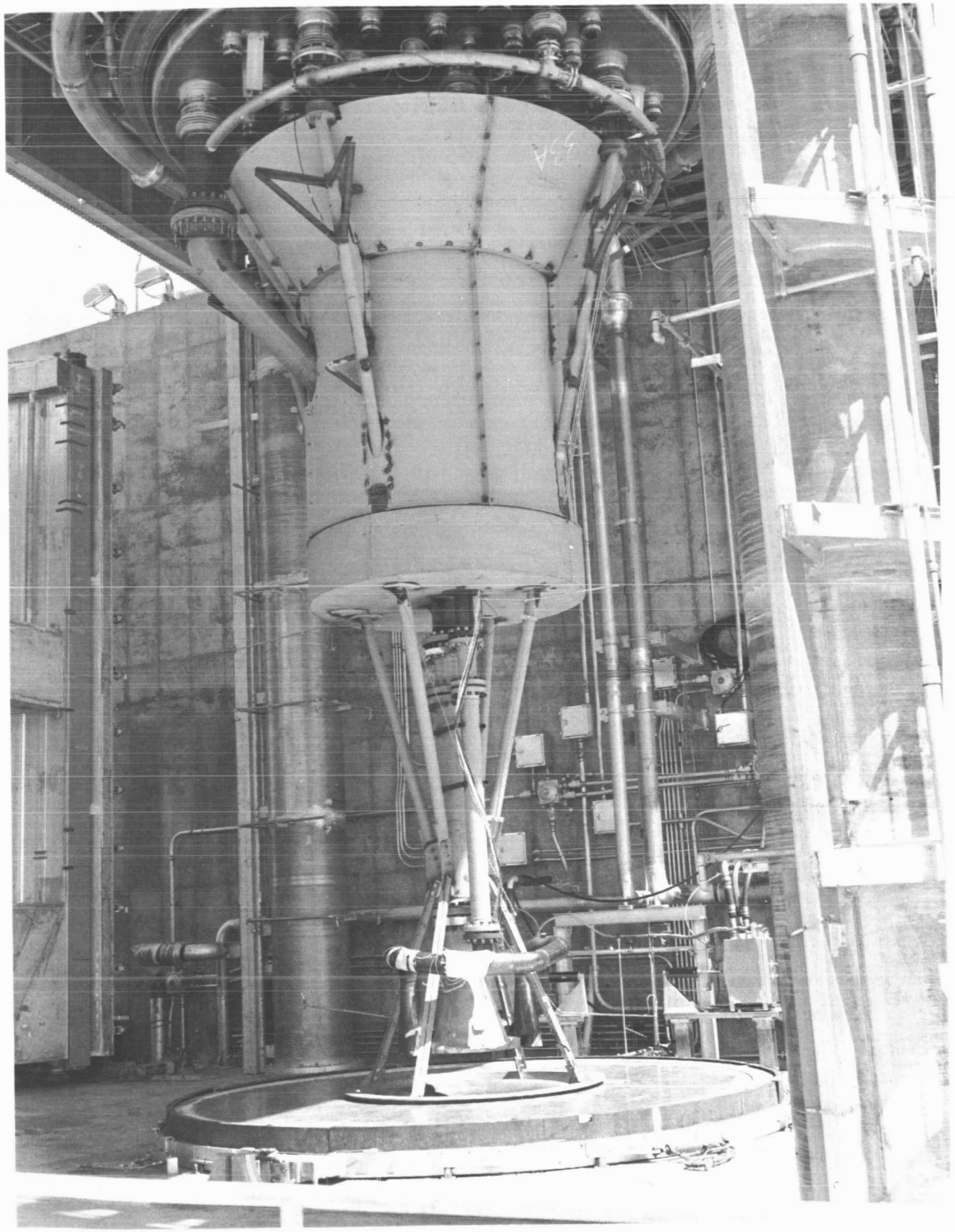


Figure 169 - CEP-1 Purge Test Setup

Various ETC modifications in support of NEPN-I were installed, such as the convolute-seal pressure-system backup, electrical-connector-panel backup, bellows holddown tabs, and circumferential banding of the ETC with steel cable. Modifications in progress during the final quarter of CY 1967 in support of NEPN-II and XECF included replacement of the trough cooling-water tubes with stainless tubing, top-trough heater-bracket redesign, installation of a redesigned ETC latching mechanism, and the provision of work platforms.

(4) Test Stand and Fluid Systems

The FEP-IA LN_2 chilldown and flow tests were conducted on 4 October 1966. The chill-maintenance test was satisfactorily completed. Run No. 2, which consisted of the first flow test to maximum LN_2 flow rate, was scrubbed because of erratic operation of security valve PCV-517.

While PCV-517 was being replaced with an Annin valve, the FEP-II, Run Day No. 1, gaseous-cooldown-system flow tests were initiated on 20 October 1966. The first test covered the high-pressure GN_2 flow test and GH_2 system-integrity test. PCV-251 exhibited poor resolution, which was reflected in a limit cycle when PCV-251 was used in the pressure-controlled mode. The helium flow test was scrubbed because of improper operation of PCV-471 at high upstream pressure.

Before conducting a combined FEP-IIA and FEP-IB on 26 October 1966, various system deficiencies were corrected, including replacement of the PCV-471 controller. FEP-IIA consisted of a checkout of PCV-471 with GHe. Upon termination of the flow test, PCV-471 was leaking excessively across the valve seat because of a severely damaged valve seat. FEP-IB checkout of the newly installed Annin PCV-517 valve with LN_2 indicated that the valve impedance was much higher than expected, and the valve exhibited an undamped series of oscillations in the automatic control mode.

A large actuator was attached to PCV-471, and FEP-IIB and FEP-IC were conducted on 9 November 1966. These tests consisted of gaseous-cooldown-system flow tests and the LN_2 chilldown and flow tests, respectively. Except for difficulties encountered with valves PCV-251 and PCV-471, the tests were satisfactorily completed.

LH_2 high-pressure run vessel V-5002 was successfully leak-checked with LN_2 on 29 November 1966. Results of these tests indicated V-5002 was ready for FEP-III LH_2 tests after satisfactory operation of the PCV-472 control valve in the LH_2 cooldown system.

The LN_2 checkout of LH_2 high-pressure run vessel V-5002 was conducted on 10 January 1967, followed by FEP-III Phase-1 LH_2 tests on 14 January 1967. The GH_2 and LH_2 systems were found to be relatively free of any leakage, and fill and chill of V-5002 were accomplished satisfactorily. The pressure and vent systems of V-3801 and V-5002 performed well.

FEP-IV Phases 1 and 2 were conducted on 24 February 1967 to demonstrate the capabilities of the integrated cooldown system. Ten of the eleven planned tests were run, and approximately 95% of the test objectives were met.

LN_2 leak testing of LH_2 run vessel V-5001 was satisfactorily completed on 21 March 1967, followed by FEP-III Phase-2 LH_2 tests on 24 March 1967. All test objectives were met. These objectives included checkout of V-5001 under simulated engine operating conditions, the feasibility of the topping concept for V-5001 during extended power runs, chill-down and chill-holding characteristics of V-5001, and functional characteristics of the fluid and instrumentation systems.

Reverification of the cleanliness of LH_2 run vessel V-5001 was performed by GN_2 blowdown tests on 24 May 1967. After the third blowdown, there was no evidence of system contaminants in the effluent gas stream; and wipe tests showed the system to comply with specifications.

Checkout tests were completed 21 August 1967 on the engine valve-actuation system, the TPA heated purge system, and the TSA actuator system. The remaining test-stand auxiliary systems to be checked consist of the drum actuator, TPCV actuation, and engine purge.

Mechanical, electrical and data-system tests were completed on the test-stand adapter in preparation for the installation of XECF.

(5) Other Systems

Checkout tests were satisfactorily accomplished on the electrical power system to demonstrate the remote control and synchronizing capabilities of the diesel generators. These tests included endurance runs, paralleling tests, and a simulated failure of the utility power supply to verify isolation of the essential bus.

The final data-system accuracy tests were completed on 23 May 1967. Details of the test are covered in Report NTO-R-0113.

The process control system of the TSCS/ECS was checked out during the facility experimental plans. Checkout of the engine control system (ECS) in preparation for customer buyoff of the TSCS/ECS was suspended during the latter part of March 1967 to incorporate various TSCS modifications in support of the operator training program and the engine test program. Checkout of the ECS with the simulator was subsequently completed.

Subsystems associated with completed ETS-1 modifications were checked out to verify design requirements and system operational reliability.

c. Facility Modifications

(1) General

In addition to the steam-generator and NES-duct modifications previously discussed, various modifications and repairs were made or initiated on the facility systems to ensure system performance in accordance with design, safety, and engine requirements. Some of these activities are covered in the following paragraphs.

(2) Test Stand and Fluid Systems

The required modifications from pneumatic to hydraulic actuation were made to correct the operation of valves PCV-251 (GH_2 system), PCV-471 (GHe cooldown system), and PCV-472 (high-pressure LH_2, V-5002). The corrective action was based on an analysis of FEP-I and FEP-II test data.

The 14-in.-dia outlet-pipe assembly of LH_2 run vessel V-5001 and the pressurization, vent, and fill lines in the upper annular space of V-5001 were repaired and cleaned prior to FEP-III Phase 2.

LH_2 high-pressure run vessel V-5002 was cleaned, and carbon-resistor liquid-level probes were installed in vessels V-5001 and V-5002.

The 36 electrical harness assemblies damaged by the entrance of water were repaired, modified to preclude the entrance of moisture, and reinstalled in the ETC top shield.

The octagonal aluminum thrust ring, which had deficient welds, was replaced by a steel thrust ring. In conjunction with this modification, the load cells and aluminum thrust columns were replaced with steel thrust columns.

Other major modifications that were completed included the following;

(a) Emergency ccoldown system required for FEP-V.

(b) Engine valve actuation and purge supply required for XECF.

(c) GN_2 auxiliary systems header required for XECF.

(d) Installation of the test-stand heat shield required for XECF.

(e) FEP-V flow-piping modifications, including LN_2 soak tests.

(f) Installation of the control-drum-actuation vent system required for XECF.

(g) The replacement of gunnite on the side walls of the duct ditch near the test stand with concrete for decontamination purposes.

Modifications that were initiated consisted of adding fluid-system relief valves, engine-shield fill-and-drain system, valve and power-failure changes, actuator-supply cryo-trap, valve-guide replacements, remote control of the LN_2 vaporizer, correction of defective welds in the

fire-protection system, drum-actuator valve locks, duct-vault and pipe-chase inert system, additional gas-storage capacity consisting of GH_2 trailers, repair of the propane supply line, decontamination and heat-shield water, deluge and decontamination water control, and design of an emergency helium supply system utilizing PCV-449 to prevent air intrusion into the NES duct.

(3) Test-Stand Control System (TSCS) and Consoles

Pressure-control valves 250, 251, 471, 472, 517, and FCV-50 and their associated controllers were modified on the basis of results obtained during the EPs.

Modifications to the CTE, ATE, TSE, RIC, LFE, and ASE consoles were completed.

Simulator modifications for the TSS and steam-generator system were accomplished.

Extensive modifications to the engine control system (ECS) were completed.

Some of the modifications to Racks 37 and 38, such as the cross-correlation and frequency-response capability, were finished. The signal-conditioning and data-isolation amplifiers were installed in Rack 70. Work was in progress for installing the pump-discharge pressure averager, the nozzle-torus pressure averager, and power-supply modifications.

(4) Neutronics and Safety Systems

Incorporation of the ten basic modifications to the safety system to reflect a change in logic requested by SNPO-C and NRO was completed.

The radioactive airborne and gas-monitoring system, required primarily for personnel protection from the entry of radioactive gas or particles into the below-ground air system at ETS-1, was installed.

Installation of the Test Cell A criticality-monitoring system into the ETS-1 area-surveillance and warning system was completed. Neutron-source checkout of the system remains to be accomplished prior to XE-1.

The source drive system, required for checking all ETC S-2 shield-mounted neutron channels end-to-end prior to unlocking the drums and attempting to bring the reactor critical, was installed. Final checkout remains to be performed when the shields are again mated.

The electronics from Test Cell A were installed and checked out at ETS-1 for the fast-fission channel system. System calibration is to be accomplished at WANEF.

Other modifications that were in progress included those for combustible-gas detectors in the tunnel, LSE console modifications, parallel controls for the facility ventilating system, the test-stand equipment-room (TSER) GN_2 inerting system, and detectors for the duct-vault and pipe-chase inerting systems.

(5) Instrumentation

In an effort to increase the flexibility of the I&C patching system, the forward control room and analog-recorder patches were modified; and the system was successfully used during NEPN-I.

The event patch panels were modified, and a remote control unit for the control-point Beckman recorders was installed. Other

completed modifications included installation of galvanometer control panels and band-pass filters and galvanometer amplifiers (for tape-playback system).

Modifications to the data-acquisition system included the installation of modified printed-circuit cards for the channelization system, conversion of the digital-data-system fast events to slow events, and rework of the Dana wide-band amplifier-system grounding to eliminate noise problems.

The data-link system for transmission of ETS-1 TV video and data signals to the A&E Building was installed. System checkout was in progress on the real-time computer-programing phase and on the data-link hardware.

Modifications that were in progress and which are required or desired for XECF included the charge-amplifier system, flush-mounted-transducer signal-conditioning system, LVDT-VR system, ETS-1 test diagnostic center, control-room stereo, EIV-MCC TV interface, UTS-TV power supply, V-5001 reflectometer level measuring system, and fire protection of electrical control cabling.

(6) Other Systems

Modifications to the photographic and communications systems included rebalancing of the public-address system, the providing of 28 vdc operational capability for the communication panel, upgrading the operational life of the portable searchlight units, and installing a video-tape-recorder system.

Changeover of the communication system from ac to dc power was completed to ensure operation at all times. The headset jack locations in the control room were relocated to eliminate physical interference of equipment during control-room operations.

The fuel-supply system for the diesel generators was modified to ensure an adequate and reliable supply of fuel to each engine.

Work was in progress for placing a portion of the air-conditioning system on the "essential" bus in order to retain air-conditioning capabilities in the event of a loss of power on the "utility" bus.

d. Signal-Conditioning Programs

Signal-conditioning requirements were determined, such as the zero-balance resistor values for the NES-duct structural-strain-gage signal conditioner, the preparation of a computer design program for two- and four-arm-strain-gage signal conditioning, development of a slope-offset technique for fitting standard transducer curves to an individual transducer, and the preparation of a procedure for use of the mode-card checkout device.

A swept-potentiometer simulator and a strain-gage simulator were fabricated and satisfactorily tested by means of the mode-card checkout device.

Extensive tests were performed on the NES-duct instrumentation, which uses metal-sheathed MgO-insulated cable. Signal-conditioner modifications were devised to permit best use of the MgO cables.

Signal-conditioning requirements were determined for Statham pressure transducers for use on the XE engine. A method was also devised for incorporating shunt resistors on Mode Card ST-03 in place of mounting the resistor near each transducer.

e. Computer Programs

The basic posttest run-data processing package, consisting of eight programs, was completed and provides the capability to produce engineering-unit data, events and time-slice listings, computations, X-Y plots, and DN-3 engineering-unit tapes.

Work was completed on the calibration and diagnostic-data program that provides the capability to analyze calibration data for linearity, noise, and drift to permit a go/no-go analysis of the digital data system. It also provides slopes and intercepts that are used to calibrate raw counts prior to engineering-unit conversion.

The end-to-end patching program was written and put into operation.

Fourteen programs were written for real-time data processing on the CDC 3200 and were being integrated and debugged. A checkout program designed for acceptance testing of the data-link system was satisfactorily demonstrated.

The CDC 3200 computer channel-advance program, which automatically assigns the proper channel number to cable terminations to the ETS-1 I&C system unit lists, was put into operation.

Data were processed for the various experimental plans conducted at ETS-1.

The general data-handling plan was revised, and review comments were being resolved.

f. Channel Engineering

Channel engineering functions in support of the scheduled test programs included checkout of the automated patching system; the preparation of patch lists, data logs, unit lists, channel routing lists, and channel termination lists; the processing of engineering change requests and measurement control requirements; the maintenance of all documents necessary for the inventory of channel systems and transducers; and completion of the ETS-1 cable and cable-termination audit.

g. Planning and Procedures

Test-planning functions were performed on a continuous basis. All documentation required for the tests conducted during CY 1967 were prepared and issued, such as test descriptions, control-room operating procedures, check lists, support operational-requirements documents, and status-board and recording-data requirements.

The ETS-1 activation and test schedules were prepared, evaluated, and revised as necessary to work around problem areas having an adverse impact on the initiation of XE-1 power tests. All known ETS-1 modifications in support of facility activation and XE-1 tests were included in the appropriate schedules.

The NTO-0232 activation guide for E/STS 2-3 was prepared and presented to the design team on 19 April 1967. A PERT network defining the activation schedule for E/STS 2-3 was also established for incorporation into the eight-year program plan. Coordination was provided relative to the engine-control-system and facility-control-system logic. A list of facility requirements was prepared and submitted to the NRO Project Engineer. The GSE drawings from Marshall Space Flight Center were reviewed, including the GSE interfaces.

Configuration control of the ETS-1 facility was maintained, and support information was provided for administrative and contractual matters.

h. Test Engineering

Test predictions, FDET reports, and site test reports were prepared and issued for the test programs and experimental plans conducted during CY 1967.

Proposed modifications to the ETS-1 facility were evaluated, and coordination was provided for their implementation.

Training and console manuals were prepared to implement the operator-qualification program. Approximately 35 ETS-1 engineers attended the ETS-1 operator training course in April 1967. The subject matter covered all systems in support of engine tests, including reactor physics.

Lectures on the XE control systems and console training incorporating simulator capabilities were conducted at NRO and WANL (Large).

The preparation of documentation in support of XECF experimental plans was in progress and included the support-operations-requirement document, control-room operating procedures, and installation and removal procedures at the test stand.

XECF and XE-1 assembly operations were monitored at E-MAD, and XECF and XE-1 TS&PRB meetings were coordinated. Planning was summarized for XE-1 peripheral-poison-wire removal and was initiated for XE-1 central-poison-wire removal.

5. Safety Support of E-STS 2-3 Design (7.8.7)

A two-fold effort was developed in support of the E-STS 2-3 design by Kaiser Engineers. First, a comprehensive safety review was made of design packages as they were received from the A&E. This design review program also included the preparation of safety criteria and functional requirements for safety-oriented systems and facilities. The critiques of the proposed designs were based on national standards, accepted practice in the trade, engineering judgment, and experience gained in activation of the ETS-1 facility. Reviews of the following major design packages were accomplished:

a. Heating, ventilation and air conditioning of the control center

b. Construction features of the control center

c. Instrumentation and control systems

d. Nuclear-based interfacility separation

e. Liquid-hydrogen disposal as a result of a major leak

f. Electrical equipment and distribution system

g. Control tunnels

h. Cryogenic and high-pressure gas systems

i. Test stand deluge systems

j. Underground water distribution system

The second portion of the effort was devoted to a comprehensive review of the entire facility layout and a detailed review of the major subsystems relative to the major potential hazards. A summary of this review is essentially complete for incorporation in a special safety report being prepared at the request of SNPO and planned for completion in CY 68.

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