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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

SEMIANNUAL PROGRESS REPORT
1 January through 30 June 1961

Contract AT(10-1)-880

10 August 1961

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THE GENERAL TIRE
A SUBSIDIARY OF AEROJET-GENERAL CORPORATION
SAN RAMON, CALIFORNIA

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Published

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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

SEMIANNUAL PROGRESS REPORT

1 January through 30 June 1961

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THE ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

Semiannual Progress Report*

January through June 1961

ABSTRACT

This report contains the significant highlights of the work performed January through June 1961 in connection with the Army Gas-Cooled Reactor Systems Program. The Program includes the Gas-Cooled Reactor Experiment,and the ML-1,a prototype mobile, gas-cooled nuclear power plant. The report also contains background information on the Gas Turbine Test Facility. The status and progress of these projects is reported,as is information on associated tests and data evaluation, and the status of experimental and prototype components. The work was performed by Aerojet under Contract AT(10-1)-880 with the U. S. Atomic Energy Commission.

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PREFACE

The main objective of the Army Gas Cooled Reactor Systems Program (AGCRSP) is the development of plans and specifications for a mobile nuclear power plant suitable for military field use. The research and development program in support of this effort is being conducted by Aerojet under Contracts AT(10-1)-880 with the Atomic Energy Commission, and DA-44-192-ENG-8 with the Department of the Army.

The significant projects under the AEC contract include the design, development, and testing of fuel elements, the design and test operation of a core test facility (designated GCRE), and the design, development, construction and test operation of a prototype power plant (designated the ML-1). The Department of Army Contract provides for the design and fabrication of turbine-compressor sets for the ML-1 and for the test operation of a gas turbine test facility (GTTF) at Fort Belvoir, Virginia.

*Published by Aerojet-General Nucleonics, San Ramon, California

Work under this Contract is covered briefly in this progress report as background material.

Operation of the GCRE at NRTS began in February 1960. Evaluation of a second core to provide developmental and lifetime characteristics has been in progress since November 1960. The ML-1 reactor achieved initial criticality in March 1961 and is undergoing zero power testing. The delivery of the power conversion equipment to the reactor test site is scheduled for the Fall of 1961 and full power operation of the prototype plant is anticipated near the end of calendar 1961.

This report is organized under four major headings: NRTS Operations, ML-1 Engineering, Fuel Element Development, and GTTF Operations. Significant program activities are identified by the numbers 1.0 through 12.0 (second order headings) and detailed reports by task designation are identified by decimals following the second order headings. Figures and tables are identified with the appropriate second order heading and are included in the text close to the point of reference.

The work for each major task is reported in three categories: "Accomplishments - January through May", "Accomplishments - June", and "Anticipated Accomplishments - July".

The task breakdown, although convenient, may be misleading in that some work may be reported under several task numbers even though work was conducted in one laboratory, perhaps by one individual. The reporting of materials evaluation tasks is an example of this duplication.

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I. NRTS OPERATIONS

SUMMARY

a. Major Events:

The GCRE was operated at power at the beginning of the year until the SL-1 incident on 3 January following which the reactor was shut down for an extended design and hazards review. The facility was returned to power for endurance testing of the IB-2L fuel elements and for performance of the photoneutron experiment in mid-February. In April the reactor was shut down to investigate the failure of a pressure tube in the tube bundle. Certain other deficiencies, specifically in the areas of fuel elements and control blades, were discovered during this investigation. The reactor was shut down on 5 April; repair and modification programs have been in progress during this period.

The ML-1 control cab and reactor skid were delivered to NRTS early in February. The reactor achieved initial criticality on 30 March. Additional criticality studies and low power experiments have been conducted since that time. The ML-1 reactor performed satisfactorily during initial operation.

b. Problem Areas:

The major problems at GCRE are repair of the pressure tube, repair of the IB-2L fuel element inert components, and resolution of the question of using AISI Type 17-4PH material in the reactor stud bolts.

Uncorrected but minor problems at the ML-1 are associated with the annunciator and SAM (Site Area Monitoring) systems.

c. Schedules:

The test program at the GCRE facility is essentially three months behind schedule due to these difficulties. It is estimated that the reactor will be returned to power operation by the middle of August.

The ML-1 reactor skid test program is essentially on schedule. All crucial target dates have been met.

1.0 GCRE AND ML-1 OPERATIONS

1.1 GCRE Operations (Task 60-XXX)

Review - January through May:

a. Plant Factor: The GCRE plant factor was 0.135. Two major periods of shutdown occurred. The reactor was shut down 3 January for decontamination after the SL-1 incident. Return to power operation was delayed by directive from the Atomic Energy Commission, Idaho Operations Office, until safety reviews were completed on 14 February. The reactor was shut down 5 April for pressure vessel repairs.

b. Experimental Program: A total of 1031 Mw-hr were logged during the report period; the accumulated total logged in endurance testing of the IB-2L fuel elements is 2239 Mw-hr.

Several experiments were performed to measure the heat losses in the reactor and to check the reactor power calibration. The corrected power calculation determined that the previously reported powers should be increased by 1% and that the reported power is accurate to $\pm$ 10%.

Additional reactivity coefficient data were obtained to refine previous data. The newly established coefficients are:

Temperature	+ .34 x 10^{-6}	$\delta k/k/^{o}F$
Pressure	- 3.0 x 10^{-6}	$\delta k/k/psi$
Flow	+ 30 x 10^{-6}	$\delta k/k/lb/sec$

"Photoneutron Experiment II," (ANSOP 9629) was completed. The data indicate that experimental and calculated shutdown photoneutron fluxes agree within a factor of two.

"ML-1 Instrumentation Test" (Experiment 9623) was completed. The ML-1 neutron detectors were located near the GCRE in the pool and the reactor was operated at several power levels to calibrate and adjust the ML-1 nuclear instruments.

Final re-orificing of the IB-2L core was accomplished during the January shutdown. The peak reactor power after re-orificing was limited to 1.8 Mw for 109 Mw-hr by the outlet gas temperature of the fuel element in position G-4. Investigation revealed that the orifice size in position G-4 was 0.560-in. instead of the required 0.830-in. An 0.830-in. orifice was installed in position G-4 and the reactor operated at 2.2 Mw for 301 Mw-hr. The outlet gas temperatures for individual fuel elements indicated that the radial temperature profile was flat within $\pm$ 30^{o}F degrees. The final power run for the period was limited to 1.8 Mw for 410 Mw-hr by the outlet gas temperature of the fuel element in position E-2 where the thermocouple previously was inoperative. Investigation revealed that the orifice size in position E-2 was 0.560-in. instead of the required 0.680-in.

The operating core was reduced from 55 to 54 fuel elements in March to compensate for the burnup of the burnable poison.

AREA Hot Cell work during the period included inspection of the separation of the upper hanger from the bell housing in element IB-2L-29; inspection of a failed upper hanger retainer nut; complete inspection of IB-2T-1 and initiation of inspection of elements IB-2L-2 and IB-2L-33.

c. Safety Review: The AEC-IDO Reactor Safety Review Committee reviewed Aerojet's standard operating procedures; management and operational philosophy; nuclear safety attitude and controls; and the qualifications of key personnel who operate and maintain the reactor. The results of the review indicated that Aerojet was satisfactory in all aspects.

d. Reactor Maintenance and Component Development:

1) General: A field design review of the GCRE facility was conducted in February to determine if the facility, as modified and as operated, performed within the original design intent. The following areas were investigated: Electrical system; primary loop components; instrumentation; reactor pressure vessel; and reactor control mechanisms.

The safety aspects of facility operation were emphasized throughout the review. The operation was found to be consistent with the original design intent; minor equipment modifications recommended by the review committee were essentially completed by the end of May.

2) Control Rods: Newly designed and tested screwjack units were installed in safety rod actuator 2 and shutdown rod actuators 4, 5 and 6. The modification includes a new lead screw with more rugged microswitches (mounted as integral parts of the lead screw) replacing the Lear units and the microswitch gear train. Immediately before the modification, the magnet in shutdown rod actuator 6 failed to hold. Inspection revealed that the housing was filled with water. The water entered the housing when the housing was not pressurized due to an improperly connected pressurization hose.

The fine rod actuator was repaired twice; the shim rod actuator 2 was repaired twice; and the setback rod actuator was repaired once during the period. The failures were due to wear which resulted in lead screw binding. The fine rod actuator is being redesigned and the setback actuator design is being reviewed.

3) Nuclear Instrumentation: The Log N system exhibited periods of instability. The causes and correction were as follows:

1) The ion chamber power supply batteries required replacement on several occasions. These batteries apparently had been stored long enough to reduce their useful life. Electronic power supplies were installed to replace the batteries at the end of the period.

2) The Channels 3 and 4 ion chambers required replacement. The chambers were replaced with new units.

3) The lead wire insulation in the ion chamber housing was hardened and cracked by radiation effects. New lead wire was installed.

4) The Channel 4 Flexonic hose was observed to contain water and was temporarily replaced with a rubber hose.

4) Pressure Vessel: The reactor was shut down 5 April after a leak developed in a pressure tube near the cooling channel in the upper tube sheet. Boroscope inspection of position A-2 revealed a 100^{o} circumferential crack. All other reactor positions were inspected with a boroscope. The crack in position A-2 is the only demonstrated tube bundle defect.

5) Fuel Elements: It was observed during inspection of the IB-2L fuel elements in January that the roll pins that connect the bell housing to the upper hanger were sheared in three elements. The inspection was made after the fuel pin array had been withdrawn from the liner assembly during normal fuel element handling. It was observed during the April inspection of the fuel elements that the roll pins had sheared in forty additional elements and that a separation of approximately 1/8 inch had occurred between the bell housing and the upper support hanger. The failure mechanism and repair program are being evaluated. This failure is significant in terms of the mechanical integrity of the fuel element but has no implication of any sort on reactor nuclear safety.

The inspection in January also revealed that the retainer nut on the central pin bundle support rod was missing from four elements. This failure, demonstrated in the laboratory, occurs as a result of impact forces imposed on the fuel element during orifice changing. This problem apparently was solved by eliminating handling procedures that impose impact forces on the element.

Difficulty was experienced in properly seating the orifices in the fuel elements. Weld shrinkage in the fuel elements was shown to be the source of the interference. This problem was eliminated by relieving orifice diameter in the area of the weld.

6) Control Blades: Inspection of the tungsten control blades revealed that chromium plating was flaking off and that sliding surfaces had become roughened. These blades will be replaced with tungsten blades encased in stainless steel.

7) Reactor Vessel Bolts: The integrity of the AISI Type 17-4PH bolts in the reactor and main flanges was questioned as a result of stress corrosion failure of this material in other reactors. The problems associated with replacing the bolts, or proving the integrity of the existing bolts, are being studied.

Accomplishments - June:

a. Plant Factor: The GCRE plant factor for June was 0. The reactor has been shut down since 5 April for pressure vessel repair.

b. Experimental Program: A total of 2239 Mw-hr have been logged in endurance tests of the IB-2L fuel elements.

c. Reactor Maintenance and Component Development:

1) Fuel Elements: The fuel element orifices were removed with a new tool (Figure 1:1) designed to remove and install orifices without imposing impact forces on the elements. The lower spiders were then re-inspected. The fuel pins were out of the lower spider in IB-2L-22, -36, -37, and -58, as previously reported. Contrary to the previous inspection, the fuel pins were in place in fuel elements IB-2L-10 and -41. During the orifice removal and inspection, fuel element IB-2L-20 was dropped and subsequent inspection revealed that the upper hanger support nut was missing and that two minor dents existed in the outer liner. The orifice could not be removed from fuel element IB-2L-38 using standard techniques.

The inner liner of the fuel elements in the area of the "weep holes" was inspected for evidence of inner liner buckling. No indication of buckling of the inner liner was found in any of the elements inspected.

The separations between the inner liner and the upper support hanger and the separations between the bell housing and the upper support hanger of the fuel elements were measured to reveal any indication of ratcheting. The two dimensions were comparable on all elements, showing no evidence of ratcheting.

Fuel element IB-2L-2 and the fuel element liner assembly from fuel element IB-2L-33 were disassembled and inspected in the AREA Hot Cell. There was no evidence of binding at the expansion joints at ambient temperature and no indications of previous binding. The tack welds on inner liner flanges were found to be broken, indicating that the inner liner top had expanded upward. The IB-2L-2 inner liner flange was also cracked. The IB-2L-2 expansion joint was measured and sectioned. The measured clearance was 0.013-in.; this is the same as the "as fabricated" clearance. The IB-2L-2 spacer wires and fuel pins were measured and the pins were transferred to the MTR Hot Cell for metallography.

2) General: The outlet gas thermocouples and gas sampling tubes for individual fuel elements were measured and inspected with the boroscope to obtain data for temperature interpretation and evaluation. The position of the A-2 crack was determined to be located between 207^o and 312^o relative to plant north.

An inside caliper was attached to the bottom of the boroscope and the inside diameters of the pressure tubes were measured at various locations. Fifty tubes inspected: 14 tubes exhibited diameters in the cooling channel area of the upper tube sheet more than 0.015-in. larger than the other areas of the tubes. Generally the smallest diameter in the tube is just below the upper weld.

The AISI Type 17-4PH reactor head bolts were removed from the pool. These bolts (in use for over a year and 1000 full-power hours) have been subjected to about 14 tightening operations. Six of the 28 bolts were sent to San Ramon for destructive testing. No evidence of stress corrosion cracking was observed in any of the bolts (Zyglo test).

The Diesel control cabinet was relocated to eliminate vibration.

A water softener was installed upstream of the demineralizers to increase demineralizer resin life.

Routine inspection of the main loop heater revealed that one coil was out of the top guide and slightly bowed, and that the top guide pin was bent. Lack of a center guide pin, presumably not installed during fabrication, was the apparent cause of the damage. The repair of the heater was completed except for X-ray examination of the repaired areas.

Anticipated Accomplishments - July:

The west actuator bank fast rod modification will be completed.

The failed section of the A-2 pressure tube will be removed and the metallographic examination completed. The A-2 pressure tube will be sealed.

The fuel element repair program will be initiated. Work will continue on studies to determine the cause of the pressure tube and fuel element failures.

The IB-2L-2 and IB-2T-1 metallography will be completed in the MTR Hot Cell.

X-ray examination of the heater repair will be completed.

1.2 ML-1 Operations (Task 46-XXX)

Review - January through May:

a. Experimental Program: The ML-1 experimental program at NRTS began when the ML-1 control cab arrived at NRTS on 14 February 1961. The cab was installed at the GCRE facility and the nuclear instruments were checked using the GCRE reactor neutron source. The cab was moved into position at the ML-1 control building on 2 March.

The ML-1 reactor arrived at NRTS on 4 February 1961 and was unloaded and placed in the ML-1 test building. Preparations for the initial critical experiment were started immediately. Initial criticality of the ML-1 reactor was attained at about 1330 hours on 30 March with a core loading of 47 fuel elements.

When the initial critical experiment was completed, a series of experiments was initiated to determine such preliminary operational data as control blade reactivity worth, operational core loading determination, and moderator and shield water reactivity worths. Twenty such experiments were performed by the end of May. The purpose and significant results of these experiments are presented in Table 1-1 on the following page.

b. Operational Problems: The SAM (Site Area Monitoring) system has not operated satisfactorily since arrival at the site. The electronic calibration system has not functioned properly, thus requiring frequent calibration with a 1000 Roentgen source to maintain the integrity of the system. The components of this system were returned to the vendor for modification late in the period. A substitute unit was installed to replace the defective system.

TABLE 1-1 - SUMMARY OF ML-1 EXPERIMENTAL PROGRAM

ANSOP	TITLE	PURPOSE	SIGNIFICANT RESULTS
16001	ML-1 Nuclear Instrument Checkout at GCRE	To test the integrity of the nuclear instrumentation, determine channel overlaps and check and set scram functions prior to the initial criticality.	Design sensitivity of the nuclear instrumentation was verified and required adjustments completed.
16200	Initial Critical Experiment	To determine the clean, cold critical core loading of the ML-1 reactor.	The clean cold critical loading was determined to be 47 fuel elements.
16202	Preliminary Control Rod Calibration	To determine the preliminary reactivity worth of the ML-1 reactor control rods.	Results indicate rods are worth slightly less than predicted by critical experiment work.
16240	Reactivity Worth of Tungsten Baffle and Shield Water	To determine reactivity of the tungsten baffle and the shield water.	Reactivity of shield water essentially zero. Reactivity of tungsten baffle approximately + 0.13% $\delta k/k$.
16208	Operating Core Determination	To establish the number and location of reactivity shims required for a core loading of 61 fuel elements with an excess reactivity of 1.5% $\delta k/k$.	Core configuration of 61 elements and 28 heavy shims has a δk excess of 1.2 to 14%.
16210	Final Control Blade Calibration	To calibrate control rods for reactor operations.	Preliminary study of data indicates shim 2 worth 1.9% $\delta k/k$ and regulating rod 0.45% $\delta k/k$.
16211	Final Shield Water & Tungsten Baffle Reactivity Determination	To determine reactivity worth of the shield water and tungsten baffle after poison shim installation.	Shield water reactivity of -.025% $\delta k/k$. Tungsten baffle reactivity +0.17% $\delta k/k$.
16212	Wet Critical Experiment	To demonstrate that the flooded, shimmed 61 fuel element ML-1 core would remain subcritical with any one of shim control rods withdrawn.	Reactor critical with safety 1, safety 2 and regulating rods full out, shim 1 and 3 full in and shim 2 at 38.5 degrees.
16214	Reactor Drying Test	To demonstrate feasibility of drying core gas passages after core flooding by circulation of heated air through the gas passages.	Core passages dry after 20 hours of drying skid operation.
16216	Nuclear Power Calibration and Flux Mapping	To determine nuclear power distribution in the ML-1-1 core.	Results not analyzed.

Temporary jumper cables, used between the control cab and the reactor until the prototype cables became available, produced inaccurate instrument readings and spurious scram signals. Installation of the prototype cables largely corrected these difficulties.

Numerous spurious short period scrams were experienced during operational periods. These were attributed to power transients in the incoming control cab power. A strip chart recorder was installed on the power supply to measure the magnitude of voltage fluctuations, and to determine the relationship between the voltage fluctuations and the spurious scrams. This problem still is being investigated.

Two of the log count rate channel B_{10} nuclear detectors failed and were returned to the vendor.

c. General: The prototype signal and power cables between the control cab and the reactor skid were installed and checked except for one cable with connectors not compatible with the connector on the junction box. This connector will be replaced.

Investigation of spurious scrams attributed to noise transients in the nuclear instrumentation led to the installation of resistance/capacitance filters on the control rod actuators and the rod withdrawal switch, and additional shielding on the nuclear coaxial cables in the control cab. These steps eliminated most spurious scrams attributable to noise transients.

The input impedance of the nuclear channel recorders in the analysis racks was increased to prevent excessive loading of the recorder output from the nuclear channel. All recording instruments in the analysis racks were calibrated and checked.

The drying skid, the field demineralizer unit, and the control rod actuator test jig were received and checked.

Cable connectors more suitable for the service in the prototype system were installed in the nuclear instrument system.

Kilowatt-hour meters were installed in the auxiliary control building and the test building to meter the power consumption at the ML-1 facility.

Accomplishments - June:

a. Experimental Program: "Nuclear Power Calibration and Flux Mapping" (ANSOP 16216) was continued to 9 June when the experiment was terminated because of a shortage of unirradiated test capsules. The "bare" (not cadmium-covered) capsule runs were completed. These runs were required to permit sizing of the ML-1 fuel element orifices. Analysis of the data has not been completed.

"Moderator Water Temperature Reactivity Determination" (ANSOP 16234) was initiated on 21 June and completed on 26 June. The data obtained from this experiment have not been fully evaluated. However, an average positive reactivity coefficient of 4.4×10^{-5} $\delta k/k/^{\circ}F$ was measured between $100^{\circ}F$ and 180°. The coefficient was positive throughout the temperature range.

"Gas Pressure Coefficient Determination" (ANSOP 16238) was completed on 29 June. Initial review of the data indicates that the coefficient is small in magnitude and negative in sign.

b. Operational Problems: The main moderator water pump failed repeatedly after several minutes of operation. Investigation determined that the thermal breaker installed in the control circuit was rated at 18-amp but the pump motor was designed for 22-amp. A 22-amp thermal breaker was installed and a prototype change initiated.

The moderator water vent valve failed during performance of ANSOP 16234 causing loss of moderator water and a resultant low level signal. The vent line was capped off temporarily* in order to complete the experiment. A spare valve was installed later.

The ion chamber signal coaxial cable that passes through the shield water region failed on Channel 3. Investigation determined that the dielectric (polyethylene) will not withstand temperatures above 176°F. The normal operating temperature of the shield water at power is 190°F. A non-prototype cable was installed until cable with improved high temperature properties is obtained.

The charging rate of the control cab battery charger is excessive and the unit operates after the batteries are fully charged. Field efforts to correct this condition were unsuccessful. The unit will be removed when operations permit and bench-checked.

c. General: The moderator water system was restored to the original prototype configuration after the "Wet Critical Experiment" was completed. (The surge tanks had been removed to eliminate the possibility of accidental flooding until adequate control to maintain a flooded core in the subcritical condition was demonstrated.)

The interior surfaces of the facility water storage tanks were repainted and the system returned to service.

Three formal training sessions were held for the ML-1 reactor operators (including the military personnel). The sessions covered radiological safety and nuclear instrumentation as well as reactor operation.

Design plans covering the modification of the ML-1 facility, including the addition of 600 square feet of space to the control building, were reviewed and the comments returned to the Engineering and Construction Division, AEC-IDO. This work is scheduled to be completed in the Fall of 1961.

Anticipated Accomplishments - July:

The "ML-1 Flooded Core Experiments" (ANSOPs 16252 - 16253 - 16254 and 16256) will be completed.

The "Low Power Shielding Experiment" (ANSOP 16240) will be initiated.

The remaining portion of "ML-1-10, Power Mapping Experiment" (ANSOP 16216) will be accomplished.

*This valve is essential only for power operation of the reactor.

Work will continue on the preparation of Phase II Standard Operating Procedures.

1.3 NRTS Test Planning and Evaluation (Tasks 64-XXX and 24-XXX)

Review - January through May:

a. Experimental Support: Sixty-seven GCRE and ML-1 experimental and operating procedures were reviewed by the Procedure Review Board during this period. Twenty-nine experimental test plans were processed.

Experiments in the GCRE were terminated when the reactor was shutdown in April. Prior to the shutdown, the photoneutron experiment, the ML-1 nuclear instrument calibration experiment, and the first phase of the dose distribution experiment were completed.

The ML-1 achieved initial criticality on 30 March. Support was provided for the ensuing experimental program.

Hot cell examination of IB-2L-2 elements with mechanical failures provided an opportunity to experimentally determine burnup of burnable poison. Two techniques are being used, one of determining isotopic composition using a mass spectograph and the other using the AGN 201 reactor as a reactivity measuring device.

A glass dosimeter system is being developed for use in experiments where high level gamma dosimetry is required (ML-1 shielding evaluation, for example). Two kinds of glass dosimeters will be used: silver-activated phosphate glass covers the range from 10^2 to 10^4 R/hr, and cobalt-activated borosillicate glass covers the 10^4 to 5×10^6 R/hr range. The former is read out on a fluorimeter and the latter on a colorimeter adapted to this purpose. A calibration program to determine instrument response versus dose, fading effects, temperature effects, thermal neutron response, and required heat treatment is about 70% complete.

Preliminary planning for the ML-1 operational and shutdown shielding experiments was completed. The initial phases of this work will involve reactor operation at power levels up to 30 w. The objectives of the experiment are the evaluation of the gross performance of the shutdown and operational shield; and the measurement of internal flux distribution and source terms for use in evaluating calculational methods.

b. Analysis: An equation to relate coolant flow and reactor ΔT to total nuclear power was developed for GCRE. The equation accounts for the effects of heat loss by conduction and for gamma deposition between the points at which temperatures are measured.

Analysis of temperature transients to be expected during the shutdown cooling experiment was initiated. Calculations were made of temperature transients occurring from a loss of flow at full power and at reduced reactor inlet temperature. This analysis will be verified in Phases I and II of the shutdown cooling experiment and used as the basis for transient calculations for loss of flow experiments at full power and 800°F inlet temperature.

Analysis was initiated to determine the conditions at which the ML-1 moderator can be drained after power operation. Preliminary results indicate that the moderator can be drained without hazard only if the gas passages are flooded or are cooled by a low flow of gas.

A nuclear evaluation was made of replacement materials for the GCRE slow rods. Silver appears to give about the same epithermal-to-total absorption ratio and the same total absorption, when diluted by a factor of 5, as the present rods.

Accomplishments - June:

a. Experimental Support: "ML-1 Shield Experiment Phase I: Low Power Test" (OETP 204) was written to cover that portion of the ML-1 shielding evaluation that will be performed at 30 w or less. These tests provide for measurement of dose rates and flux distribution within the shield as well as external to the shield tank to a distance of 25 feet from the reactor centerline. The effect of boron concentration in the shield water will be investigated extensively. Methods of detection will include gamma film checks, thermal and epithermal neutron foil and wire activation, and the use of gamma and fast neutron survey instruments. Implementation of the tests was discussed with NRTS operations personnel. The discussions included procurement, fabrication, and calibration procedures; and specification of a dosimetry grid which would be unaffected by physical obstructions. The results of these discussions are being incorporated in an addendum to the test plan. Procurement of detectors and fabrication of detector holders were initiated.

Final arrangements were made for the mass spectographic determination of the burnout of burnable poison. The cadmium will be separated, using an ion exchange column, and sent to the Oak Ridge National Laboratory for spectographic analysis.

An experimental test plan was prepared for a coast-down and depressurization experiment at GCRE. This information will be used to specify conditions for the shutdown cooling experiment.

b. Analysis: The absorbed fast neutron doses in the AISI Type 17-4PH studs on the GCRE pressure vessel were calculated to be 8×10^{17} nvt (>1 Mev) in the tube sheet flanges and 4×10^{17} nvt (>1 Mev) in the upper plenum flange.

The temperatures encountered in the studs were calculated to be $272^{o}F$ in the upper tube sheet studs; $330^{o}F$ in the lower tube sheet studs and $140^{o}F$ in the upper plenum flange bolts.

Analysis of a mixed plate-type IB-2L core was initiated as a backup to the IB-2L fuel element repair. An analysis of the doses to be expected during the ML-1 fuel element re-work was initiated.

Anticipated Accomplishments - July:

Support (on-site) will be provided for the ML-1 shielding experiment (low power) to be conducted at NRTS.

Results of the burnable poison burnup experiments will be completed.

Doses will be established for the ML-1 fuel element re-work.

The method to be used to determine IB-2L fuel burnup will be established and the burnup analysis will be initiated.

1.4 GCRE Engineering Support (Task 65-XXX)

Review - January through May:

a. Torquing of Pressure Vessel Main Flanges: After remote underwater work on the reactor in November, it was apparent that modifications to the torquing tool design were desirable to reduce the overall size of the tool and to adapt it for use from the pool bridge. The revised tool incorporated smaller bearings and a pressurized piston return on the ratcheting mechanism. With the aid of a closed circuit underwater television system, the lower main flange bolts were torqued to 440 ft-lb in January. This repair minimized gas leakage in the lower main flange.

b. Underwater Television System: The use of a closed circuit underwater television system in the torquing operations conducted in January demonstrated the value of such a system to GCRE and ML-1 maintenance work. After evaluation of several systems, a set of specifications was developed for the procurement of a television system and a purchase order was initiated for two complete systems for use at the NRTS facilities.

c. Evaluation of AISI Type 17-4 PH Stainless Steel: The use of AISI Type 17-4 PH stainless steel in the GCRE is being evaluated because of the questionable performance of this material, when heat-treated to 900°F, in other reactors. Data from quality control inspection and the fabrication history was assembled for all such material used in the GCRE. A program was developed to define and implement a test program to determine if this material is adequate for the subject applications.

d. Lear Screwjack Modification: Modification of the Lear screwjack in the fast rod actuators continued throughout the early part of the report period. The design was altered to obtain optimum elasticity and minimum wire flexing of the electrical leads. This and other modifications* were incorporated in a prototype test unit. The prototype unit completed 225 cycles without malfunction and disassembly revealed no evidence of excessive wear. Four of the GCRE actuators were modified and modifications on the balance of the units are scheduled to be completed soon.

e. "Slow" Control Blades: Stripping and flaking of the plating on the "slow" blades was noted during the inspection conducted in April. A decision was made to fabricate new blades using the "canning" technique which had proved satisfactory on the "fast" blades. Design was completed and procurement of the tungsten alloy initiated.

*The Army Gas-Cooled Reactor Systems Program Semiannual Progress Report for July Through December 1960, IDO-28567, Aerojet-General Nucleonics, February 1961.

f. Fuel Element Activity: Coordination and assistance to other tasks was provided for work on the replacement instrumented fuel elements, the replacement ΔP-ΔT probe, orifices for the IB-2L elements, and handling tools for the repair of the IB-2L elements. One instrumented fuel element was delivered to the site.

g. Failed Pressure Tube Repair: Equipment to remove a section of the failed pressure tube was developed and tested. This equipment includes a holding fixture to position and support the cutting fixture from the upper plenum flange. Two circumferential and two longitudinal cuts will be made with the cutting fixture to remove the section of the tube containing the failure. A combination seal and dummy plug, for use in repairing the failed tube, was designed and developed.

Accomplishments - June:

Approval was received from the Contracting Officer for purchase of two television systems for use at NRTS. A purchase order was placed for delivery on 3 July. Modification of one pan-and-tilt unit for underwater use was begun.

Irradiated and unused AISI Type 17-4 PH reactor cover bolts were Zyglo-inspected for evidence of stress corrosion cracking, were sectioned and metallurgically examined, and samples were torqued to destruction. No evidence of stress corrosion cracking was found. The only physical change in the bolts is an increase in strength; ductility and hardness have remained essentially unchanged.

A test was conducted to evaluate problems which might develop as a result of installing "slow" blades "canned" in stainless steel in the existing aluminum blade guides. Inspection of a prototype blade and guide after 250,000 insert/withdraw cycles indicated that galling and guide wear would not be problems.

Fabrication of the handling tools for the repair of IB-2L fuel elements was completed. The preparation of quality control specifications and repair operation procedures was initiated.

Design and fabrication of the sealing device was completed. A remote handling tool to install and tighten the device was designed and fabricated.

Anticipated Accomplishments - July:

The closed circuit television systems will be received and shipped to NRTS. The system will be used immediately in repairing the GCRE pressure vessel and fuel elements.

The metallurgical examination of cover bolts will be completed and two studs from the lower main reactor flange will be examined.

The modification of the remaining four fast rod actuators will be completed and fabrication of the new slow blades will be initiated.

The replacement ΔP-ΔT probe will be completed and delivered to the site. Fabrication of replacement orifices for the IB-2L fuel elements will be completed.

The failed section of the pressure tube will be removed and the sealing device will be tested and installed.

1.5 ML-1 Engineering Support (Task 25-XXX)

Review - January through May:

a. Blowdown Gas Storage Tank: Specifications were prepared for the 15,000 gallon blowdown gas storage tank and the tank was ordered.

b. ML-1 "As-Built" Drawings: Assembly drawings and final inspection records for the ML-1 reactor skid, control cab, drying skid and cable reel skid were forwarded to the ML-1 site. Procedures were implemented to document and control prototype and non-prototype modifications to the power plant. Procedures were established which authorize this task to function as the customer acceptance agency at San Ramon for all components prepared for shipment to NRTS.

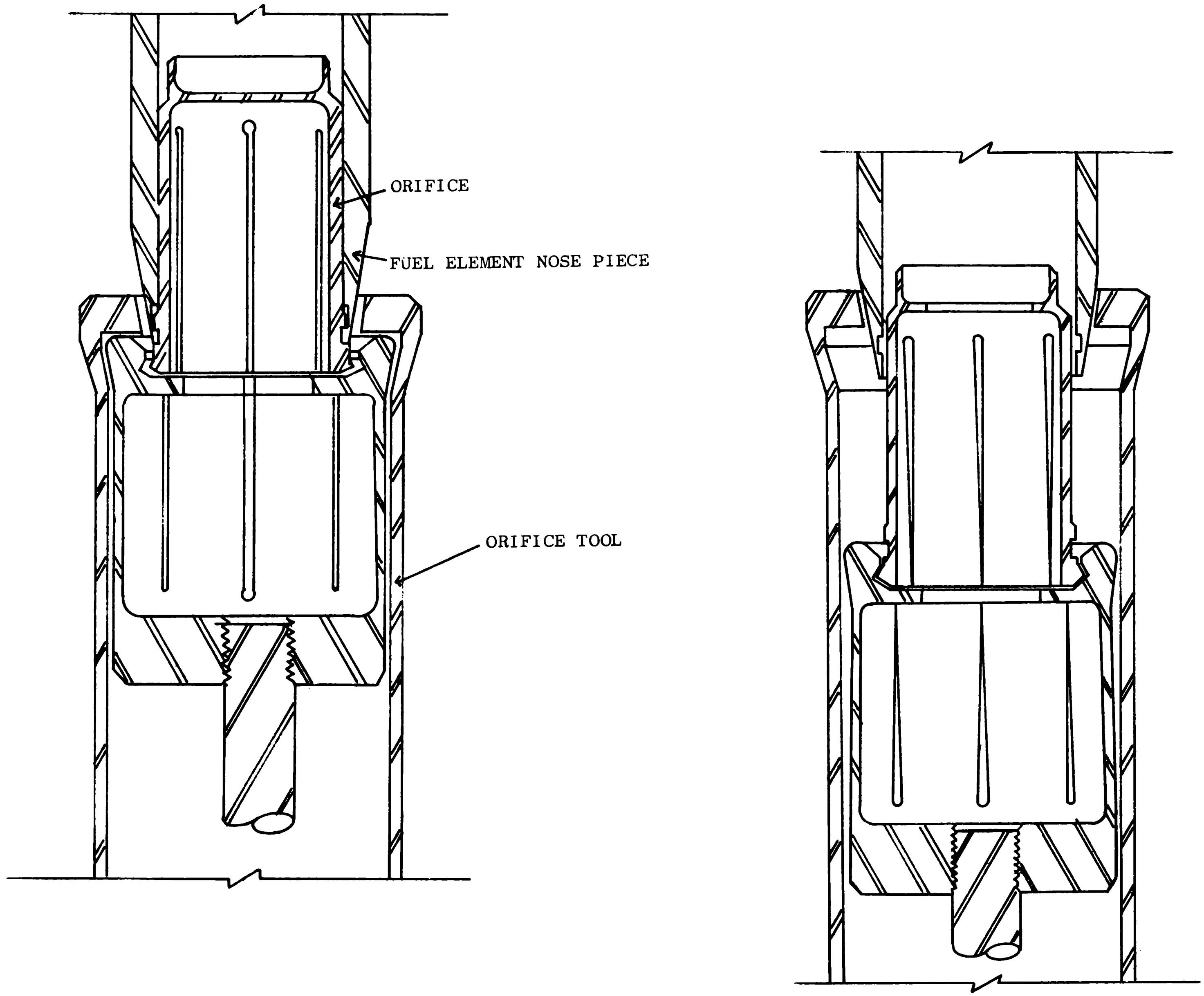
Accomplishments - June:

The oil temperature chassis, the precooler monitor and the fast pressure loss system were accepted for shipment to NRTS pending evaluation of quality control data and operating procedures. Liaison was maintained for several modifications to equipment being tested at NRTS to correct minor design deficiencies or to improve operating characteristics.

Anticipated Accomplishments - July:

Liaison between the ML-1 operating group and San Ramon will continue.

ORIFICE REMOVAL TOOL



ML-1 ENGINEERING

SUMMARY

a. Major Events:

The assembly of the ML-1 reactor package was completed and the package was checked and shipped to NRTS 31 January 1961. The assembly of the developmental power conversion skid was completed, except for some control and instrumentation wiring, and moved from the assembly area to the test facility. The ML-1 reactor achieved dry criticality 30 March 1961.

Batteries and the battery charger, and the graphic panels for the control cab were received from the vendors. The compressor pressure measuring system also was received.

The assembly of the control cab was completed at San Ramon and delivered to NRTS on 15 February. The cable reel skid was completed at San Ramon and delivered to NRTS on 5 February. The oil cooler for the power conversion skid was completed on 27 February.

The ML-1 reactor achieved wet criticality on 29 March. The recuperator and precooler for the prototype power conversion skid were delivered to Azusa. These units were supplied by Griscom-Russell.

The Stratos turbine was delivered. Most of the tests scheduled for the Clark turbine were completed at the vendor's plant. The alternator and start motor completed initial testing and were sent out for rework. The lubrication system was mocked up for the Stratos configuration and tested. The mockup for the Clark system was in process.

Static tests of the power conversion skid were initiated. The recuperator and precooler for the prototype power conversion skid were shipped to Azusa by the vendor. Assembly and testing of the alternator continued.

b. Problem Areas:

Major problems were concerned with the delay in delivery of equipment from vendors. In addition, significant problems arose in the development of the alternator.

Problems of delivery were resolved and all equipment was delivered for construction of the developmental skid.

The results of the modifications made to the alternator to improve design performance will not be known until completion of tests in July. It appears, however, that the remaining problems on the alternator can be resolved during this time.

c. Schedules:

The pacing items were the fabrication of the recuperator, precooler, alternator and prototype cabling. As a result of these delivery problems and the design problems in the development of the alternator, the delivery to NRTS of the prototype power conversion skid is now scheduled for late September.

No changes in schedule are contemplated at the end of the period.

2.0 REACTOR ENGINEERING

2.1 Control Elements Test and Evaluation (Task 88-XXX)

Review - January through May:

This task was initiated 1 February.

A test stand was reconditioned and shipped to NRTS for use in checking components prior to installation as replacements in the reactor.

Surface treatment of AISI Type 440C stainless steel was determined by corrosion tests performed on the material.

A technique was developed for wearing-in new actuator clutches.

Modifications are being made to the moderator system as a result of a feasibility study of the possibility of temporarily isolating the dashpots from the moderator system.

Acceptance testing of spare parts was performed.

Accomplishments - June:

No effort was expended by this task during June.

Anticipated Accomplishments - July:

Acceptance testing of spares will be continued.

2.2 Afterheat Removal (Tasks 88-4XX and 88-5XX)

Review - January through May:

a. Transportation Afterheat Condenser System: Tests demonstrated the feasibility of removing ML-1 afterheat during transportation by using a condenser and natural convection. These tests also showed that a borated moderator system would present no operational problems during transportation.

The afterheat condenser system was designed, parts purchased and fabrication was initiated in May.

b. Emergency Afterheat System: Preliminary concepts for emergency afterheat removal (for use after coolant loss or turbine seizure) were formulated. Sizing calculations and a survey of available components were initiated.

Accomplishments - June:

Fabrication of the afterheat condenser continued on a limited basis.

Determination of the requirements for the removal of emergency afterheat continued.

Fabrication of a dashpot manifold block valve assembly was initiated.

Anticipated Accomplishments - July:

Fabrication of the afterheat condenser will continue.

Determination of the requirements for the removal of emergency afterheat will continue.

The dashpot manifold block valve assembly will be completed.

2.3 Reactor Assembly (Tasks 88-8XX and 88-9XX)

Review - January through May:

The reactor assembly flow chart was up-dated and expanded to include testing details.

This task was completed with the delivery of the reactor to NRTS on 31 January.

3.0 POWER CONVERSION EQUIPMENT

3.1 Turbine-Compressor Set Fabrication

(Note: This report covers the work progress of the Power Conversion Project on the AGCRSP during the period of 1 January through 30 June 1961. The work progress on the turbine-compressor set design and fabrication, being performed under Contract DA-44-192-ENG-8, is included for background material.)

Review - January through May:

This task includes the procurement of an axial-compressor turbine-compressor set from Clark Brothers and a centrifugal-compressor turbine-compressor set from Stratos Division, Fairchild Engine and Airplane Corporation.

Fabrication and calibration tests of the Stratos TCS-670 turbine-compressor set (Figure 3:1) were completed. The open-cycle tests were conducted with unheated low pressure air as a working fluid. About 25 hr at rated design speed were accumulated on the t-c set. No vibration occurred in excess of 1-g and no leakage through the seals was experienced during testing.

Curves summarizing the data obtained on the Stratos open-cycle testing are included as Figure 3:2, 3:3, and 3:4. These show that the performance of the t-c set should be slightly better than predicted by design calculations.

Comparison of the actual compressor efficiency of 84.5% with the data used in the performance summary prepared under Contract AT(10-1)-880, shows that the actual efficiency is approximately 0.9% higher. The 84.6% turbine efficiency, based on the extrapolation of the Stratos performance curve, is the same as that assumed in the reference data.

The Stratos TCS-670 t-c set was delivered to Aerojet and installed on the developmental power conversion skid.

The fabrication and the mechanical and calibration tests of the Clark Brothers t-c set were completed in the period. In the open-cycle tests, approximately 65 hr total running time, including 5 hr at self-sustained condition, were accumulated on the t-c set. No vibration occurred in excess of 1-g and no oil leakage through the seals was experienced during these tests.

The calibration tests of the compressor showed that the efficiency was lower than design. This is attributed to the Reynolds number during open-cycle tests being approximately 100,000 compared to the 900,000 predicted for during closed-cycle operation. Analysis indicated that the efficiency will increase by 5 to 8 points in closed-cycle operation. Extrapolation of turbine performance to ML-1 design point operation shows that the turbine will be about 85% efficient.

Disassembly and inspection of the t-c set before shipment disclosed excessive wear on the compressor journal bearing and some fatigue and overheating of the turbine journal bearing. As the damage was attributed to insufficient oil, provisions were made to increase the oil supply to each bearing by use of separate external oil supply lines to each bearing and changing from one oil feed hole to three oil feed holes for each bearing. Re-assembly of the t-c set was initiated.

Accomplishments - June:

Tests at the vendor's on the Clark t-c set demonstrated that the lubrication of the journal bearings was satisfactorily improved. Disassembly and inspection of the t-c set after the tests disclosed no signs of fatigue or overheating of the bearings due to improper lubrication. However, several small copper particles had become imbedded in the babbitt linings, scoring the linings and slightly scoring the turbine shaft journal. Investigation disclosed that the copper particles resulted from the inadequate cleaning of the external lubrication system lines before the last series of tests.

The t-c set was reassembled with new bearings. The lubrication system will be flushed and cleaned before retesting the t-c set to assure that bearing operation is satisfactory.

As the result of the above repair and retesting, Clark's delivery date was revised from 1 July to 10 July 1961. The revised t-c set delivery date is later than desirable since it will be the last component to be received for the prototype skid.

Anticipated Accomplishments - July:

The mechanical performance test will be conducted at 22,000 rpm with an 1100^{o}F turbine inlet temperature to recheck journal bearing operation.

The t-c set will be inspected, cleaned and delivered to Aerojet.

3.2 Power Conversion Skid Test Planning and Testing (Tasks 31-2XX and 31-8XX)

Review - January through May:

Preparation of the test facility for the power conversion skid continued.

Fabrication of the nitrogen heater was completed and the unit was delivered to Aerojet. The installation and electrical wiring of the nitrogen heater and associated equipment at the skid test facility were completed. The exhaust stack for the nitrogen heater was delivered and installed. The heater was fired on natural gas at the minimum fire rate to verify that the heater was undamaged by shipment. Heater performance was satisfactory.

The wiring of the control console and the installation of the instrumentation, control and electrical circuits from the test bay to the control room was completed.

The design, fabrication and checkout of the recirculating water cooling system for the prototype alternator were completed.

The variable frequency power supply/emergency power unit (EPU) was delivered and installed in the ML-1 test facility. Acceptance tests of the EPU were completed.

The Beckman gas analysis equipment was received and installation of the equipment was completed. Preliminary tests of the gas analysis equipment were completed.

The panoramic sonic analyzer received from AGN-Idaho was installed and tested.

Procurement of a 480 v, 3530 rpm, 125 hp electrical motor was initiated. This starting motor will be used during the initial power conversion skid testing if the prototype starting motor is not available.

The developmental power conversion skid was delivered to the Azusa test facility and the mating of the skid to the nitrogen heater was initiated.

The test plan for the developmental power conversion skid was completed.

Accomplishments - June:

Preparation of the power conversion skid test facility was completed.

Preparation of the power conversion test procedures continued. The following procedures were published: "Power Conversion Skid Accessory Power Measurements"; "Main Loop and Lubrication System Leak Test"; "Moderator/Lubrication Cooler, Precooler Assembly Checkout"; and, "Mechanical and Instrumentation Check List".

The power conversion skid and the heater were aligned and the mating flanges connected. The power conversion skid heater was subjected to a series of 50 psig leak tests; all leaks were repaired.

The facility gas handling control panel was completed and tested.

The alternator drive shaft extension and dynamic seal to the prototype starting motor housing were installed for use with the 3530 rpm, 125 hp drive motor. The drive motor was received and fabrication of the drive motor support stand was completed.

The connection of all test lines, controls, and auxiliary equipment to the power conversion skid was completed.

Final testing of the gas analysis equipment continued.

Anticipated Accomplishments - July:

The 125 hp starting motor will be tested and installed.

Final testing of the gas analysis equipment will be completed. These tests will include high pressure leak tests, lubrication and cleanup system checkout, precooler assembly checkout, speed control system checkout and accessory electrical power measurements.

The rotational tests on the power conversion skid will be initiated. These tests will include cold gas rotational tests and initial testing with hot gas.

3.3 Alternator, Starting Motor, Voltage Regulator, Recuperator, and Precooler (Tasks 31-3XX, 31-4XX, 86-3XX and 86-4XX)

a. Alternator, Starting Motor and Voltage Regulator

Review - January through May:

Development of the test alternator continued. The alternator thrust bearing was damaged by excessive rotor thrust loads during dynamic field excitation. Results from these tests showed that the magnetic fields created greater axial and radial forces on the alternator rotor than had been anticipated owing to non-uniformity of the flux distribution at the homo-polar air gap. These forces were beyond the capacity of the existing bearing design, and, since Kingsbury-type bearings were too large, the housings were redesigned to accommodate angular contact-ball-thrust bearings and cylindrical roller radial bearings. The design of the prototype alternator rotor and drive-end housing was modified to correct the flux distribution; however, the test alternator was reassembled with the unmodified rotor having an unequal flux distribution to expedite performance evaluation. The alternator was tested at 900, 1200 and 1300 rpm to establish the no-load saturation curve. The data from these tests (Figure 3:5) indicate that the actual voltages were half the expected value and that the voltage output of the machine varied with the rotational speed.

The reduced voltage was not due to saturation of the alternator magnetic circuit as, under saturation conditions, the per-unit volts obtained at the different speeds would have been identical. The short circuit test data (Figure 3:6) show that the reduced voltage was not the result of an electrical short circuit in the stator winding as the phase currents were balanced under short circuit saturation tests. Since the actual resistance in the field winding calculated from the field voltage and current readings was as predicted, the field winding was eliminated as the source of the trouble. The decrease in the per-unit volts with the corresponding increase in speed indicated that short circuit or eddy currents were setting up a demagnitizing effect in the magnetic circuit. Analysis indicated that the eddy currents were the result of a highly non-uniform flux field existing in the homo-polar air gap. The test alternator drive-end housing was reworked to incorporate laminated sections to eliminate eddy current losses. The alternator was then operated under no-load conditions at speeds up to 3600 rpm to establish the no-load saturation curves. Test results showed that the voltage with the laminated housing was only slightly better than that obtained with a solid housing.

In order to investigate the reason for the small improvement in the voltage performance with a laminated housing and to verify that the amount of active leakage in the air gap varies inversely as its speed, the test alternator was reassembled with the following changes:

1) The non-laminated main housing and drive-end housing were installed.

2) The rotor to drive-end housing gap was reduced to 0.170-in. and the main air gap between the rotor and stator was reduced to 0.060-in. These steps were taken to reduce the field current requirements and determine the saturation test curves.

3) Search coils were installed on the drive-end housing and stator to permit determination of the flux distribution within the machine.

Two series of static tests were conducted to establish flux curves. In the first series, the alternator was mounted on a non-magnetic support similar to the installation on the ML-1 skid. The second series of tests was conducted with the alternator installed on the steel test stand.

These data show that the amount of active flux in the air gap is an inverse function of the alternator speed. Flux versus field current at various speeds is plotted in Figure 3:7. The fact that 102% of the calculated required flux is in the air gap at static conditions verified that the low voltage in the dynamic tests was due to the demagnetizing effect in the eddy currents in the magnetic circuit. Further tests showed that the demagnetizing effects were not entirely due to the eddy currents in the drive-end housing. It was believed that the eight one-inch diameter steel holding pins in the laminated stator core were also causing eddy currents to form and that the resultant back magnetomotive force from these pins possibly was the controlling factor in limiting alternator output.

The test also showed that the leakage flux (much higher than calculated from measurements made on the partially assembled machine) caused saturation in the drive-end housing and in the rotor. This was verified as the active flux was increased to 105% of the calculated required flux when iron bars were added to portions of the magnetic circuit.

Flux data obtained with the test alternator mounted on the steel test stand showed a slight reduction in active flux due to additional flux leakage through the test stand. This condition will not be encountered during power conversion skid tests due to the use of an aluminum skid.

Subsequent dynamic tests on the alternator verified that the low output voltage was caused by a back magnetomotive force.

The above test results and the results of short circuit saturation tests conducted previously indicated the necessity of the following changes in the prototype alternator to meet the performance requirements:

1) The steel holding pins in the stator must be removed to eliminate demagnetizing effects caused by the eddy currents set up by these pins in order to develop full power with a 1.0 lagging power factor load.

2) Additional changes needed to meet the power output requirement with a 0.8 lagging power factor load include laminating the drive-end housing, increasing its effective area and adding material to the rotor-pole body to increase the effective area for carrying flux.

The test alternator was assembled incorporating the laminated drive-end housing and the stator without steel holding pins. Tests were conducted to determine power output and establish open circuit and short circuit saturation curves. Approximately 12.5 hours were accumulated on the alternator in the test program.

A power output of 320 kw was obtained at unity power factor during the load tests. Visual inspection of the voltage waveform at load conditions with unit power factor and rated current of 69.3 amp indicated the harmonic content to be less than 3%.

The open-circuit saturation tests demonstrated that the problem of decreasing per-unit volts with increasing speed was resolved by removing the steel holding pins from the stator. Although the open-circuit saturation voltage was significantly better than previous results, the voltage was 21% below the required 2400 volts. The low voltage was attributed to saturation in the drive-end housing as a result of the leakage flux being higher than indicated by design calculations. Analysis of the test results indicated that the turns per coil in the stator winding must be increased from 5 to 6 in order to meet the performance requirement.

The short-circuit saturation tests indicated that the saturation curve is 20% better than originally calculated. The rated current of 69.3 amperes was obtained with 11.5 amp field current, instead of the calculated 15 amp.

The redesign of the prototype alternator to incorporate the changes noted above was completed.

Fabrication of the redesigned rotor, the drive-end housing, and the field coil was initiated.

The fabrication and assembly of the first prototype starting motor was completed. A phase-to-phase short during the initial tests burned out the stator winding. Investigation indicated that the failure was due to weak insulation.

The second starting motor also failed in a similar manner during low-load tests. Further investigation confirmed both failures were due to weakening the insulation when forming the end turns.

The stator was rewound with a Class A insulation and testing was resumed. The tests covered both 4-pole and 2-pole operation. The results indicated that the motor delivers 52.5 hp with 2.2% slip compared to the design of 2.5% slip at 50 hp. However, the starting torque was lower than expected.

The starting motor rotor failed during full-speed operation at 2-pole conditions. Disassembly revealed that at least one of the copper distribution ring locking teeth had separated from the rotor severely damaging the stator windings and the rotor. Investigation revealed that inadequate silver soldering of the mating parts of the distribution ring had allowed movement under high centrifugal force. Rework of the rotor was initiated to include stainless steel bands around the distribution ring. The stainless steel bands also will increase the resistance of the rotor and thus bring the starting torque to the required level.

The fabrication of the second voltage-regulator static-exciter assembly was completed. Laboratory tests on the voltage regulator were completed.

Accomplishments - June:

Fabrication of the field coil and the machining of the drive-end housing were completed.

Completion of the redesigned rotor was delayed when insufficient interference between rotor and shaft was found. The interference was increased by chromium plating the shaft.

The starting motor was reassembled using the rotor reworked to include stainless steel bands around the copper distribution rings. Mechanical performance of the rotor during the starting motor tests was satisfactory.

The starting motor load tests were completed. The torque was measured at the drive-end of the alternator rotor shaft during the tests. In measured test data, therefore, the alternator rotor and friction losses appeared as motor loss, although in actuality these losses are a motor load. The starting motor performance data for four-pole operation (Figure 3:8) was corrected to eliminate the alternator rotor and friction losses from the motor performance curves. Similarly, the corrected performance data for two-pole motor operation indicates that the performance is equal to calculated design values.

Anticipated Accomplishments - July:

Rotor and drive-end housing will be delivered.

The unit will be assembled and testing initiated.

The second starting motor will be assembled and testing initiated.

b. Recuperator

Review - January through May:

The fabrication of the two recuperators was completed. The final mass spectrometer leak tests and the 24-hr nitrogen pressure and leak check showed that both units were acceptable. The first recuperator was delivered to Aerojet and installed on the developmental power conversion skid.

Accomplishments - June:

No work was done on the recuperator. The unit was retained at Griscom-Russell after completion for delivery with the precooler. The unit was shipped on 26 June.

Anticipated Accomplishments - July:

The recuperator will be installed on the second skid.

c. Precooler

Review - January through May:

The designs of the oil cooler winterization kit and precooler cover were completed.

The fabrication of the first precooler assembly was completed. In the 24-hr nitrogen pressure and leak check, total leakage from the precooler (in terms of power plant performance characteristics) was equivalent to 0.00006% of the flow rate of working gas. Although this is more than allowed by the Aerojet specification, the leakage is considered to be acceptable. The unit was delivered to Aerojet and installed on the developmental power conversion skid.

Considerable difficulty was encountered in obtaining satisfactory initial tube-to-tube sheet welds during fabrication of the first precooler. A weld development program was conducted to improve the welding technique for the second precooler. This program established welding techniques and procedures which were successful in obtaining a high percentage of acceptable initial welds and also established a satisfactory procedure for repairing welds.

Fabrication of the oil cooler and moderator cooler for the second assembly was completed except for those tasks which had to await final assembly of the structure. Fabrication and mass spectrometer tests of the precooler tube bundle were completed.

Accomplishments - June:

The components of the precooler assembly were all completed and the unit was shipped to Aerojet on 26 June. The final helium mass spectrometer leak tests showed that the total gross leakage was 0.8×10^{-6} cc/sec. The 24-hr nitrogen leakage check conducted at 145 psia revealed no leakage of nitrogen. Based upon the above tests, the precooler will be acceptable for use in conjunction with the reactor operation.

Anticipated Accomplishments - July:

The precooler will be fitted to the prototype power conversion skid.

3.4 The Power Conversion Skid (Tasks 31-5XX, 31-7XX, 86-2XX, 86-5XX, 86-6XX and 48-1XX)

a. Power Circuit

Review - January through May:

Design work was completed on the main piping including the flow measuring section for use in the power conversion skid tests at Aerojet-Azusa.

The flange and gasket evaluation tests were completed. The tests demonstrated that bolt torques required for proper sealing with Flexitallic and sheet asbestos gaskets were too high for the compressor inlet and discharge flanges. Silicon rubber gaskets, compatible with the operating temperatures and pressures, therefore, will be used at these joints to obtain proper sealing within acceptable bolt torque limits. Flexitallic gaskets will be used at the other flange joints.

Tests by the vendor of the reactor and turbine inlet expansion joints indicated that the bellows spring rates were higher than specifications.

A pre-set was applied to the expansion joints to minimize the forces transmitted to the flanges and the attached components during power plant operation. This pre-set allows the bellows to move through a null position during operation, thereby effectively reducing the forces 50%. The expansion joints for the two skids were received. The fitting and welding of the flanges to the expansion joints for the developmental skid were completed when the skid was assembled.

The fabrication of the main loop and the bypass piping was completed.

The nitrogen pressure relief valve and flow straightener were received. The acceptance test by the vendor demonstrated that the relief valve met the specifications.

The overspeed valve and the breadboard bypass valve for the developmental skid were received.

Accomplishments - June:

Power circuit fabrication and procurement were completed for both skids.

b. Skid Structure

Review - January through May:

The developmental skid structure, including the removable braces, was completed and delivered to Aerojet-Azusa. Minor items, such as threaded inserts and elastomer skids, were then installed.

The prototype skid structure was completed, including the elastomer skids, and was delivered to Azusa.

The task was completed in May.

c. Panels and Screens

Review - January through May:

The design of the end panels was completed.

Fabrication and fitting and assembly of the side panels and screens for the developmental skid were completed.

Fabrication of the sheet metal cover for the ends of the skid and the electrical bays in the precooler was initiated.

Accomplishments - June:

Fabrication of the sheet metal covering for the reactor end of the skid and the electrical bays of the precooler was completed. The covering for the alternator end will be continued after completion of the electrical connector panel attachments and wiring continuity checks.

Anticipated Accomplishments - July:

The sheet metal covering of the alternator end of the skid will be completed.

d. Assembly

Review - January through May:

The assembly of the developmental power conversion skid was completed except for some control and instrumentation wiring. A dummy alternator with a through shaft for the starting motor attachment was installed on this assembly. The skid was moved from the assembly area to the test facility on 31 May.

Accomplishments - June:

All interconnecting wiring between the motor control, generator control and instrumentation components and the motors and connectors was completed. Wiring continuity was verified.

The motor-operated gas make-up valve was reworked and installed on the skid.

Anticipated Accomplishments - July:

No assembly work on the developmental skid is anticipated beyond installation of the skid covering panels. These panels will be installed after the static checkout tests of the subsystems are completed.

Assembly of the mechanical components on the prototype skid will be initiated when the major components are delivered early in July.

e. Electrical Packaging

Review - January through May:

Designs and drawings for the electrical equipment mounting panels, generator control center, transfer switch housing, and lightning arrestor rack were completed.

The electrical wiring tabulation sheets were completed.

Fabrication of the mounting panels and the generator control brackets, panels and cover was completed. The lightning arrestor rack was completed.

The electrical and switchgear components were installed on the mounting panels which attach to the precooler and in the generator control center. The wiring of the mounting panels was completed and the wiring of the generator control center was completed with the exception of the surge inductors. The mounting panels and generator control center were installed on the first skid.

The installation of the electrical and switchgear components on the mounting panels for the prototype power conversion skid was initiated.

Accomplishments - June:

The installation and wiring of the electrical and switchgear components on the mounting panels for the prototype skid were completed and the interconnecting panel wiring was initiated.

Wiring of the second transfer contactor was continued.

Anticipated Accomplishments - July:

Interconnecting wiring of the electrical and switchgear panels will be completed. The wiring of the transfer contactor will be completed.

Mounting of the generator control components for the prototype skid will be completed.

f. Process Instrumentation

Review - January through May:

Purchase requisitions were issued for the process instrumentation equipment required for the prototype power conversion skid.

Accomplishments - June:

The equipment for the prototype power conversion skid was received except for three pressure transducers.

Anticipated Accomplishments - July:

The transducers received during July will be inspected and shipped to Aerojet-Azusa. Liaison with the vendors will continue.

g. Analysis Instrumentation

Review - January through May:

Purchase orders for analysis instrumentation for the developmental skid were duplicated to equip the prototype skid. Identical equipment types were specified to insure compatibility with the existing readout equipment.

Accomplishments - June:

Liaison was maintained to insure delivery of the few remaining components (the transducers for channels PdX 106, PdX 109, PdX 612 and PX 616).

Anticipated Accomplishments - July:

All outstanding material will be received and calibrations checked.

3.5 Lubrication and Gas Cleanup System (Tasks 31-6XX and 86-7XX)

Review - January through May:

The fabrication and procurement of lubrication system components for the two power conversion skids were completed except for the delivery of the second seal compressor.

Evaluation tests on the nitrogen/oil separator were conducted by the vendor. The performance results were satisfactory after modifications were made to reduce pressure drop across the separator under the maximum flow conditions and to improve the response time of the liquid-level control valve.

The low amount of oil contamination in the nitrogen discharge from the mechanical separator experienced during the tests indicated that the overall performance of the mechanical separator and the molecular sieve will meet the maximum limit of 5 ppm oil contamination.

The oil pump for the Clark turbine compressor set met the specification performance requirement in a 20-hour evaluation test conducted by the vendor.

The installation of the lubrication system components and associated plumbing on the developmental power conversion skid was completed.

Tests were completed on the breadboard of the partial lubrication system for the Stratos t-c set to evaluate the performance and dynamic characteristics of individual valves as well as the overall system. The system components functioned satisfactorily during simulated start, run, and stop tests. The breadboard lubrication system tests were used to establish fill and bleed procedures for the prototype system.

The breadboard lubrication system tests to evaluate the complete lubrication system performance were delayed until receipt of the second seal compressor.

Accomplishments - June:

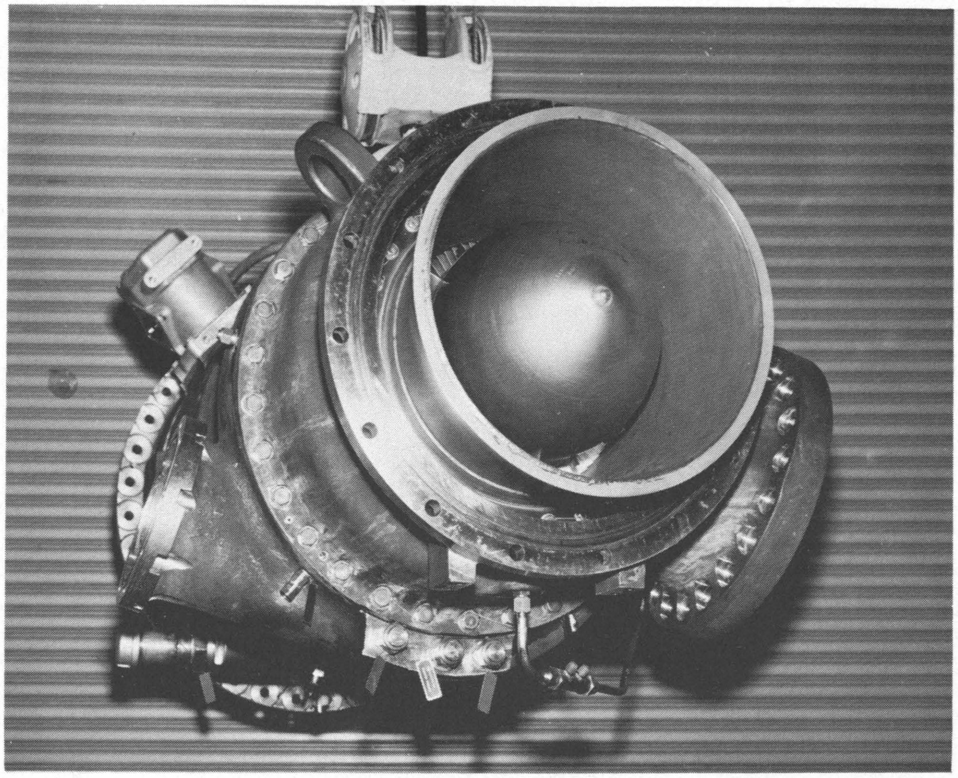
Initial tests at the vendor's facility indicated a possibility of an overtemperature condition during operation of the seal compressor. Extended acceptance tests (more than 10 hr) showed that the unit was acceptable. The compressor was delivered in mid-June.

The breadboard lubrication system assembly was resumed upon receipt of the compressor and is now 95% complete.

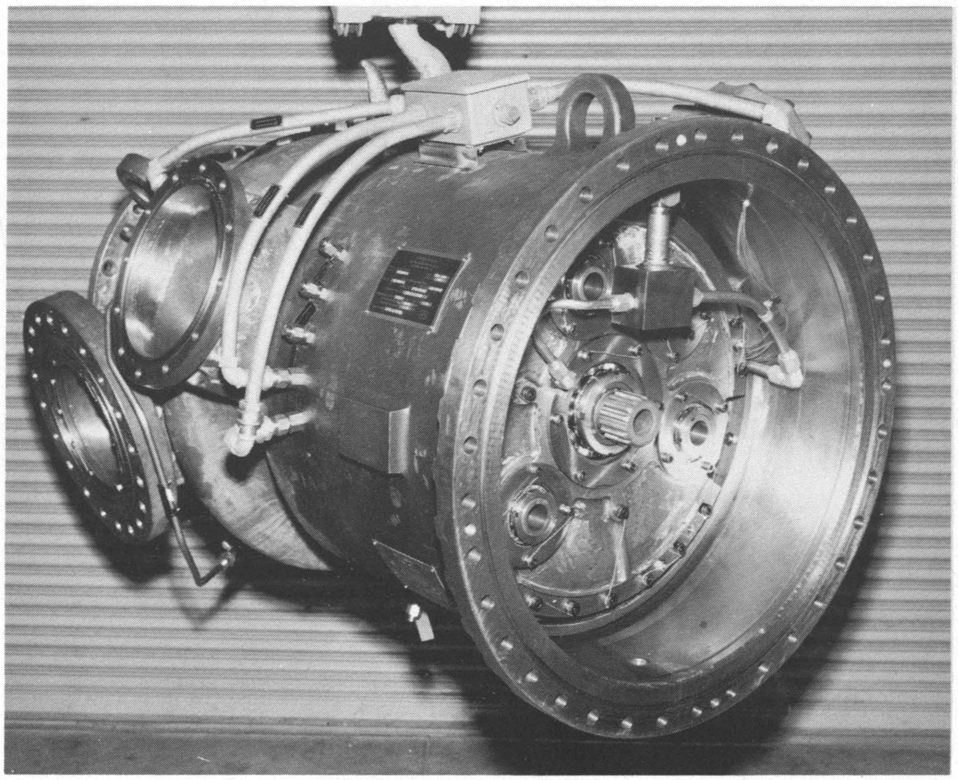
Anticipated Accomplishments - July:

The installation of components in the breadboard lubrication system will be completed and performance tests will be conducted. The installation of the lubrication system components on the prototype power conversion skid will be initiated.

THE STRATOS TURBINE-COMPRESSOR SET (TCS-670)



The Turbine Discharge End.



The Gearbox End.

FIGURE 3:1

TCS-670 COMPRESSOR CHARACTERISTICS

AIR

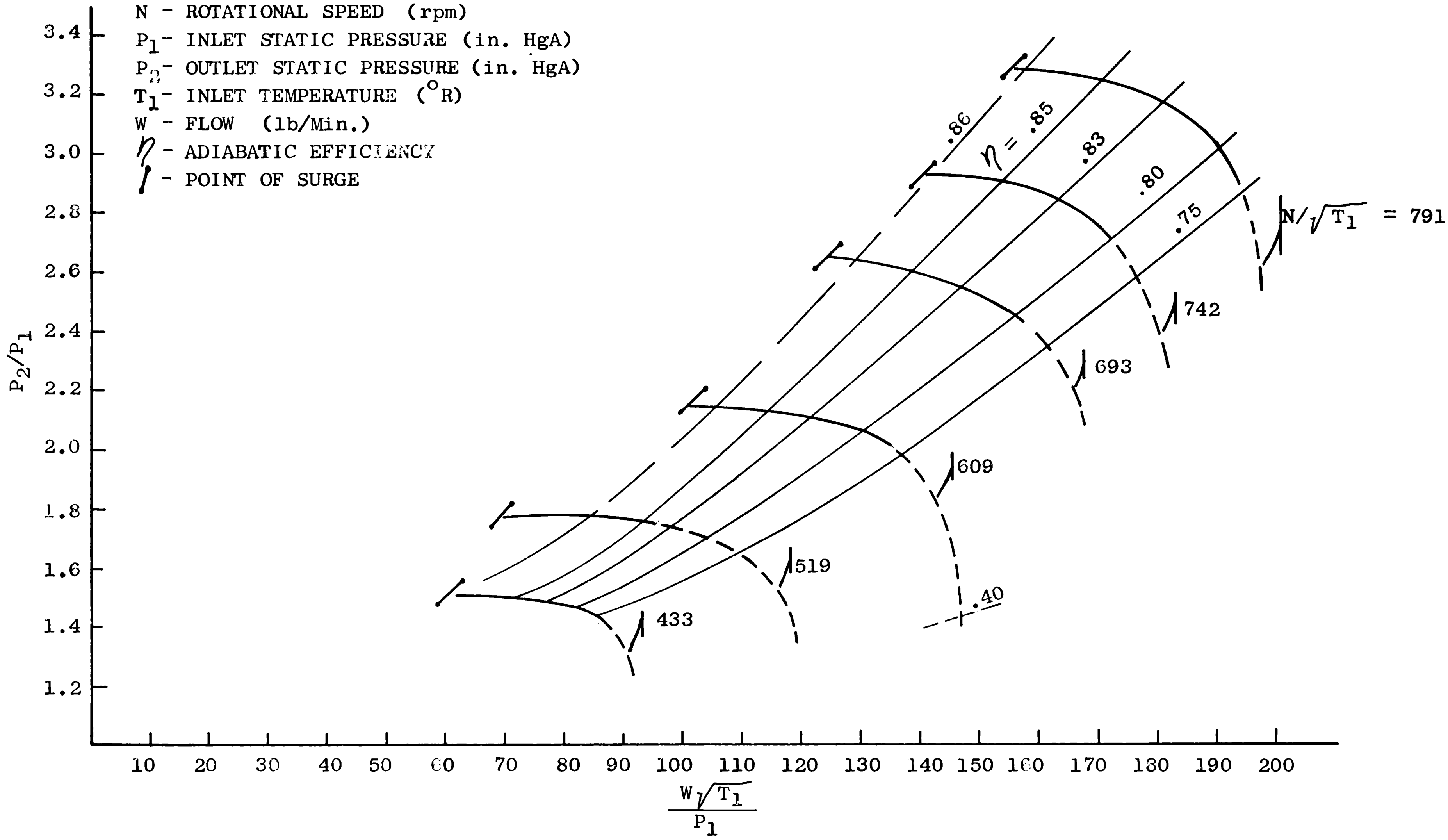


FIGURE 3:2

TCS 670 TURBINE PERFORMANCE POINT CHECK

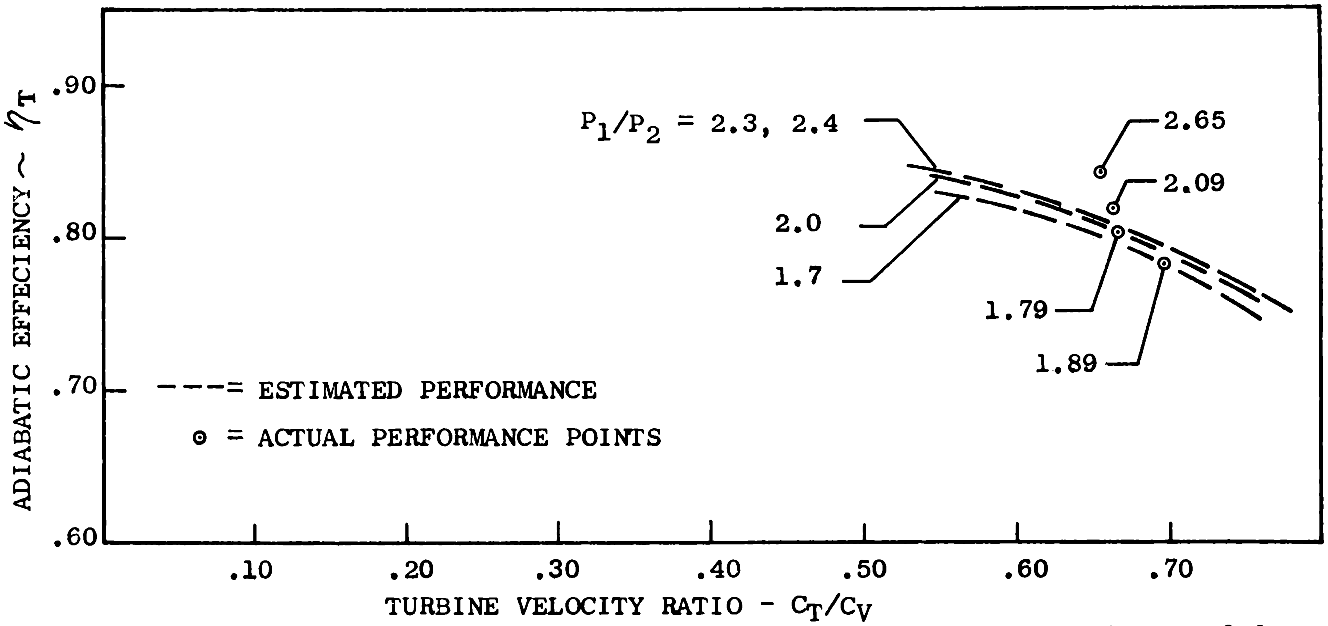


FIGURE 3:3

TCS-670 TURBINE PERFORMANCE POINT CHECK

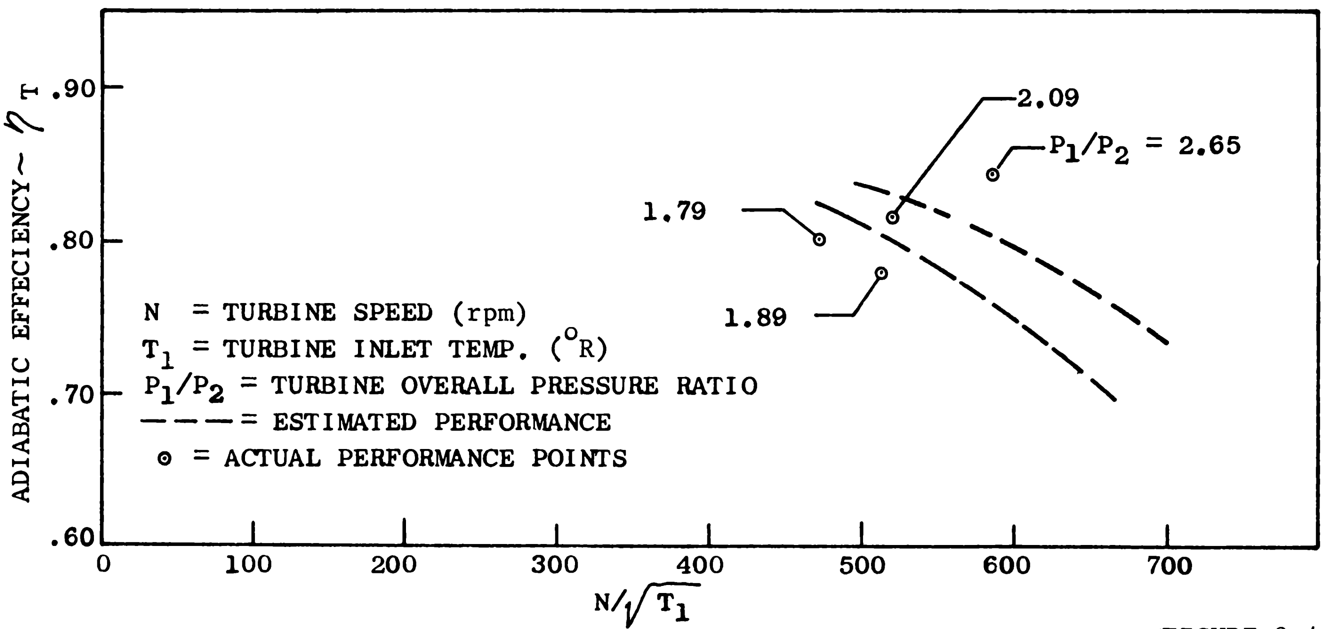


FIGURE 3:4

OPEN CIRCUIT SATURATION

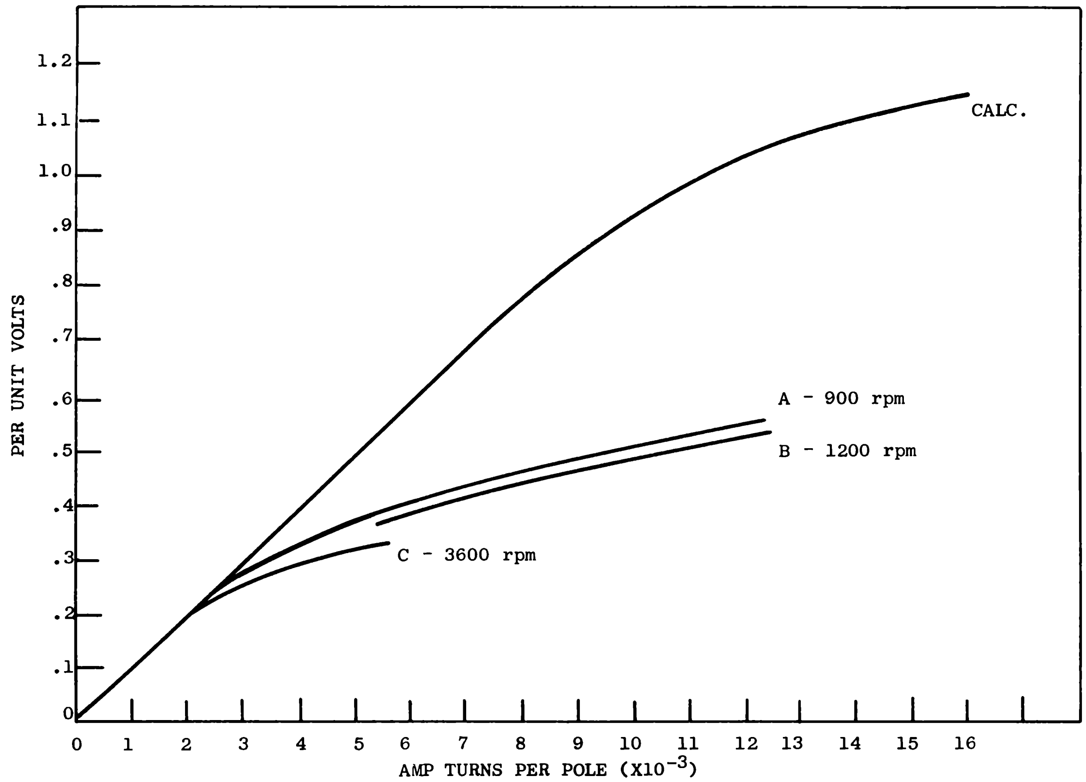


FIGURE 3:5

SHORT CIRCUIT SATURATION

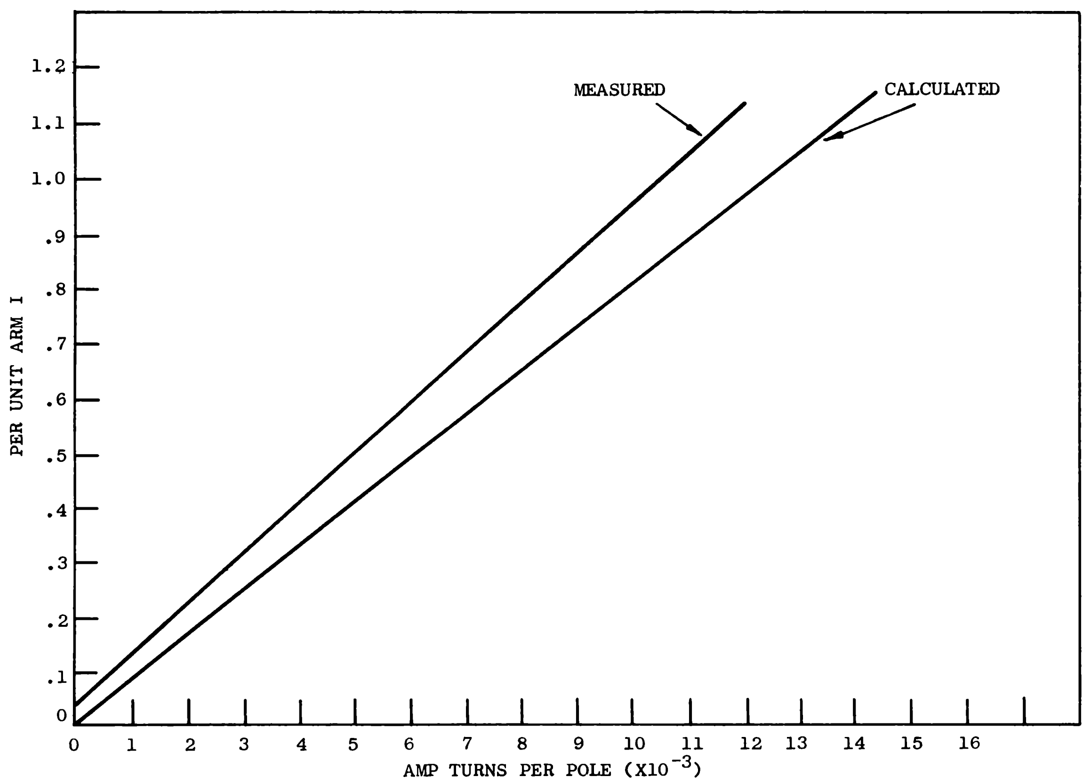


FIGURE 3:6

ACTIVE FLUX VERSUS FIELD CURRENT

(Tests of 27 to 31 March 1961)

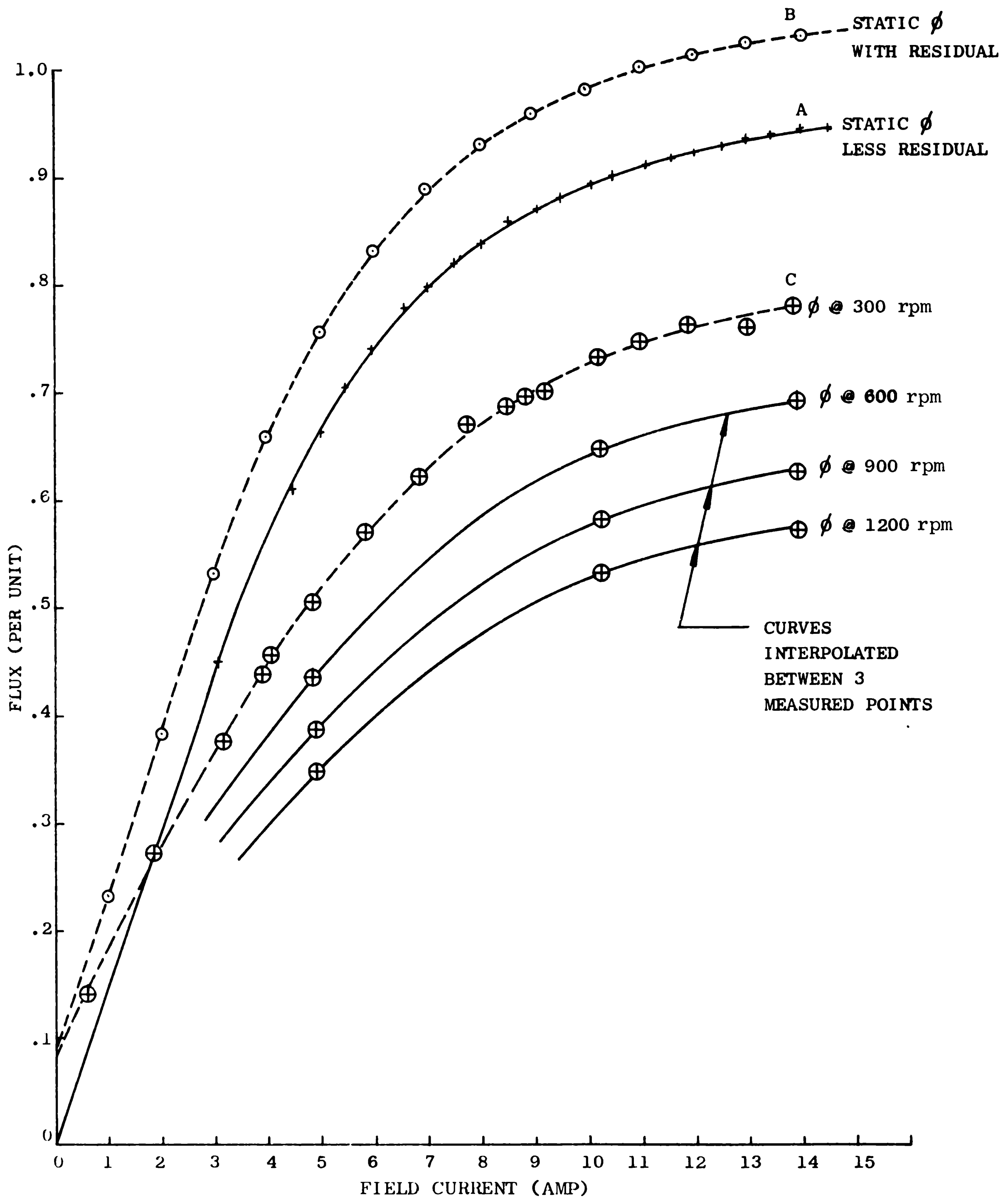


FIGURE 3:7

ML-1 STARTING MOTOR 4 POLE PERFORMANCE

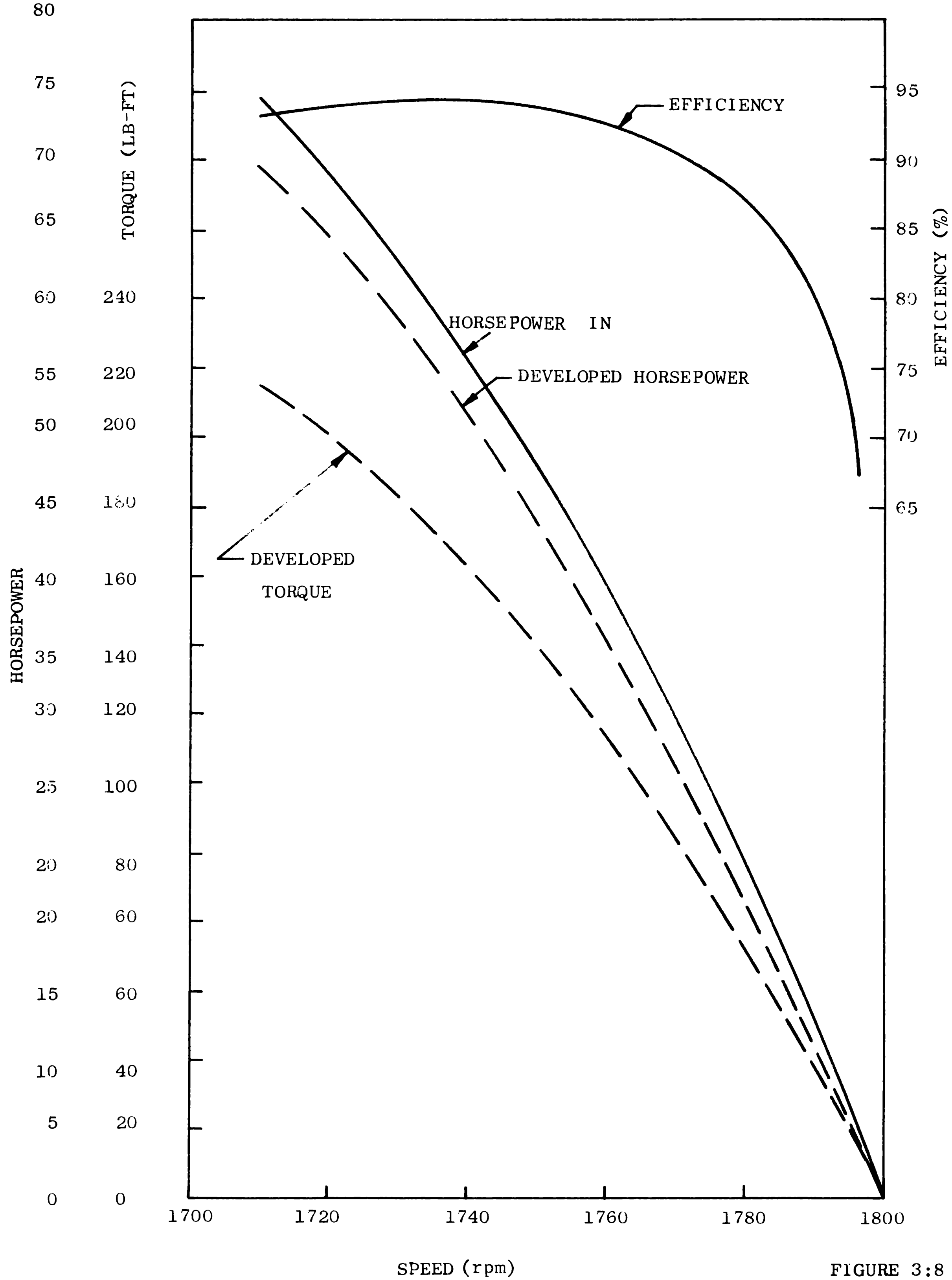


FIGURE 3:8

4.0 INSTRUMENTATION AND CONTROLS

4.1 Dynamic Analysis (Task 40-3XX and 40-4XX)

(Note: Task 40-4XX, Computer Services, was reported under a separate heading in the most recent semiannual progress report IDO-28567. Expenditures on Task 40-4XX, however, are in support of Task 40-3XX and hence are more logically reported with the work on Dynamic Analysis.)

Review - January through May:

Write up of the analog model was completed and the finished wiring diagrams were retained for use in support of skid testing.

Accomplishments - June:

This task was inactive in June.

Anticipated Accomplishments - July:

Work will be performed if requested in support of skid testing.

4.2 Systems Analysis (Task 40-5XX and 40-6XX)

(Note: Task 40-6XX, Computer Services, was reported under a separate heading in the most recent semiannual progress report IDO-28567. Expenditures on Task 40-6XX, however, are in direct support of Task 40-5XX and hence are more logically reported with Systems Analysis.)

Review - January through May:

The CHOP writeup, a description of the CHOP code, was not completed due to re-direction of efforts. Support of development skid testing now is emphasized. The NUDE code was completed and was checked for continuity but was not debugged.

Accomplishments - June:

This task was inactive in June.

Anticipated Accomplishments - July:

Work will be performed if required in support of skid testing.

4.3 Analysis Instrumentation (Task 83-1XX)

Review - January through May:

Transducers and associated installation hardware for the analysis instrumentation were received and installed on the developmental power conversion skid. The transducers were calibrated before installation.

The junction box (used to house the thermocouple reference junctions, the pressure transducer selector and the calibration system) was completed and shipped to NRTS.

The gas analysis system equipment was received at Aerojet for use during the checkout of the power conversion skid. This equipment will sense contamination of the coolant gas by moisture, oxygen or hydrocarbons.

Accomplishments - June:

The vendor of the coolant gas analysis system was requested to perform field setup of the equipment in accordance with the terms of the purchase contract.

Anticipated Accomplishments - July:

The gas analysis equipment will be accepted for use in the power conversion skid tests.

4.4 Reactor Electrical Equipment (Task 87-1XX)

Review - January through May:

The drawings of the electrical power equipment were completed and modified to reflect the "as built" status. This equipment includes the motor control center schematic, generator protection system schematic, single line electrical control drawing, wiring diagrams, and inverter fabrication drawings. The components to be mounted on the power conversion skid were shipped to Aerojet-Azusa after acceptance check at Aerojet-San Ramon.

The initial purchase of surge inductors did not meet specifications and were returned to the vendor for redesign. The modified units met all specifications and were shipped to Aerojet-Azusa for inclusion on the developmental and prototype power conversion skids.

The dc-to-ac inverter was fabricated and completely checked. The original design criteria (requiring less than a 5% harmonic distortion in wave shape) was met. The components designed to be mounted in the control cab were received, inspected and mounted in the control cab.

Accomplishments - June:

Task 87-1XX was closed on 1 June.

4.5 Electrical Equipment, Prototype Fabrication (Task 87-2XX)

Review - January through May:

Wiring of the control cab was completed for all components of the electrical power equipment. These components include the generator protection system; motor control system; battery inverter emergency power system; transfer switch; and the 440 single phase, 3 phase power circuitry for the instrumentation systems. Each circuit was individually tested during the checkout phase for continuity and operation to ensure reliability of operation. Although minor discrepancies were found in both the wiring and design, these were rectified without any major effect on schedule. All circuit breakers, transformers, relays and switches were individually checked for conformity to specifications.

The battery inverter system was completely tested under full load after being installed in the control cab.

The high voltage terminals on the vacuum circuit breakers were modified to provide more room on the power conversion skid. The circuit breakers were tested before shipment to Aerojet-Azusa for installation on the power conversion skid.

Accomplishments - June:

The work order was closed on 1 June after delivery of all items to Azusa.

4.6 Neutron Monitoring and Controls (Tasks 87-3XX and 87-4XX)

Review - January through May:

The equipment comprising the seven operational neutron monitoring channels, the blade control and position indicating system, and the incipient-fault monitoring annunciator system was completely checked out using the GCRE reactor. The equipment then was installed in the control cab and on the reactor skid and now is in preliminary operation at the ML-1.

To permit test operation of the reactor without the power conversion skid, a temporary junction box was equipped with the nuclear instrumentation preamplifiers, the site area monitoring system junction box, the motor starters for the moderator circulating pump, the moderator heater controls and all associated cable connectors. These components are needed for the critical experiments and normally are housed on the power conversion skid.

Fabrication and checkout was completed on the portable air monitor, the precooler leakage monitor, the site area radiation monitoring system and the fast neutron monitor for the control cab. All portable radiation survey meters and protective clothing were delivered to the ML-1 site.

Accomplishments - June:

Bids were solicited for improved display modules for the annunciator system and the associated power supply drawer.

A specification was prepared and a requisition issued for coaxial cable suitable for operation at 250°F. This cable will replace the RG 59/U cable, rated for 80°C operation, now installed on the reactor skid.

The exhaust blower required to complete the particulate trap for the precooler monitor was received and the assembly was completed and checked.

The "as-built" drawings for modification of the fast neutron survey meter were completed.

Anticipated Accomplishments - July:

No future work is scheduled under this task.

4.7 Process Instrumentation and Controls (Tasks 87-5XX and 87-6XX)

Review - January through May:

An engineering calibration procedure was established for the bearing temperature chassis when being tested with the various temperature transducers.

The fast pressure loss chassis was completed and tested. It was shipped to the ML-1 site for final installation in the control cab.

The reactor temperature controller was modified by the vendor, and installed in the speed and temperature chassis.

Work on test procedures for the ML-1 speed control loop continued.

Accomplishments - June:

The prototype magnetic amplifier and valve system were subjected to a nitrogen flow test at the Azusa test facility according to the requirements of test procedure 143W89TR2 and AGC specification 60012. The test results indicated the following:

1) Calibration and Response: The calibration curves of the feedback voltage, input control current, motor control voltage, step input signal, ac tachometer output voltage and linear position potentiometer voltage showed that the speed of response of the valve system would meet specifications (300 millisec from closed to open position). The speed response was also 300 milliseconds from an open position to the nearest closed steady state position.

2) Response Time with Maximum Flow (7.25 - 8.4 lb/sec): With maximum gas flow through the valve, three speed response runs were performed to determine repeatability in the position servo loop system. The speed of response records indicated a range of 240 to 280 millisec from closed to open position, and 190 to 230 millisec from open to closed position. After reviewing the test data, it was agreed that the performance characteristics met the specifications and that additional response tests would not be required.

Aerojet received the first prototype magnetic amplifier and valve system and began preliminary systems checkout with the speed controller chassis for calibration of the process control system.

Anticipated Accomplishments - July:

No future work is scheduled under this task.

4.8 Reactor Cab and Electrical Power (Tasks 87-7XX and 87-8XX)

Review - January through May:

All components and systems were mounted in the control cab and wired. Each system was individually tested by the insertion of simulated signals to the inputs on the amplifiers and power control equipment. "As-built" changes were made to the fabrication drawings to reflect changes made during testing. All connectors, cables, relays and other minor components were received and tested during the course of fabrication before installation in the cab. There were no major design changes required after operational checking of each system. The lighting system, air conditioner, generator monitoring panel, paralleling networks, battery and battery charging systems all met the operational design criteria. The control cab (Figure 4:1) was shipped to the ML-1 site. The cab was shipped on a 2-1/2 ton M35 Army vehicle in February (Figure 4:2). The weight of the control cab was approximately 6,000 lbs.

Quotations were received for the cables connecting the power conversion skid with the control cab. Drawings were approved and fabrication started in February. The cables were delivered to the ML-1 site after being checked. All cables are now installed and operational.

Accomplishments - June:

This task was closed on 1 June.

4.9 Spares (Tasks 89-5XX, 89-6XX and 89-7XX)

Review - January through May:

a. Process Instrumentation: The procurement of spares was completed, except for the fast pressure loss system transducer, the main sump gas pressure transducer, the valve drive magnetic amplifier and bypass control valve.

b. Analysis and Health Physics: Spare transducers and expendable parts were ordered for all analysis instrumentation channels and health physics equipment.

Accomplishments - June:

a. Process Instrumentation: The prototype magnetic amplifier and bypass control valve were tested and evaluated, and are being integrated into the ML-1 process control system.

b. Analysis and Health Physics: The spare TX 110 thermocouples were received. Liaison with the vendor was maintained to assure scheduled delivery of the spare transducers for measurement channels PdX 106, PdX 109, PdX 612, and PX 616.

Anticipated Accomplishments - July:

a. Process Instrumentation: Liaison on the outstanding spare components will continue.

b. Analysis and Health Physics: All outstanding spare parts will be received and checked for calibration.

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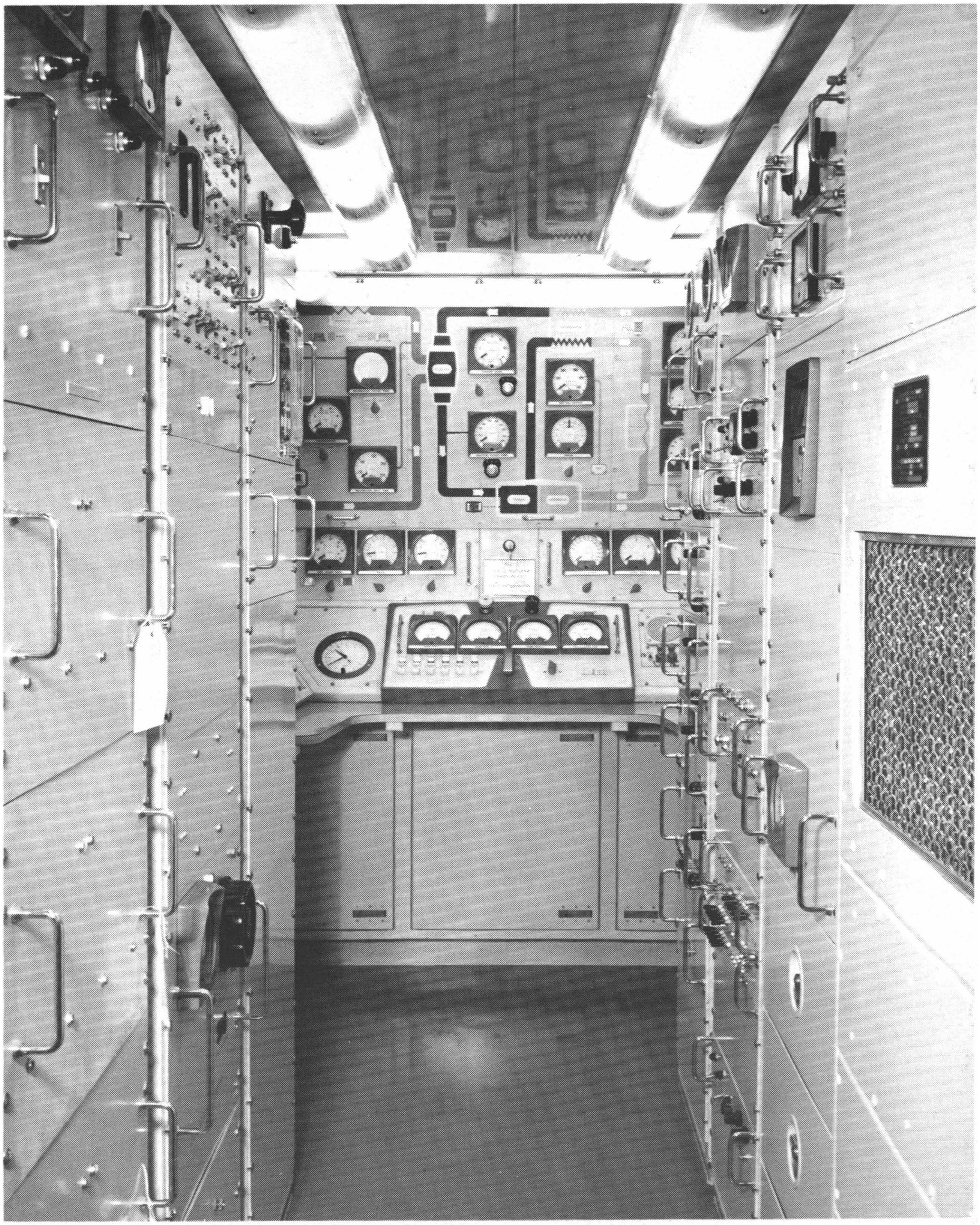

COMPLETED CONTROL CAB

FIGURE 4:1

FIGURE 4:2

THE CONTROL CAB MOUNTED ON A M-35 ARMY VEHICLE FOR TRANSPORT TO THE ML-1 SITE.

5.0 AUXILIARIES

5.1 Systems Integration and Liaison (Task 40-1XX)

Review - January through May:

No significant changes were made to the piping and instrumentation diagrams. Liaison was maintained with Aerojet-Azusa.

Accomplishments - June:

No changes were made to the piping and instrumentation diagram. Liaison was maintained with Aerojet-Azusa.

Anticipated Accomplishments - July:

Liaison will be continued. The piping and instrumentation diagrams will be brought up to date to reflect the "as-built" ML-1.

5.2 Shock Mounts (Task 81-1XX)

Review - January through May:

Fabrication of the two sets of power conversion skid beam assemblies was completed at Aerojet-Downey, and the assemblies were shipped to Aerojet-Azusa for installation on the power conversion skids.

This task was completed in March.

5.3 Transportation (Task 41-2XX)

Review - January through May:

The ML-1 Control Cab was loaded on a M35 cargo truck and shipped to NRTS in February. Tune-up and winterizing of the Army truck, supervision of the loading and tiedown operations and planning and coordination of the cab shipment was done under this task.

Fabrication of all loading and tiedown equipment for the ML-1 plant was completed.

Technical work on the ML-1 Transport Manual was completed and the manual is in the process of being published. This manual defines loading and tiedown procedures for all ML-1 packages for the various modes of transport.

This task was completed in May.

5.4 Gas Storage Skid (Task 84-XXX)

Review - January through May:

Design, fabrication and assembly of the ML-1 gas storage skid was completed. Testing of the ML-1 gas handling system commenced.

Accomplishments - June:

Helium leak testing and operational checkout of the ML-1 gas storage skid continued. The gas transfer diaphragm compressor developed a crack in the body forging during operation and was returned to the vendor for repairs.

Anticipated Accomplishments - July:

Repair of the gas transfer diaphragm compressor will be completed by the vendor.

5.5 Water Treatment Equipment (Tasks 85-1XX and 85-2XX)

Review - January through May:

Fabrication of the ML-1 water make-up demineralizer and shield water mixing equipment was completed and shipped to NRTS in February. The boron test kit was shipped to NRTS at that time.

5.6 Failed Fuel Element Detector (Task 49-3XX)

Review - January through May:

The inpile loop testing for the carbon filter concept was completed in January. A new concept, using radioiodine activity in the flooding water of the ML-1 core during a fuel element changing operation, was studied in February.

An iodine-water detection test using an irradiated fuel pin was run in which both radioiodine 131 and 133 were detected on a gamma-ray spectrometer. The test and literature showed the adaptability of the concept to ML-1. Work on the carbon filter concept was discontinued. Equipment utilizing the radioiodine concept was designed.

Equipment was designed and fabricated to remove individual samples of water from each core fuel element in the ML-1. Test equipment also was designed for use in the GCRE and use of the GCRE reactor for final proof testing of the radioiodine concept was requested. The test also established anticipated operating procedures for use in the ML-1.

Accomplishments - June:

Assembly and testing of the ML-1 equipment was completed. All test objectives were met. The equipment was submerged in water and operated to test the accumulator response and sample quantity, and the fuel element "O" ring seal. Each of the 61 accumulators filled with water in each test run. The sample was about 150 cc of water per accumulator. Some accumulators developed small pin-hole leaks after 4 or 5 test runs. These leaks allowed water to get into the vacuum manifold; however, the leaking accumulators each still contained a full sample of water and did not prevent satisfactory operation of the equipment. The accumulator pin-hole problem will be corrected, however, for use in the ML-1. The fuel element "O" ring seal was found to be adequate.

Drawings for the GCRE test equipment were completed, and all materials were ordered.

Anticipated Accomplishments - July:

New accumulators will be ordered for the ML-1 equipment with the pin-hole problem corrected. Fabrication of the GCRE test equipment will begin and is scheduled for completion by the end of the month.

5.7 Remote Handling (Task 49-5XX)

Review - January through May:

The remote handling tools needed for cold criticality work were delivered to the ML-1 site.

Preliminary layouts and engineering studies were made for the shield tank extension and support frame to replace fuel elements individually.

Preliminary radiation studies were made for the expedient shielding around the tank extension.

A preliminary design for a 19-element fuel transportation cask was made; this work included shielding analysis and heat transfer analysis.

Preliminary engineering studies and layouts were prepared for equipment to completely refuel the core.

A revised plenum cap fastener design was made and a test model built and evaluated. The design was satisfactory but was not used due to problems of the suitability of 17-4 PH stainless steel.

Additional 7-hole tube sheet samples were machined and the proposed GCRE repair plug was installed and tensile tested at Aerojet-Downey.

Accomplishments - June:

Engineering calculations for the tank extension and support structure were completed.

Liaison with a vendor was established in connection with fabrication of the rubber tank liner. The materials, methods of construction and design of the pneumatic seal were decided.

Preliminary discussions were held to determine if Aerojet-Downey has adequate manufacturing facilities for building the tank extension and support frame.

Upper and lower gas duct blind flanges were designed and layouts were completed.

A preliminary layout was made of the remote handling tools in place on the tank extension. This layout revealed the need for modification of the upper gas duct clamp handling tools. A new layout of the upper gas duct clamp handling tools was initiated.

Anticipated Accomplishments - July:

Fabrication details for the shield tank extension will be completed.

Fabrication details for the rubber tank liner will be completed.

A purchase specification for the rubber liner will be written and requests for quotation will be initiated.

Details of upper and lower gas duct blind flanges will be completed.

The layout of remote handling tools in the tank extension will be completed and the tool extension handles will be revised.

Additional radiation level studies in the vicinity of the tank seal and the plenum cap storage area will be initiated.

The plenum cap sling modification will be completed and shipped to NRTS.

Additional tests on the captive nut mock-up will be run to determine the effect of stud harness on galling.

A layout will be prepared to determine the feasibility of installing captive nuts on the plenum cap in the area beneath the gas duct.

The use of the hydraulic nut torquing tool on the gas duct clamp will be investigated.

5.8 Support Equipment (Tasks 85-3XX and 85-4XX)

Review - January through May:

a. Cable Reel Skid: Fabrication of the cable reel equipment was completed in January and the unit was shipped to NRTS the following month.

b. Reactor Drying Skid: The skid-mounted reactor drying equipment was shipped to NRTS in January. The Chromolox heating element was returned to the vendor in March for replacement of defective wiring and modification to the terminal housing. It was returned to NRTS in April and used in the reactor core drying operations in May. Work on this task was completed in April.

5.9 Transportation Study (Task 38-1XX)

Review - January through May:

The objective of this study is to prepare a plan for peacetime transportation of the ML-1. The plan is to include route planning, security and safety measures, preparation and restoration of plant sites, and the required liaison with federal agencies. The study was authorized on 14 April by AEC-IDO, and will continue through 30 September 1961.

Logistic ground rules include movement of the ML-1 will be from NRTS to Fort Leonard Wood, to Fort Huachuca, and to Fort Greely. These movements will be made with the fuel element removed, without shield or moderator water in the reactor, and with a reactor that has operated at high power levels for 10,000 hr. For the purposes of the study, it also is assumed that the lubricating oil reservoir of the power conversion skid is full, and that the working fluid is stored on the gas storage skid.

The following activities were in process at the end of May: Selection of tentative routes for transporting the ML-1 under the above conditions; preparation of an outline of an experimental program to be conducted at the ML-1 site, NRTS; compilation of statutes, regulations and agencies involved in transport of nuclear materials; and an outline of the final report.

A final draft of the program work plan was completed by the end of the period.

Accomplishments - June:

Compilation of statutes, regulations and agencies involved in transport of nuclear materials continued.

Tentative routings between the relevant locations were selected.

Planning of an experimental program was initiated.

A preliminary outline of the format of the final report was completed.

Anticipated Accomplishments - July:

Planning of an experimental program will be completed.

A major portion of the information on statutes, regulations and agencies involved in transport of nuclear materials will be compiled.

Liaison will be established to obtain information on transportation procedures, and formats required for transportation plans.

5.10 Fabrication Review (Task 39-6XX)

Review - January through May:

This review was made to use knowledge gained in fabricating the ML-1 before submitting the ML-1A drawings. Approval was received in April and the work was initiated.

Design personnel were invited to submit lists of desirable design changes. These lists were screened to eliminate suggestions beyond the scope of this fabrication review. In general, the scope was defined as modifying only those items which did not require operational evidence for assessment of their merits.

These changes were compared with drawings of the affected component and the modified prints were discussed in detail with key personnel at Aerojet-Downey. These personnel were invited to make suggestions.

This task will produce a report recommending component design changes which would be desirable to include in the ML-1A drawings, making them somewhat different from the "as-built" drawing file.

Accomplishments - June:

A fabrication review was conducted with manufacturing personnel at Aerojet-Downey.

Suggestions from these personnel were incorporated into proposed design change drawings.

Work was started on the summary report.

Anticipated Accomplishments - July:

Technical work on the report will be completed.

6.0 THE ML-1A (Tasks 51-XXX, 52-XXX and 53-XXX)

Review - January through May:

a. ML-1 and ML-1A Drawings: Work continued on the ML-1 "as-built" drawings and the "ML-1 Basic Parts List". "Basic Parts Lists" are being prepared in both Army Corps of Engineers part number sequence and Aerojet part number sequence. Since both sets of numbers are integrated into an IBM punched card system, listing and cross-referencing is simplified.

Work continued on the preparation of ML-1A, Class I, mono-detail drawings. Twelve individual packages of these mono-detail drawings were forwarded for formal review.

b. Specifications: A schedule for submission of the technical portion of the "ML-1A Performance Specifications" was forwarded to IDO and ARM.

"Section 1, General Requirements and Characteristics" and "Section 2, ML-1A Reactor Package Assembly" were submitted to IDO and ARM on 24 March, and 11 May 1961, respectively, for review and comments. "Section 3, ML-1A Power Conversion Assembly" was distributed 12 May 1961, for in-house comments.

Two individual packages of ML-1 design specifications were submitted to the U. S. Army Engineer Maintenance Center and IDO as back-up information.

Work continued toward the submission of ML-1 design specifications and the ML-1A performance specifications.

c. ML-1 Maintenance Package: An outline of the "ML-1 Maintenance Package" was submitted to IDO on 27 February.

The collection of data, art-work, instructions, etc, for filling in the synoptic outline of the ML-1 maintenance package continued.

Accomplishments - June:

a. ML-1 and ML-1A Drawings: Work continued on all phases of this task. Effort on the completion of drawings was reduced by approximately 30% due to a limitation of funds without affecting the overall completion date (May 1962).

b. ML-1A Specifications: A draft of the proposed Section 4 of the "ML-1A Control Shelter and Instrumentation" was completed and circulated for in-house review.

The third submission of a package of ten ML-1 design specifications was made to IDO, ARM, and the U. S. Army Engineer Maintenance Center.

c. ML-1 Maintenance Package: Work continued on the control cab manual. The draft of the gas storage skid manual is being circulated in-house for review.

Anticipated Accomplishments - July:

a. ML-1 and ML-1A Drawings: About 74% of ML-1 "as-built", and 6% of ML-1A, Class 1, mono-detail drawings will have been completed by the end of July.

Work on drawings and on up-dating the "ML-1 Basic Parts List" will continue.

Preparation of Army format drawings for the power conversion assembly will begin at Aerojet-Azusa.

b. ML-1A Specifications: A draft of "Section 3 of the ML-1A Power Conversion Assembly" will be submitted to IDO and ARM for review and comment.

A draft of "Section 5 of the ML-1A Gas Supply Equipment Assembly" will be completed and circulated in in-house review.

c. ML-1 Maintenance Package: The control cab manual will be essentially completed by the end of July.

Revision of the gas supply unit manual will begin.

Preparation of the power conversion assembly manual will begin.

III. FUEL ELEMENT DEVELOPMENT

SUMMARY

a. Major Events:

Sixty-nine ML-1 first core (ML-1-I) fuel elements were shipped to NRTS in two shipments. These elements were used in the ML-1 reactor when initial criticality was attained on 31 March. Criticality was achieved with 47 elements; extrapolation of data from the critical assembly predicted 48 elements; PDQ calculations predicted 45.5 elements.

Two ML-1 prototype test elements (designated IB-8T) had been irradiated for 2920 hr in the GETR loop by the end of the period. The average power of each element is 54 kw.

Preliminary data indicate that maximum corrosion penetration at 10,000 hr of 1.8% cobalt Hastelloy-X is about 0.002-in. in either reference gas (99.5 vol% nitrogen plus 0.5 vol% oxygen) or air at 300 psi and 1750^{o}F. However at 5,000 hr, the low-cobalt (0.07% Co) Hastelloy-X used in the IB-2L and ML-1-I fuel pins showed 0.0018-in. corrosion penetration in reference gas and 0.006-in. corrosion penetration in air under the same conditions.

Irradiation was completed on two capsules of ML-1-I fuel pellet specimens. One capsule, containing solid UO_2, was irradiated to 9000 hr equivalent ML-1 burn-up. The other, containing BeO-UO_2, was irradiated to 13,000 hr equivalent ML-1 burn-up. Hot cell examination showed that all UO_2 specimens were intact and that there was no central melting. Hot cell examination of the BeO-UO_2 capsule was initiated late in the report period.

Test irradiation of the IB-7T-1 defective pin was completed. The activity of the coolant indicated that fission product release from a defective fuel pin would be much less than expected. Only a small fraction of the activity released from the pellet is transferred to the coolant stream.

A product improvement program for the IB-3L and ML-1-II elements was initiated. Data from out-of-pile tests led to the decision to use a turbulence promoter surface on the fuel pins. This configuration, combined with the larger flow area and improved fuel distribution of the element is expected to lower the maximum surface temperature by 80 F degrees as compared to ML-1.

b. Problem Areas:

Minor mechanical deficiencies were found in a majority of the IB-2L elements. These deficiencies include: nut broken off the support rod; sheared bell pins; and outer liner damage. Almost all of these deficiencies can be repaired with minor modifications.

c. Schedule:

The project is about on schedule at the end of this report period.

7.0 FUEL ELEMENT DEVELOPMENT

7.1 Mechanical Development (Task 11-1XX)

Review - January through May:

a. Center Support Rod Tests (IB-2L): Previous tests indicated the center support rod would fail at 640 lb static tensile load. Recent impact tests on this part showed failure (fracture) at an impact energy of 6.2 ft-lb. This is equivalent to dropping a IB-2L fuel element 9.5 in. onto a non-resilient surface. The location and mode of failure of this part under laboratory conditions duplicated the failures of the IB-2L center support rod found at the GCRE site (Figure 7:1). It was concluded that failures of the center support rod at the GCRE could be the result of dropping the fuel elements into the reactor pressure tubes.

b. Roll Pin Tests (IB-2L): Laboratory impact tests were performed on the bell-hanger support assembly. The three roll pins of the assembly sheared and the bell and hanger displaced about 1/16-in. at an impact energy of 7.5 ft-lb (Figure 7:2). The failure of this assembly was typical of the failures found at the GCRE. It was concluded that either the action of the orifice removal tool at GCRE, or the thermal expansion of the inner liner (after failure of the expansion joint) could impart sufficient dynamic and static loads to produce such failures.

c. Modified Pin Bundle Tests (IB-2L): The modified pin bundle support, designed to replace the center support rod, was subjected to static and impact loading tests. This part failed at 800 lb static loading and 9.2 ft-lb impact energy. The part generally failed by deformation and rupture of the legs (Figure 7:3 and 7:4). One impact test, however, produced a fracture near the welded section at the upper end of the part (Figure 7:5). This modified support is about 50% stronger under impact conditions than the earlier design.

d. Insulation Development (IB-3L/IB-14R): Four types of commercially-available insulation are being investigated for use in the annulus between the inner and outer liners: Thermoflex (Johns-Manville); Refrasil (H. I. Thompson Fiberglass); Fiberfrax (Carborundum Corp.); and Tipersul (E. I. Du Pont De Nemours). Refrasil tape (0.015-in. thick x 1-3/8-in. wide) wrapped in three layers over the inner liner was easiest to assemble. Results from current studies indicate that the amount of minor constituents (boron, etc.) found in Thermoflex, Refrasil, and Tipersul are within the permissible range (< 0.25 wt% B_2O_3). The amount of burnable binder in the insulation varied from 4 to 6 wt% for all insulations tested. Refrasil was found to contain about 6 wt% moisture (water) in addition to about 4% burnable binder.

Accomplishments - June:

a. Inner Liner Buckling Test (IB-2L): The inner liner was mechanically stressed under compression to simulate restricted thermal expansion. The maximum static load for buckling occurred between 1200 and 1500 lb. The flange at the upper end of the inner liner either partially or completely ruptured in all cases after 3 to 5 completely reversed mechanical cycles. Other points of failure were noted at "weep hole" locations and at the upper spider positioning grooves.

b. The Center Support Rod (IB-2L): The center support rod was tested under compressive force. Buckling occurred between 800 and 900 lb.

c. Bell-Hanger Assembly (IB-2L): The bell-hanger assembly is being tested to determine the force required to separate the assembly after the roll pins are drilled out. Preliminary results indicate that this force is about 200 lb on a part previously subjected to thermal shocks. The test piece is being thermally shocked and cycled; further separation tests will be made after the thermal treatment.

d. Insulation Development (IB-3L/IB-14R): Tensile tests performed on Refrasil tape insulation showed the average load required to tear unused Refrasil (1-3/8-in. wide) tape was 34 lb. Tensile properties decreased 22.6% after the tape was subjected to 1400^{o}F for 500-hr; the average load required to tear the insulation then being 26.3 lb, and a linear shrinkage of about 4% was found.

An insulation package was assembled using 0.045-in. dia wire to separate the inner liner from the outer liner. The overall heat transfer coefficient for this model was the lowest of all insulating methods tried. The direct thermal conduction through the wire spacers from the inner to the outer liner creates hot spots on the burnable poison. This work is about 90% complete.

e. Outer Liner Spinning Development (IB-3L/IB-14R): A process is being developed for spinning the outer liner to an increased diameter to accommodate the permanent poison. One successful spinning run was made. The original tools and fixtures for this process are being modified.

Anticipated Accomplishments - July:

Work on IB-2L problems will be completed.

The insulation development program will be completed.

The outer liner spinning development will be completed.

7.2 Out-of-Pile Loop Testing (Task 11-2XX)

Review - January through May:

a. Fluid Flow Tests: Fluid flow tests were run on three proposed fuel element configurations for the IB-3L core. The configurations tested included: a twisted half-round turbulence promoter; a boundary layer turbulence promoter, and a shortened pitch for the normal spacer wires to increase turbulence. It was found that though each configuration had a friction factor greater than the friction factor for the basic ML-1 fuel element, the design in each case could be adjusted by increasing the free flow area so that the pressure drop across the proposed IB-3L element would be the same as for the ML-1 element.

Data from tests on twisted half-round turbulence promoter models indicate that pressure drop increases with increased twisting of the center pin; however, the spread between all models is very small (Figure 7:6). It is reasoned that the effect of the twisted pin is small because the turbulence produced is confined by the inner ring of pins. By the same reasoning, any heat transfer advantage would be confined to the same region, therefore, the design was dropped from further consideration.

The results of tests on models with shortened pitch of spacer wires are shown in Figure 7:7. Figure 7:7a shows that similar models with equal equivalent diameter have equal friction factors.

Tests on boundary layer turbulence promoters showed that for a given fin height, the friction factor increases with decreasing pitch; however, for a given pitch-to-height ratio, the friction factor decreases with fin height (Figure 7:8). From the work of V. Walker*, it is estimated that the correlation for friction factor would reach a peak at (x/d) = 4. For smaller (x/d) ratios the fins are so close together the flow probably does not re-attach between fins, therefore, the fins are submerged in a static, turbulent layer and are not effective.

b. Heat Transfer Tests: Heat transfer tests using the thermal capacitance discharge method were run on the same models as described for the fluid flow tests above. It was found that the only configuration which offered a significant temperature improvement (i.e., decrease in wall temperature for equivalent ML-1 operating conditions) was the boundary layer turbulence promoter. A temperature improvement of 80 F degrees was measured for this design. The configuration for IB-14R in-pile element was designed using the correlations found with these tests.

The results of a test with half-round turbulence promoters is shown in Figure 7:9. Using the correlation shown it was calculated that the temperature improvement for the pin wall would be only 20 F degrees. The results from the tests with shortened spacer wire pitches are shown in Figure 7:10. Using the correlation shown, it was calculated that the temperature improvement for the pin wall would be approximately 20 F degrees.

Since the boundary layer turbulence promoters showed the most promise, a large number of tests were done with these models in order to find an optimum design. The data from the early test was correlated versus pitch as shown in Figure 7:11. Using this correlation, the configuration for the IB-14R in-pile element was selected. A temperature improvement of 80 F degrees was measured for this configuration. As data from additional tests became available, it was found better to correlate the data versus the pitch-height ratio. With the additional data, it was determined that the configuration for IB-14R would be retained for IB-3L, and that geometrical tolerances of ± 0.001 in. on height would

*Walker, V., "The Improvement of Fuel Element Heat Transfer by Surface Roughing", Nucl. Engineering, p. 144, April 1961.

not cause a significant loss in the temperature improvement. The results of all the tests are shown in Figure 7:12.

c. Flow Visualization Study: A flow visualization study using a dye injection technique was made to understand the basic flow mechanisms of the boundary layer turbulence promoters. It was found that turbulence stalls occurred for distances of 1-1/2 fin heights up-stream and 4 fin heights down-stream of the fin. The flow re-attached at the end of the down-stream stall and a normal turbulent boundary layer developed until the next down-stream fin was approached. These phenomena are pictured in Figures 7:13 through 7:15. Round and rectangular fins were tested with no apparent difference in the results.

d. Mass Transfer Tests: The dye studies illustrated the flow patterns in the neighborhood of the turbulence promoter but did nothing to indicate the variations in heat transfer for the same area. Mass transfer tests were used to measure the axial variation of heat transfer on the faces of the turbulence promoters and in the region between promoters. It was found that the up-stream face had the highest transfer rate, 1.5 times the average in the region between promoters. The transfer rates on the top and down-stream faces were approximately the same as the average for the region between promoters. The data for a particular run are shown in Figure 7:16. The variation of transfer rate between promoters was roughly saw-toothed in shape as shown in Figure 7:17. A series of tests was run with the fin height held constant, the pitch being varied, and a second series of tests with the pitch constant but the height varying. In each ease, the general shape of the curve was the same and the maximum value always occurred four heights down-stream and the minimum value two heights up-stream of a fin. From these tests, it was concluded that the region where the transfer rate could be improved was the down-stream face. Tests to this end are being conducted.

e. Fuel Element Insulation Tests: Tests were run to measure the effectiveness of the fuel element insulation configuration. With the reference design it was found that the overall heat transfer coefficient, considering the resistance from the inside of the insulation liner to the moderator water, is 5.28 Btu/hr-ft^2-^{o}F at a liner temperature of 1000^{o}F. The coefficient increased with increasing temperature as shown in Figure 7:18. At 1000^{o}F liner temperature, the heat loss from the element is 1.1 kw. For those elements which include a poison shim between the element and the pressure tube, the heat loss is increased by 4%.

Refrasil insulation was tested in place of the reference, Thermoflex. It was found that the heat loss increased by 11%. This is relatively insignificant since the heat loss is only 2% of the heat generated, the additional heat loss would be only 0.2%. The Refrasil has some mechanical advantages. Other insulations are being tested.

Accomplishments - June:

Thermal tests on the IB-3L insulation liner were completed. Three insulation types were tested: Thermoflex, Refrasil, and radiation barrier with stagnant gas layer. The results of the tests are shown in Figure 7:19. Since the effective thermal conductances of all the types are approximately the same, the design for the IB-3L can be based on mechanical considerations.

Three mass transfer tests were made with models incorporating a ramp-shaped down-stream face on the boundary layer turbulence promoter. Three ramp angles were tried: 30^o, 14^o, and 8^o. The results are shown in Figure 7:6, 7:20 and 7:21. It is evident that the region of low heat transfer on the down-stream face can be eliminated by incorporating a ramp. The analysis and correlation of this data is continuing.

No heat transfer tests were completed using the thermal capacitance discharge method to determine the effect of temperature dependent properties due to erratic operation of the equipment. It was determined that long use had led to the gradual maladjustment of the equipment. Thermocouples were re-calibrated, pressure leaks were found and corrected, thermal leaks in insulation were located and corrected, and proof tests of the system are being run to ensure reproducible data.

A thermal test for the expansion joint between the fuel element inner and outer insulation liners is being designed.

Anticipated Accomplishments - July:

The data from all the mass transfer tests will be analyzed and correlated.

The effect of temperature dependent properties on the heat transfer correlation for the IB-3L element will be determined.

The M-1 model of the IB-4R in-pile element will be available 15 July for flow tests and flow control orifice calibration tests.

Equipment for the thermal test of the IB-2L element expansion joint will be procured and assembled and the tests run.

7.3 Materials Evaluation (Task 11-3XX)

Review - January through May:

a. Gas Corrosion Tests: Specimens of Hastelloy-X (reference alloy for fuel pins), Inconel and other promising nickel-based alloys were exposed to atmospheres of reference gas and air at 1750°F and 300 psi for durations to 10,000 hr. Preliminary data indicate that the maximum corrosion penetration of Hastelloy-X to be about 0.002-in. in either gas, after 10,000 hr in the reference gas. The average values for corrosion penetrations of Hastelloy-X heat No. X-4307 and Inconel are tabulated in Table 7-1. Figures 7:22 through 7:30 illustrate the microstructures of these alloys in the as-received, 5000 hr, and 10,000 hr corrosion conditions.

Corrosion testing of low cobalt (0.07% Co) Hastelloy-X indicated intergranular oxidation to a depth of 0.006-in. after 5000 hr in 1750°F air at 300 psi. In reference gas under similar conditions, internal oxidation was 0.0018-in. deep. Figures 7:31 and 7:32 show the microstructures of the low cobalt Hastelloy-X after these exposures.

Tensile tests were performed on the corrosion specimens at room temperature. Both Hastelloy-X and Inconel exhibited decreasing strength and ductility

TABLE 7-1 - AVERAGE DEPTH* OF MAXIMUM INTERNAL OXIDATION PENETRATION FOR SPECIMENS CORRODED AT 1750°F, 300 PSI

	Hastelloy-X		Inconel	
Exposure (hr)	Air	Ref**	Air	Ref**
1,000	0.0009	0.0007	0.0013	0.0013
2,500	0.0015	0.0012	0.0020	0.0016
5,000	0.0017	0.0015	0.0024	0.0018
7,500	----	0.0015	0.0030	0.0045
10,000	0.0020	0.0020	----	0.0075

* Plus oxide scale formed on surface (approximately 1.0 mil maximum) in inches.

** Reference coolant is 99.5 vol% N_2 + 0.5 vol% O_2.

and strength appeared to be adequate even after 10,000 hr. This data is tabulated in Table 7-2 on the following page.

b. Creep Tests: Creep tests were performed on Hastelloy-X specimens at 1750°F under stresses of 2000, 1500, and 1000 psi. Plots of elongation versus time were obtained. The secondary creep rates were found to be quite adequately fitted by the power law correlation:

$$\dot{\epsilon} = 6.55 \times 10^{-17} \sigma^{4.15}$$

where

σ = applied uniaxial stress (psi)

$\dot{\epsilon}$ = secondary creep rate (1/hr)

Figure 7:33 illustrates these data.

c. Fuel Oxidation Tests:

1. Defective Pin Tests: Tests were performed with UO_2 and BeO-UO_2 pellets encapsulated in Hastelloy-X tubing simulating the configuration of the ML-1 fuel pins. Holes (0.004-in. dia) were made in the cladding and the specimens held in 300 psi air and reference gas for up to 300 hr at 1800°F. Pressure fluctuations (± 2 psi at 5 sec intervals) were introduced to simulate reactor operation. The results of these tests are listed below:

1) Operation of defective fuel pins with air as a coolant will result in rapid oxidation of the UO_2 to U_3O_8 and swelling of the fuel pins.

2) Continued operation of the swollen fuel pins in air will accelerate oxidation of the cladding and cause spalling of the oxide scale.

3) Oxidation of a stack of fuel pellets is retarded by the swelling of pellets nearest the defect.

4) Oxidation of UO_2 pellets in air occurs at a faster rate than oxidation of BeO-UO_2 pellets.

TABLE 7-2 - AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES OF ALLOYS EXPOSED AT 1750°F

Exposure	Ultimate Tensile Strength, psi	0.2% Offset Yield Strength, psi	% Elongation
A. HASTELLOY-X			
As-Received	117,000	66,000	41
500 hr, Ref*	110,000	52,000	28
1000 hr,	114,000	54,000	30
2500 hr,	100,000	40,000	25
5000 hr,	112,000	51,000	29
7500 hr,	106,000	46,900	31
10,000 hr, Ref*	92,000	44,000	14
2500 hr, Air	98,000	49,000	31
5000 hr,	105,000	51,000	23
7500 hr,	104,000	45,000	23
10,000 hr, Air	94,000	45,000	20
B. INCONEL			
As-Received	90,000	34,000	46
2500 hr, Ref*	72,000	17,000	40
5000 hr, Ref*	75,000	26,000	40
7500 hr,	74,000	18,000	36
10,000 hr, Ref*	56,000	20,000	28
5000 hr, Air	62,000	30,000	31
7500 hr, Air	62,000	25,000	38
C. INCONEL-702			
As-Received	108,000	44,000	58
2500 hr, Ref*	111,000	61,000	24
5000 hr, Ref*	113,000	59,000	37
5000 hr, Air	120,000	68,000	25
10,000 hr, Air	88,000	44,000	25

* Reference coolant is 99.5 vol% N_2 + 0.5 vol% O_2

5) Oxidation of UO_2 and BeO-UO_2 in the reference gas occurs at a much slower rate than in air.

6) A leak at the top of the fuel pin will usually result in slightly faster oxidation than a leak at the bottom of the fuel pin because of the spacer void at the top of the fuel pin.

2. Coated Particle Fabrication: (Note: Coated particle fabrication is being performed by BMI under a separate contract with the USAEC. This task, however, maintains technical cognizance of the work.)

d. Hydrocarbon Fouling Test: Turbine oil was injected (to 2 wt%) into reference gas flowing at reference velocities over Hastelloy-X tubing heated to 1750°F. In short time periods (30 min), the turbine oil does not significantly affect the corrosion or microstructure of the tubing. No visible surface scale is formed on sample tubing specimens, but when a spiral spacer is wrapped around the tubing, a thin (approximately 0.0001-in. thick) scale forms in the stagnant flow areas underneath the wire (Figure 7:34).

e. Mechanical and Thermal Fatigue Tests:

1. Mechanical Fatigue Testing: Cyclic mechanical fatigue tests were performed by BMI on reference ML-1 fuel pin tubing at 1400°, 1600°, 1800°, and 2000°F and four different stress ratios. Ten hour creep tests were performed by Aerojet to support this work.

A final report prepared by Battelle is being evaluated by Aerojet.

The conclusion from this report was that stress-rupture failures are more pronounced than fatigue failures with increasing temperatures. Although this tubing was supposed to be from one heat of materials and made by the same manufacturing process, it apparently contained material from two batches, as the material fell clearly into two groups of widely differing strength characteristics. This situation underlines the necessity of obtaining material exhibiting the best strength properties.

2. Thermal Fatigue Tests: Finned tubing was exposed to 1000 thermal cycles between 300° and 1800°F without detrimental results. A longer-duration test was started on a finned tubing specimen. This test will investigate the possibility that a fin imposes a notch and will determine how well the fin resists corrosion effects under cycling.

e. Design and Fabrication Support: Samples of silver-plated stainless steel shims were tested for 23 hr at 600°F in 99.5 vol% N_2 + 0.5 vol% O_2 followed by water quenching and soaking at room temperature for one hour. Fifty cycles were completed without serious deterioration of the silver plating. A few small blisters appeared on the silver plating early in the testing, but the blisters had not enlarged or flaked at the completion of the test.

Two alloys were selected as backup materials for the present ML-1 reactivity shim of silver-plated stainless steel. The two alloys selected have the following compositions:

Cobalt Alloy (Nivco 10)

Co%	Ni%	Ti%	Zr%	Al%	Fe%	C%
73.5	22.5	1.8	1.10	0.22	0.30	0.20

Silver Alloy (Consil 995)

Ag%	Ni%	Mg%
99.55	0.2	0.25

Typical tensile properties of the two alloys are:

Cobalt Alloy (Nivco 10)

Temp, ^{o}F	Ultimate Tensile Strength, psi	0.2% Offset Yield Strength	Elongation in one inch, %
70	165,000	110,000	25
800	136,000	95,000	24
Silver Alloy (Consil 995)			
70	67,000	60,000	9
800	26,000	----	3

The cobalt and silver alloys are to be used in a thickness of 0.014-in. and 0.005-in., respectively. Enough of each alloy to fabricate the shims was ordered. Samples of the cobalt and silver alloys were obtained and the following evaluation tests were started:

1) Gas Corrosion Test: Exposure to ML-1 reference atmosphere at 300 psi and 800^{o}F for periods of 500, 1000 and 2500 hr. Samples of the silver-plated stainless steel that will be used for ML-1 shims were also included in this test.

2) Quench Test: Twenty-three hours at 600^{o}F in ML-1 reference gas followed by water quenching and "soaking" at room temperature for one hour.

3) Demineralized Water Corrosion: Sections of cobalt alloy and silver alloy were wired to AISI Type 316 stainless steel (outer liner material) to check for resistance to water corrosion at 200^{o}F and to determine effects of galvanic-type or crevice-type corrosion. This test will run for 500 hr.

Samples of the silver and cobalt alloy were given to a vendor for trial fabrication. Tests revealed both alloys can be easily fabricated to the necessary shape.

A sprayed alumina (Al_2O_3) coating was investigated for use in the expansion joint of the IB-14R experimental fuel element to help prevent galling and binding. Tests were initiated on samples of the alumina coating sprayed on small diameter Hastelloy-X tubing. The test consists of sliding a section of the alumina-coated Hastelloy-X tubing against AISI Type 316 stainless steel at 800°F. A light load is applied to the section with the alumina coating,and the assembly moves 1/8-in. per stroke at two strokes per minute.

Accomplishments - June:

a. Gas Corrosion Tests: Gas corrosion testing of Hastelloy-X and Inconel was continued at 1750°F in both air and reference gas to provide duplicate 10,000 hr exposure data. Specimens obtained during the month include a 10,000 hr air exposure sample of Nichrome V for use in the final evaluation of this alloy; and 1000 hr reference gas exposure samples of Inconel to provide additional data on this alloy.

Samples of gas from the exhaust of the reference gas corrosion furnace were obtained and submitted for analysis as part of the monitoring of these furnaces. Periodic dew point determinations continue to show dew points lower than -30°F.

An air screening test of five heats of Hastelloy-X containing various percentages of cobalt was terminated. This test was performed to attempt to relate the cobalt content of Hastelloy-X to corrosion rates.

b. Creep Tests: Specimens of two heats of Hastelloy-X tested for 1000 hr at 1750°F under a stress of 1000 psi were removed from the creep test machines and examined. A vacuum-melted heat (No. X-04085 containing 2.03% cobalt) had a 0.4% elongation in two inches and a 0.5% elongation in one inch. Heat No.E-9505 (0.28% cobalt) had 14.5% elongation in two inches and 24.2% elongation in one inch. This test demonstrates that the 2% cobalt alloy has significantly better creep strength at 1750°F than the 0.28% cobalt alloy.

c. Fuel Oxidation Testing: The out-of-pile IB-7T control specimen (see Task 18-1XX, Section 9.2) was removed from the test after a time corresponding to one GETR cycle. The specimen was examined by X-rays, measurements of the diameter, and metallography. The UO_2 pellet located adjacent to the leak was found to be swollen, but not sufficiently to bulge the cladding. Extensive cracking of the UO_2 was noted. Figure 7:35 shows a section of the specimen taken through the defect. The microstructure of the Hastelloy-X cladding was unaffected (Figure 7:36).

d. Fatigue Tests:

1. Defective Pin Testing: A Hastelloy-X tubing specimen, machined with turbulence promoters, failed after about 8400 thermal cycles between 1800°F and about 300°F. This corresponds to about 700 hr, primarily at 1800°F, with one cooling cycle every five minutes. This failure is attributed to a combination of thermal fatigue and oxidation by the air. The corrosion is accelerated by thermal shocking which causes the oxide scale to spall.

2. Coated Particle Fabrication: (Note: Coated particle fabrication is being performed by BMI under a separate contract with the USAEC. This task, however, maintains technical cognizance of the work.)

e. Design and Fabrication Support: In the corrosion test on alternate ML-1 reactivity shim materials (wherein the cobalt and silver alloys were cycled between 600°F and a water quench) the cobalt alloy developed a green corrosion product on the surface but the silver alloy was unaffected.

The 500-hr gas corrosion tests in the ML-1 reference atmosphere at 800°F and 300 psi was completed. There was no appreciable weight gain or loss for any of the samples, as shown below.

	Original Weight (grams)	500 hr Exposure Weight (grams) (avg of 3 samples)
Silver Alloy	2.0087	2.0089
Cobalt Alloy	1.5427	1.5447
Silver-plated stainless steel	1.7366	1.7380

The thickness of the samples did not change. A non-adherent scale formed on the cobalt alloy that flaked off easily. The surface of the silver alloy was slightly tarnished, but no visible scale was formed.

The water corrosion test in 200°F demineralized water for 500-hr was completed. The silver alloy showed no effects. The cobalt alloy showed some slight evidence of crevice corrosion and a few spots of discoloration.

Because of the poor resistance to scaling of the cobalt alloy, samples of the cobalt alloy were obtained with a coating of chromium plate 0.0001- to 0.0003-in. thick. The oxidation resistance of the chromium should reduce formation of scale at 800°F. Samples of the chromium-plated cobalt alloy were included in the gas corrosion test (ML-1 reference atmosphere at 300 psi and 800°F). Also included in the gas corrosion test is a section of AISI Type 316 stainless steel clamped to a section of silver alloy. This test will determine if there is a bonding tendency between an outer liner of the fuel element and a silver alloy shim.

A drawing of the ML-1 shims with silver and cobalt alloys was released.

The test of the alumina coating for the expansion joint completed 1000 cycles. There is no apparent wear on the alumina coating. The scale that forms on the AISI Type 316 stainless steel at 800°F rubbed off where it was in contact with the alumina coating.

Three sample inner liners of AISI Type 316 stainless steel were fabricated with the expansion joint configuration that utilizes the alumina coating.

Anticipated Accomplishments - July:

a. Gas Corrosion Tests: Specimens obtained from the screening in air of Hastelloy-X heats containing various cobalt percentages will be evaluated by metallographic examination. Attempts will be made to relate corrosion resistance with cobalt content. A 1000-hr screening run of these alloys in the reference gas at 1750°F will be completed.

Operation of the reference gas and air corrosion tests will continue in order to develop additional 10,000-hr corrosion data on Hastelloy-X and Inconel in both the reference gas and air during the latter part of August.

b. Creep Tests: Specimens from two Hastelloy-X heats which were examined after 1000 hr at 1750°F with a 1000 psi stress will be creep tested under these same conditions until rupture. This will provide a confirmation of the secondary creep rate and the time to rupture.

c. Fuel Oxidation Tests: Out-of-pile testing of the IB-7T BeO-UO_2 defected pin will be terminated after eight weeks (two GETR cycles).

The oxidized pellet from the out-of-pile IB-7T-1 control test will be submitted to a vendor for determination of the U/O ratio. Metallographic examination of the oxidized UO_2 pellet from this test will be completed.

d. Thermal Fatigue Tests:

1. Defective Pin Testing: Thermal fatigue testing will be performed on a Hastelloy-X tube specimen with turbulence promoters. The thermal cycling conditions will be the same as performed in May, but the specimen will be examined after 250 hr.

e. Design and Fabrication: The gas corrosion test will continue. One-thousand-hour tests will be completed on the shim materials.

The alumina coating will be sprayed on the expansion joint section of the inner liners and the joint will be assembled and tested.

The test results for 10,000 cycles on the alumina coating versus AISI Type 316 stainless steel at 800°F will be available.

The 500-hr gas corrosion tests on the chrome plated cobalt alloy will be completed.

7.4 Process Development (Task 11-4XX)

Review - January through May:

Material specifications for Hastelloy-X fuel pin tubing for IB-3L fuel elements were compared to known capabilities of vendors. Exceptions in material composition can be met by using one selected heat of material. Metallurgical requirements will be improved by close liaison with the vendor. Flaw defect size of 5% of wall thickness cannot be guaranteed by the vendor. Improvement from 10% defect size to 5% will be by inspection and sorting at Aerojet.

Silver-plated reactivity shims for the ML-1 were fabricated and passed the inspection methods developed during trial runs. (Additional studies of alternate materials and corrosion are reported earlier in this report.)

A mock-up of the ML-1 pressure vessel tube sheet was designed and fabricated to aid the final inspection of ML-1 fuel elements. This mock-up modifies the fuel element inspection gage to include the welded joint between the pressure vessel tube sheet and tubes. The modified inspection gage allows inspection of ML-1 shims with the ML-1 fuel elements.

Thermocouples were brazed into fuel pins as required for instrumented fuel elements. Helium leak tests determined all joints to be satisfactory without rework.

A procedure for installing ML-1 orifices was prepared, tested, and released.

Orifices for use in IB-2L fuel elements were redesigned to eliminate problems of orifices not seating and falling out, and orifices sticking, thus requiring high insertion or removal loads. Re-orificing problems with sticking orifices are believed to be responsible for some of the damages to the IB-2L power fuel element.

Process development for the IB-14R fuel element began with fabrication of turbulence promoters. Turbulence promoters are ground into the outer surface of Hastelloy-X fuel pin tubing by thread grinding techniques. Development of the grinding process was completed. Methods for detecting grinding flaws were developed and the equipment was set up. Process development for the IB-14R was started for welding fuel pin end plugs, brazing fuel pin thermocouples, inspection, and tooling.

Mechanical design and operational problems with IB-2L fuel elements were studied and repair plans were begun. Four problem areas were studied: nut broken off support rod; failed roll pins in hanger, and hanger separated from bell; fuel pin points out of lower spider; and dents in outer liner. Examples of these problems are shown in Figure 7:37. Inspection of elements in the hot cell, laboratory testing, inspection of elements at the GCRE test site, and design review are the techniques used to define the problems. Nuts broken from support rods are believed to result from forces applied while handling and re-orificing. A modified pin bundle support will be installed. Hangers probably separate from bells because the differential thermal expansion between the liners is not adequately absorbed by the expansion joint in the lower part of the element. This expansion also lifts the pins out of the lower spider. The pin bundle in the future will be lowered by using the modified pin bundle handling tool with the nuts removed from the hanger rod to allow free upward expansion of the inner liner. Dents in the outer liner result from handling; improved handling tools were fabricated.

Accomplishments - June:

Process development for IB-14R continued. Development of fuel pin end plug welding and instrument fuel pin brazing is complete (Figure 7:38). Trial runs, using parts from production orders, will continue in order to refine the process parameters. Fuel pin end plugs are welded at 42 amp for 17 seconds. Welding time was increased from 16 to 17 seconds to provide complete overlap. Slope time is 20 seconds. Thermocouples are brazed at a setting giving a meter reading of 4.5 amp.

An improved method of fabricating thermocouple splices has been completed. Splices are being fabricated for testing to determine the limiting service conditions. Figure 7:39 shows the six steps of the splicing method.

Inspection of IB-2L fuel elements in the hot cells continued. Liner expansion joints on IB-2L-2, -33 and -53 were examined and found to be operable at room temperature. The top flanges of the inner liner on these elements appear to have separated from the bell. Spot welds were broken and the flange on IB-2L-2 is cracked.

Repairs to IB-2L elements will be made next month. Procedures were written and tools fabricated. Tool checkout and trial runs are in process. The first repair will include installation of the modified pin bundle support to lower the pin bundle 1/8 in. and provide support where the support rod nuts have broken and removal of the remaining support rod nuts.

Anticipated Accomplishments - July:

Testing of fuel element liner expansion joints will continue.

Modification procedures for the ML-1 core will be planned and written.

Trial runs on production parts for process development and assembly development for IB-14R-a fuel elements, thermocouple harness and water seal bushing will continue.

Testing will be completed and process procedure for thermocouple splicing will be written.

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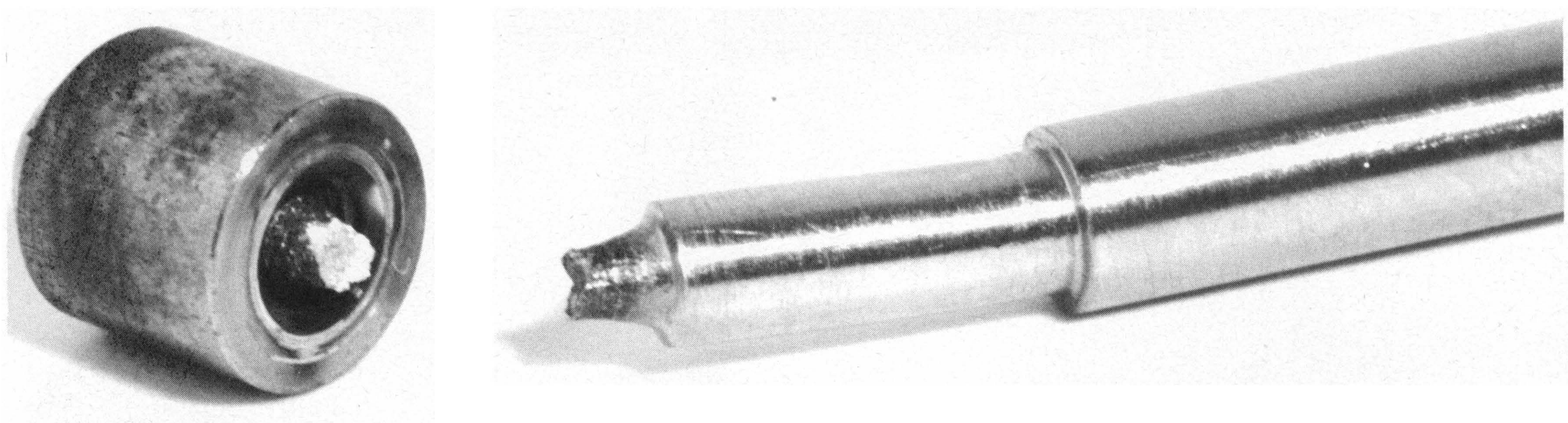
6. Hall, W.B., "Heat Transfer in Channels Composed of Rough and Smooth Surfaces," IGR-TN/W-832, UKAEA, 1958.

ORIGINAL IB-2L CENTER SUPPORT ROD



IMPACT LOADING OF 6.2 FT-LB OF KINETIC ENERGY CAUSED FAILURE AT THREAD RELIEF SECTION

FIGURE 7:1

IB-2L ROLL PINS - IMPACT SHEARING TEST

COMPLETE SHEARING OF ROLL PINS NOTED AT 1440 LB (DYNAMIC); 7.5 FT-LB KINETIC ENERGY

FIGURE 7:2

STATIC LOAD TESTS ON IB-2L PIN BUNDLE SUPPORT

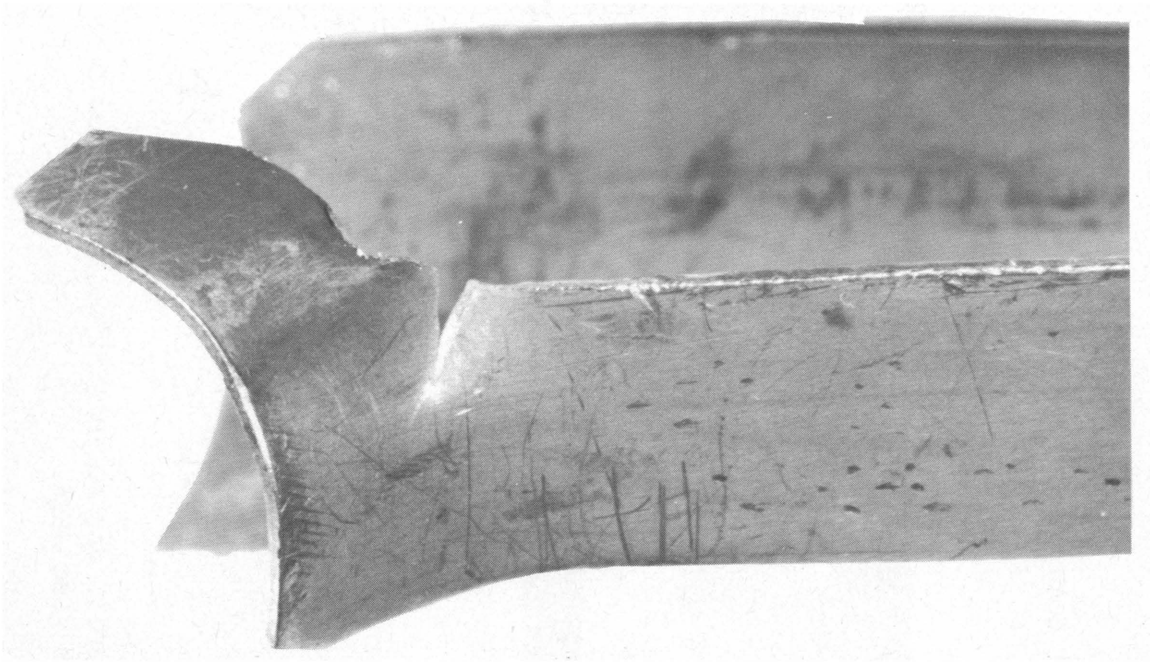


FIGURE 7:3 RUPTURE OF LEG OCURRED AT APPROXIMATELY 800 LB.

IB-2L PIN BUNDLE SUPPORT

FIGURE 7:4 RUPTURE AND DEFORMATION OF ALL THREE LEGS WAS NOTED AT 2,160 LB (DYNAMIC); 9.2 FT-LB KINETIC ENERGY.

IB-2L PIN BUNDLE SUPPORT - IMPACT LOAD TESTING

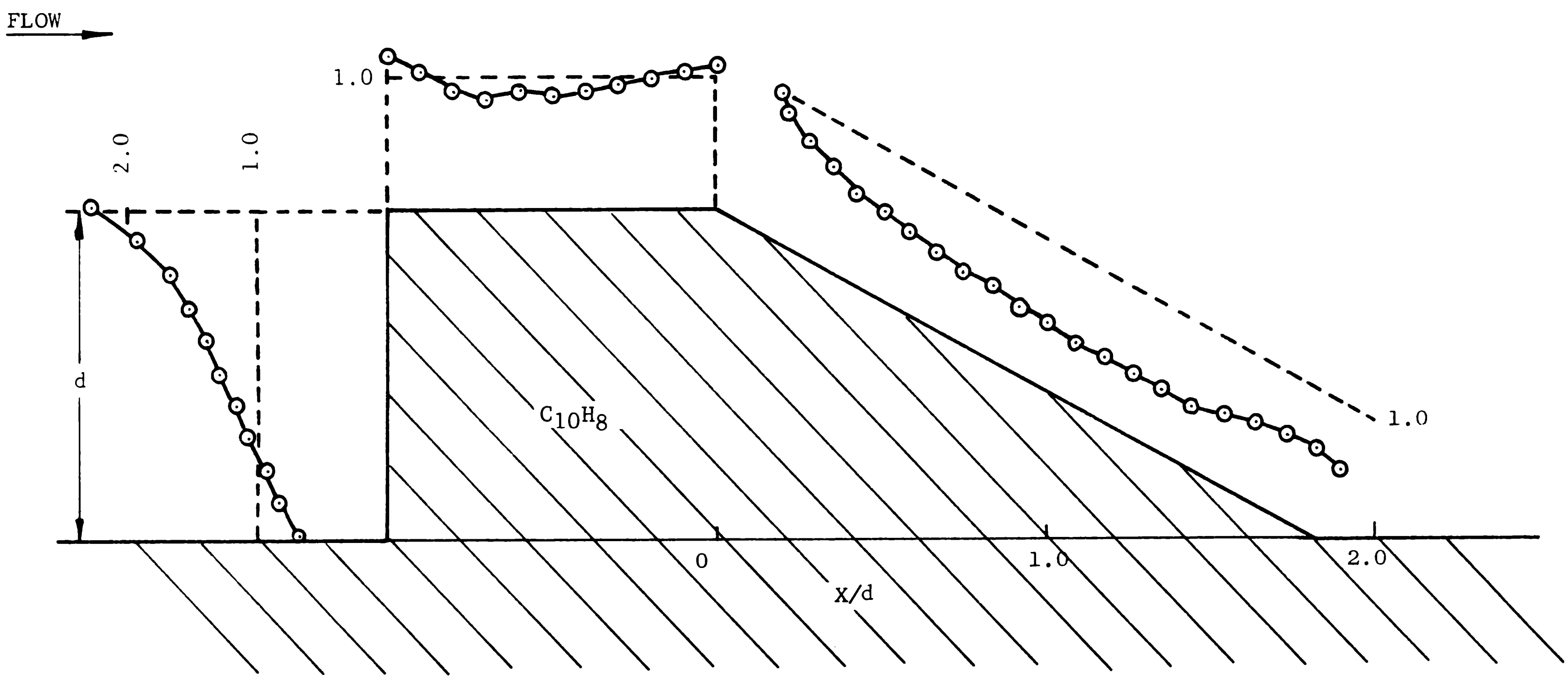
RUPTURE AND DEFORMATION OF UPPER SUPPORT RING NEAR WELD JOINT WAS NOTED AT 2160 LB (DYNAMIC); 9.2 FT-LB KINETIC ENERGY. DEFORMATION OF LEGS AND FEET IS ALSO SEEN.

FIGURE 7:5

TWISTED HALF-ROUND TURBULENCE PROMOTERS

MASS TRANSFER TEST NO. 6
NORMALIZED TRANSFER COEFFICIENT *
ANNULAR FLOW - CIRCULAR FINS ON INNER SURFACE

DIA. OF INNER ROD (in.)	= 2.50	⟶ 0.250	EQUIVALENT
ANNULAR SPACE (in.)	= 0.500	⟶ 0.050	EQUIVALENT
FIN HEIGHT, d, (in.)	= 0.125	⟶ 0.0125	EQUIVALENT
FIN PITCH, X, (in.)	= 0.250	⟶ 0.250	EQUIVALENT
RAMP LENGTH (in.)	= 0.224	⟶ 0.224	EQUIVALENT



*NORMALIZED WITH RESPECT TO FRONTAL, TOP, AND RAMP SURFACES.

FIGURE 7:6

COMPARISON OF FRICTION FACTORS

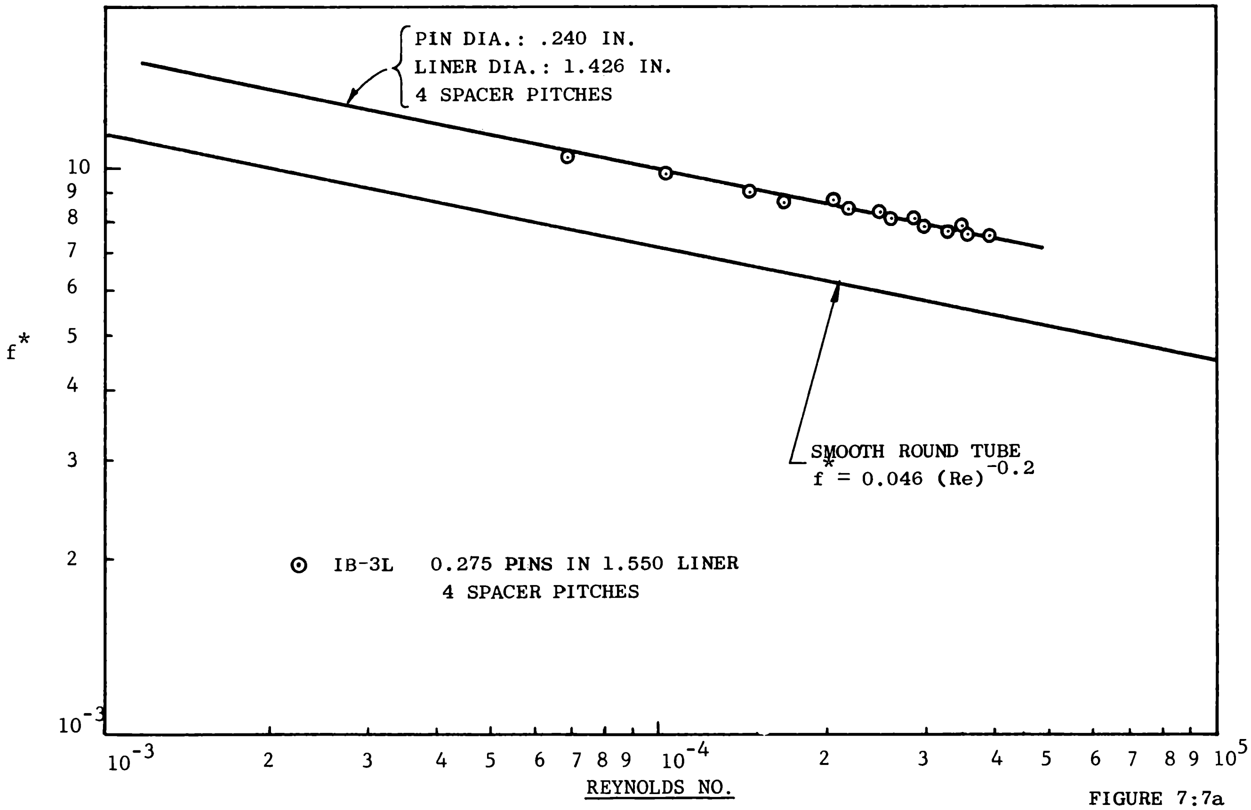


FIGURE 7:7a

MODELS WITH SMOOTH PINS

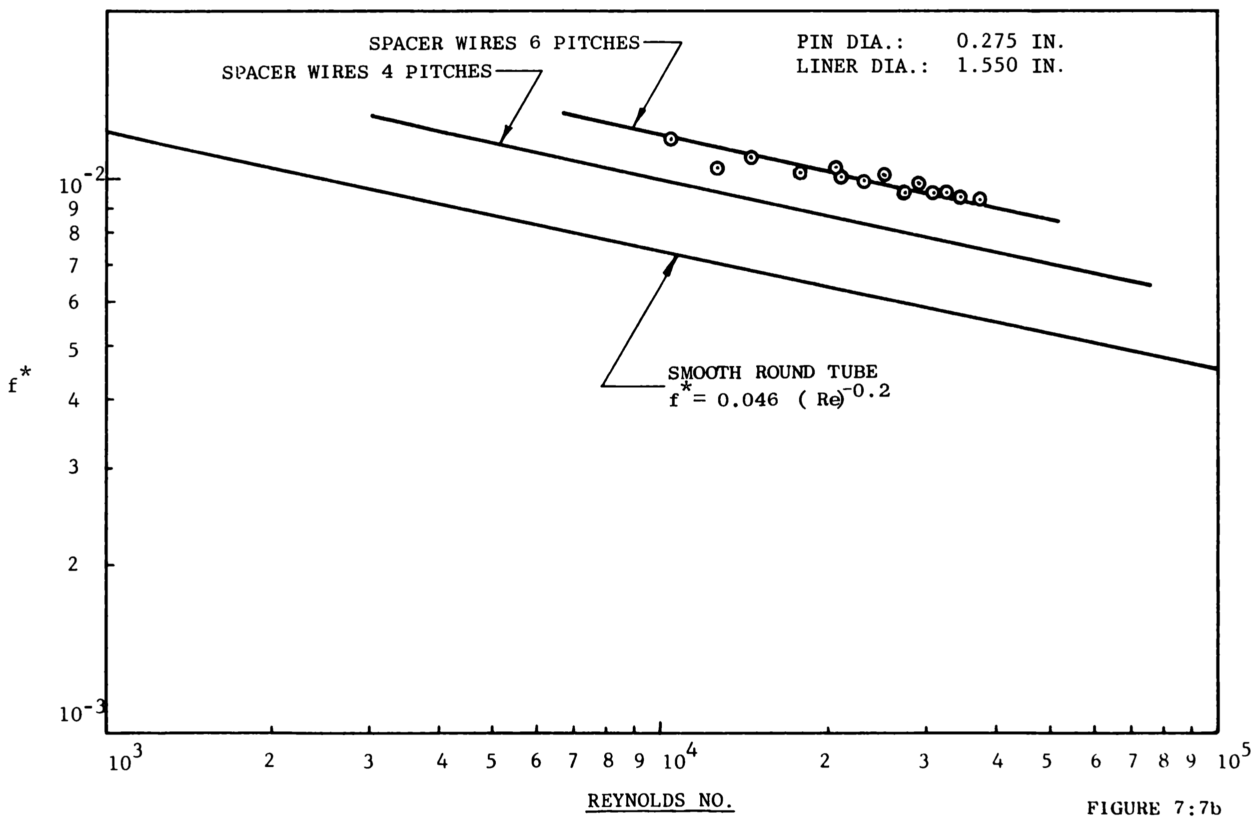


FIGURE 7:7b

FRICTION FACTORS FOR EXTENDED SURFACE MODELS

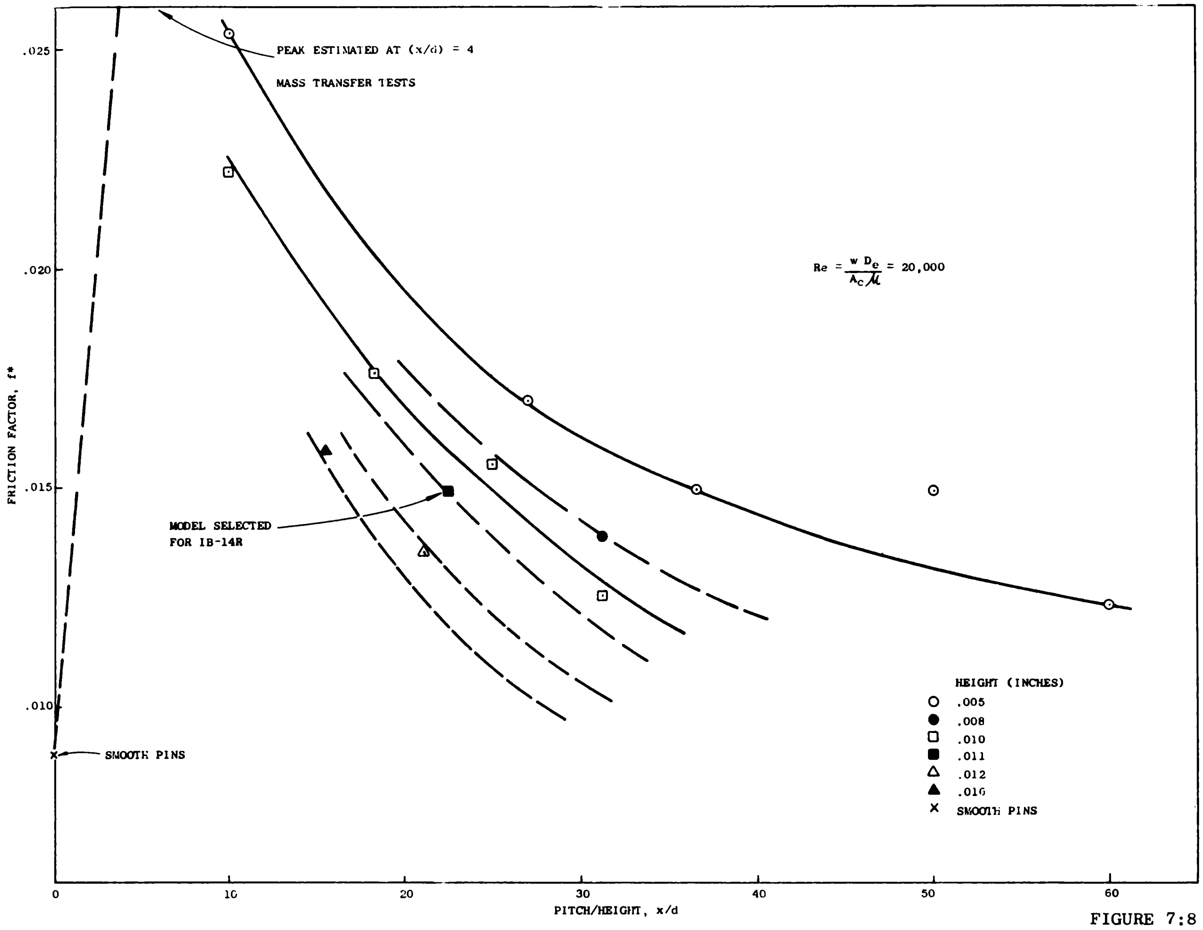


FIGURE 7:8

HEAT TRANSFER CORRELATION FOR MODEL WITH TURBULENCE PROMOTER P/D = 5

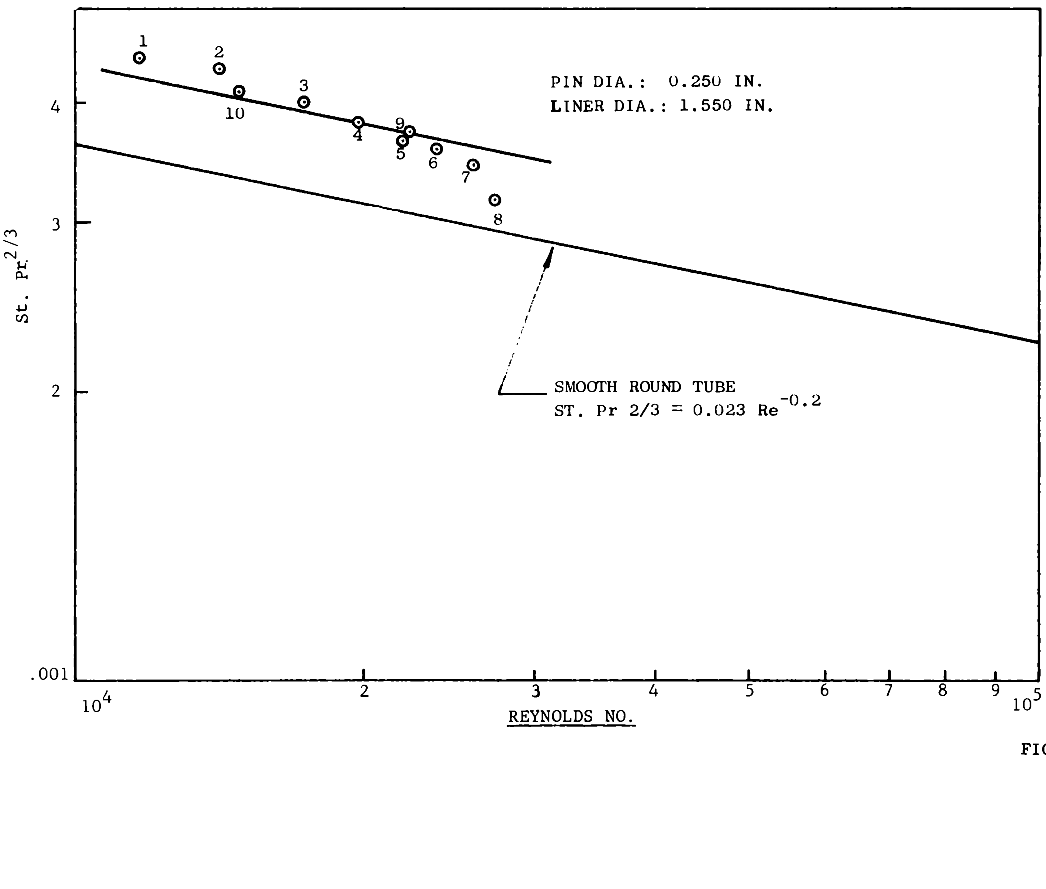


FIGURE 7:9

HEAT TRANSFER CORRELATION FOR
SMOOTH PIN MODEL WITH 6 SPACER PITCHES

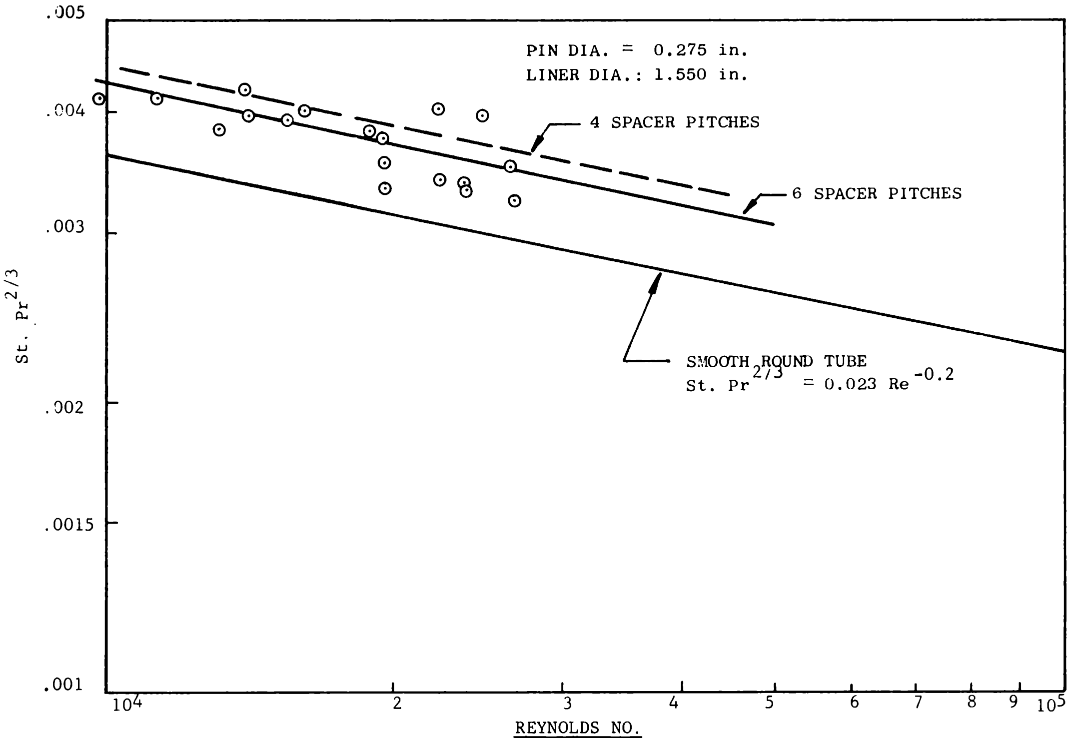


FIGURE 7:10

HEAT TRANSFER CORRELATIONS FOR MODELS WITH FIXED PITCH (.250") AND VARIABLE HEIGHT FINS

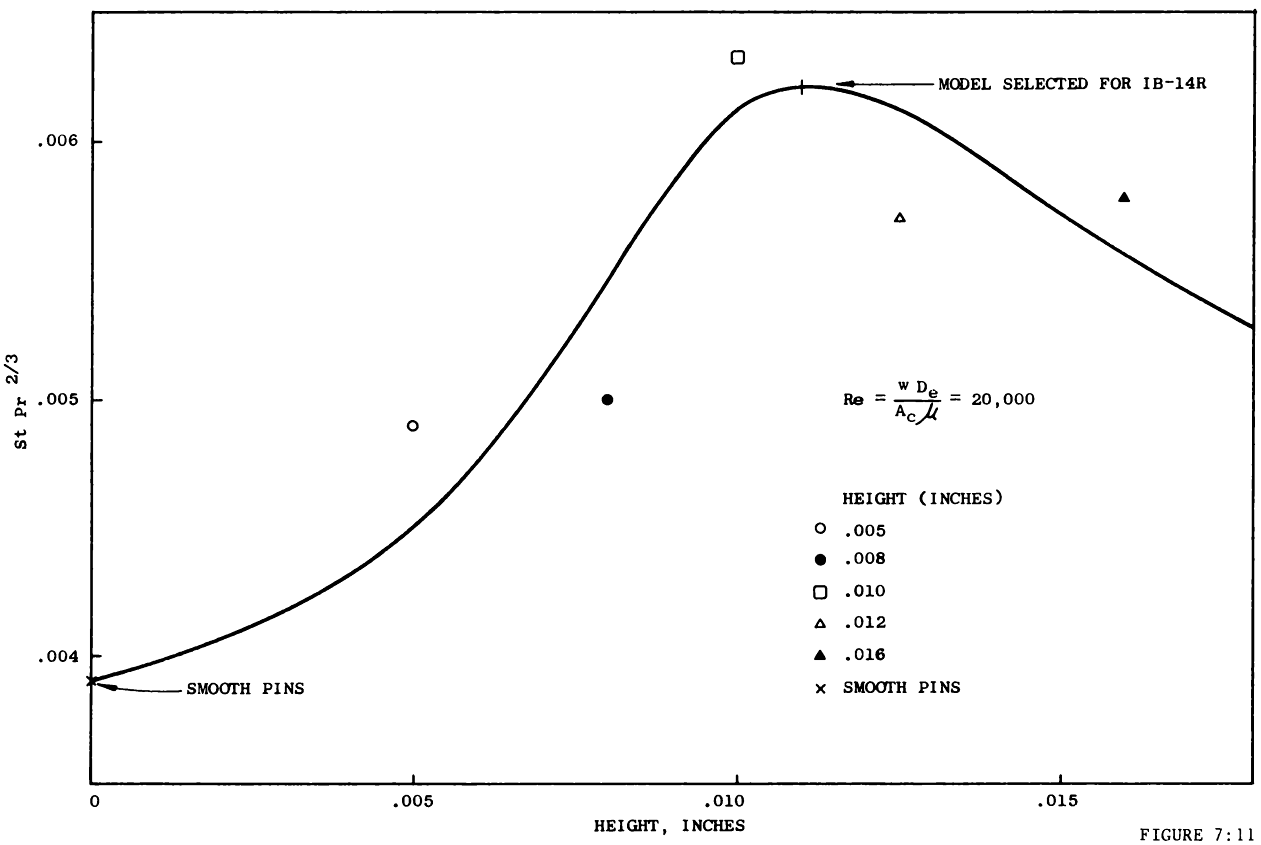


FIGURE 7:11

COMPARISON OF HEAT TRANSFER CORRELATION FOR EXTENDED SURFACE MODELS

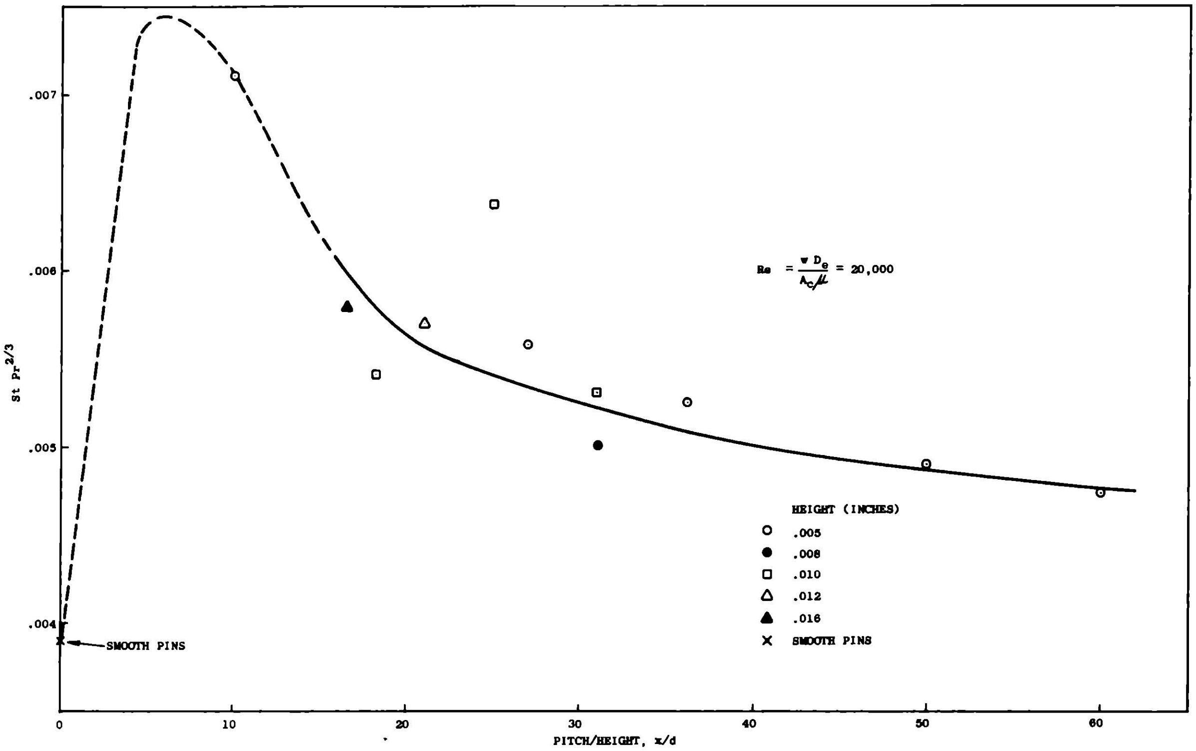


FIGURE 7:12

DYE VISUALIZATION OF DOWNSTREAM STALL - SIDE VIEW

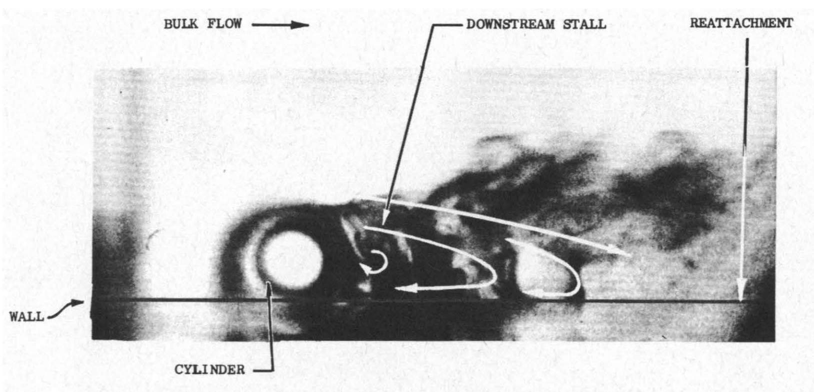


FIGURE 7:13

TURBULENT MIXING BETWEEN BOUNDARY LAYER AND BULK FLOW - SIDE VIEW

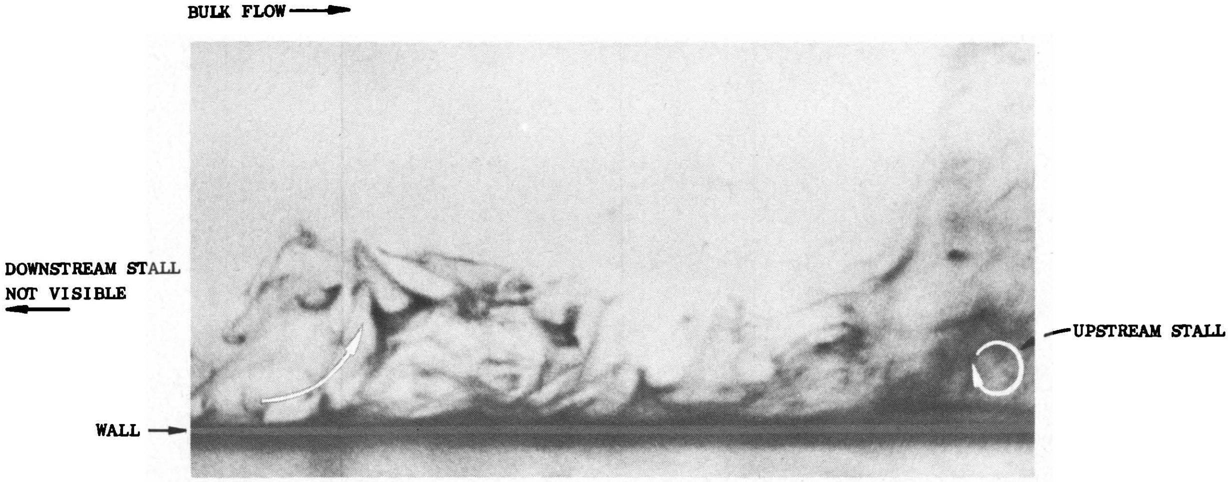


FIGURE 7:14

DYE VISUALIZATION OF UPSTREAM CYLINDER STALL - SIDE VIEW

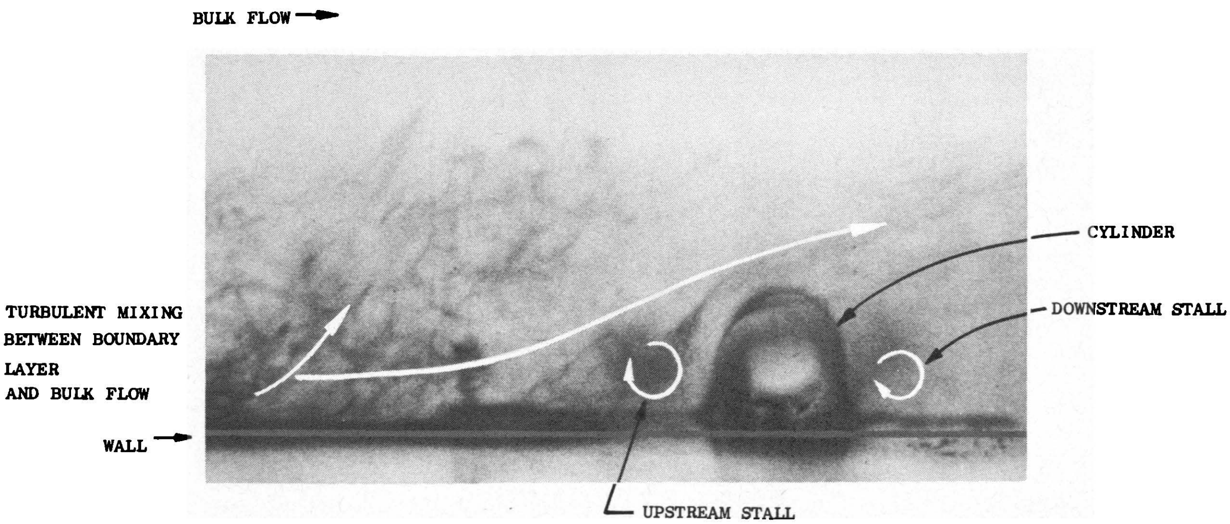


FIGURE 7:15

VARIATION OF TRANSFER COEFFICIENT AROUND FIN PROFILE

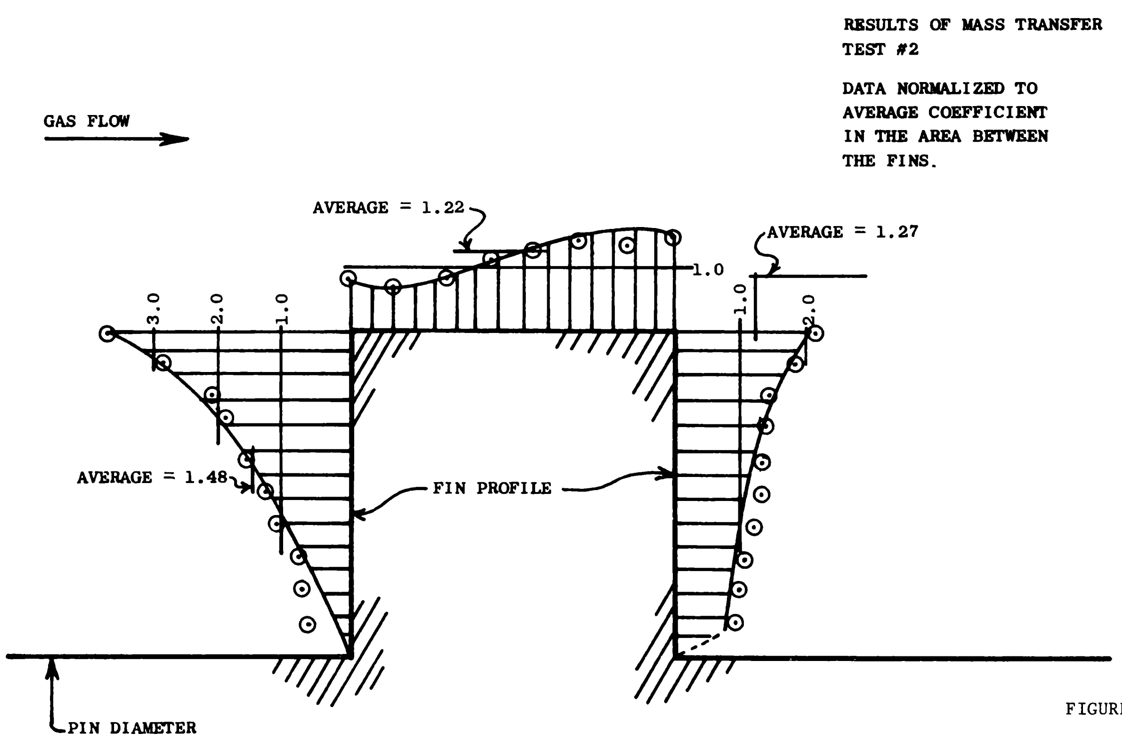


FIGURE 7:16

AXIAL VARIATION OF TRANSFER COEFFICIENT BETWEEN EXTENDED SURFACES*

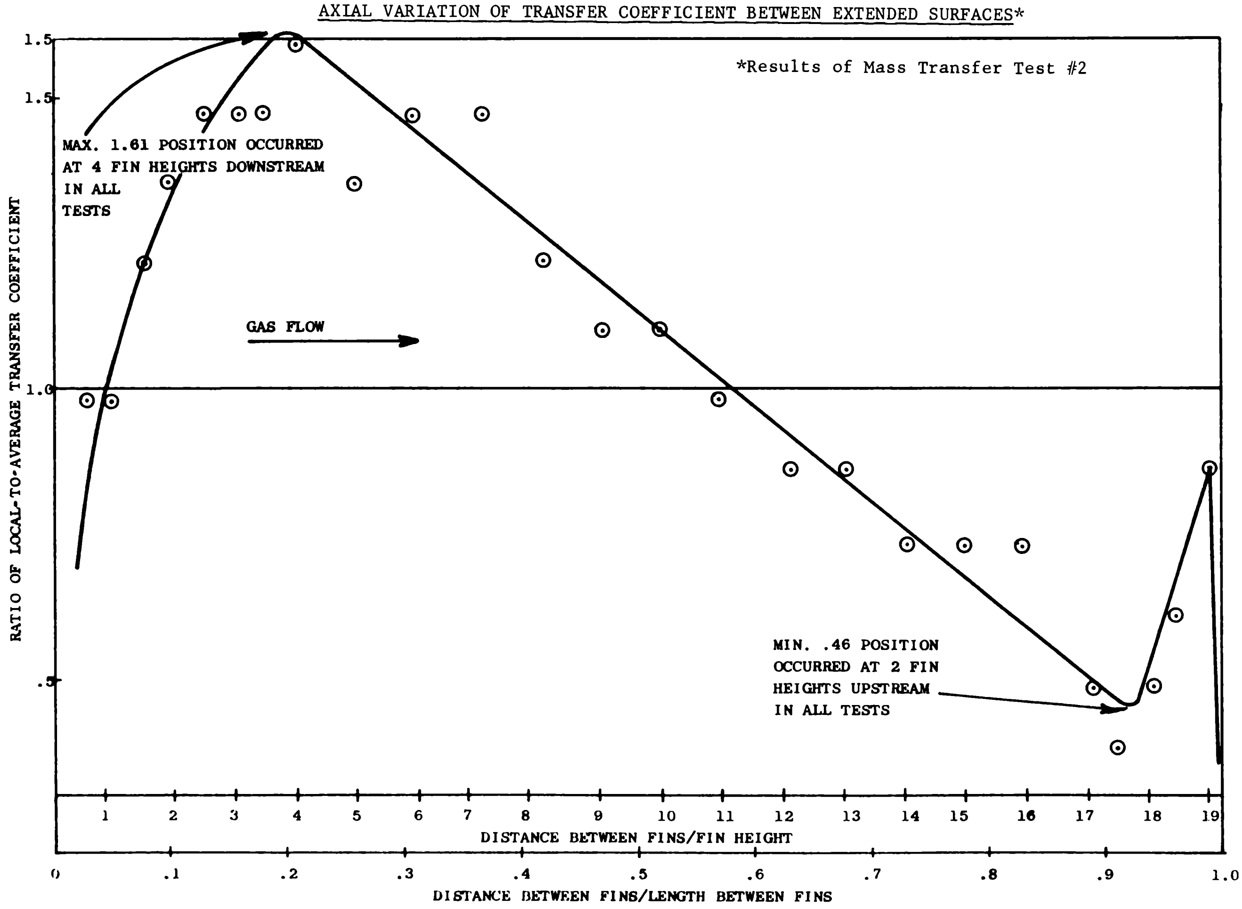


FIGURE 7:17

WATER HEAT FLUX

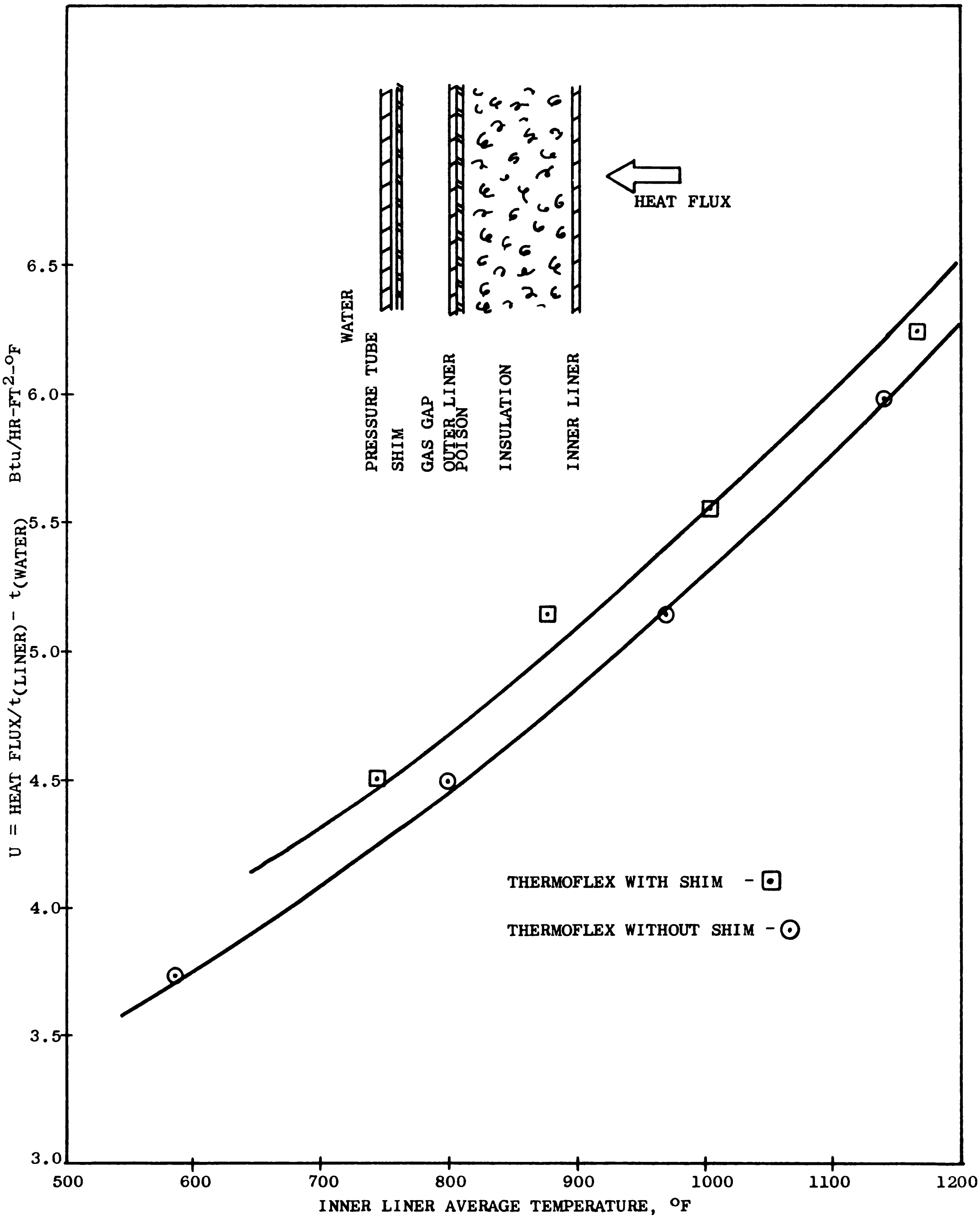


FIGURE 7:18

OVERALL CONDUCTIVITY OF SEVERAL INSULATION ASSEMBLIES

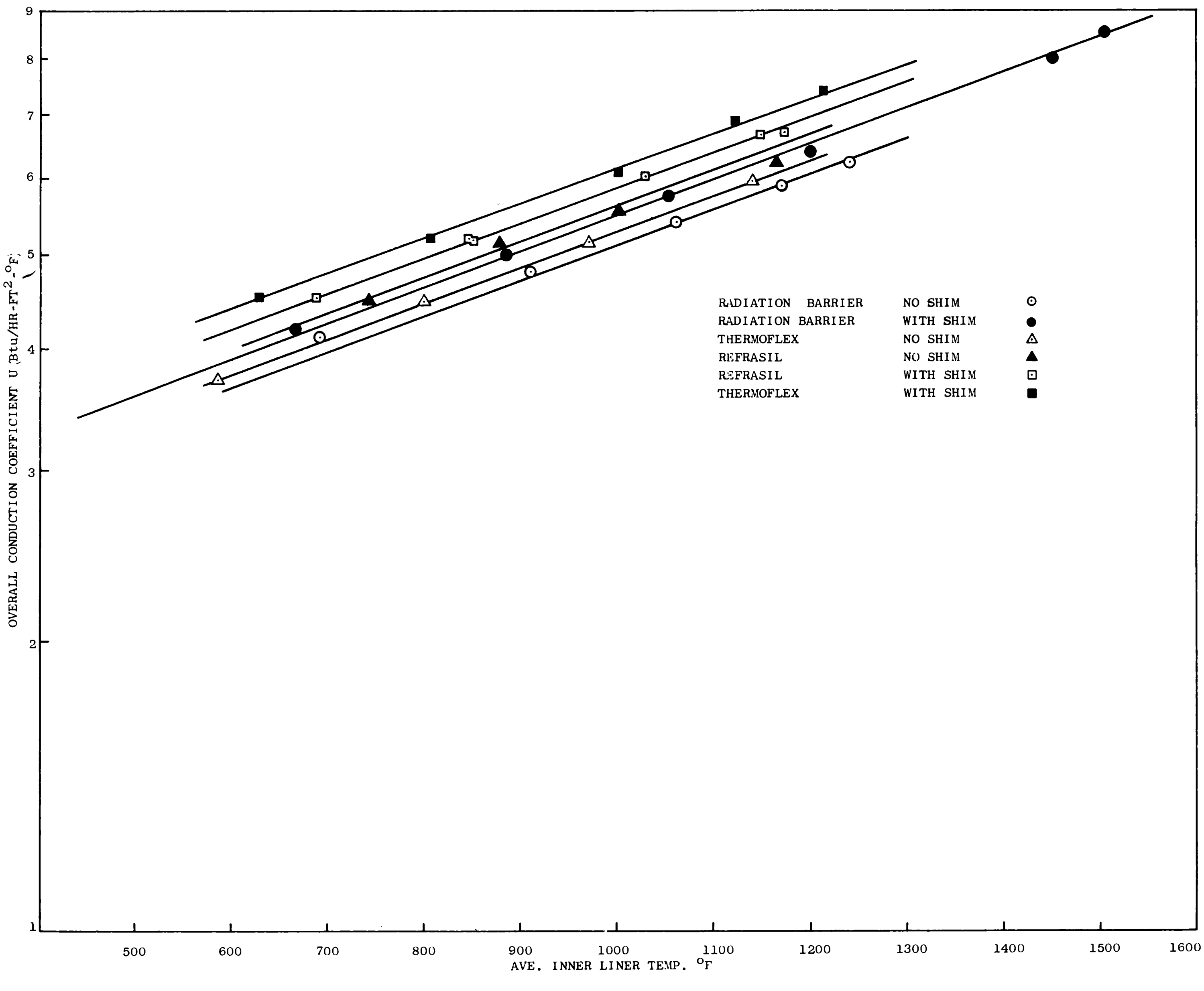
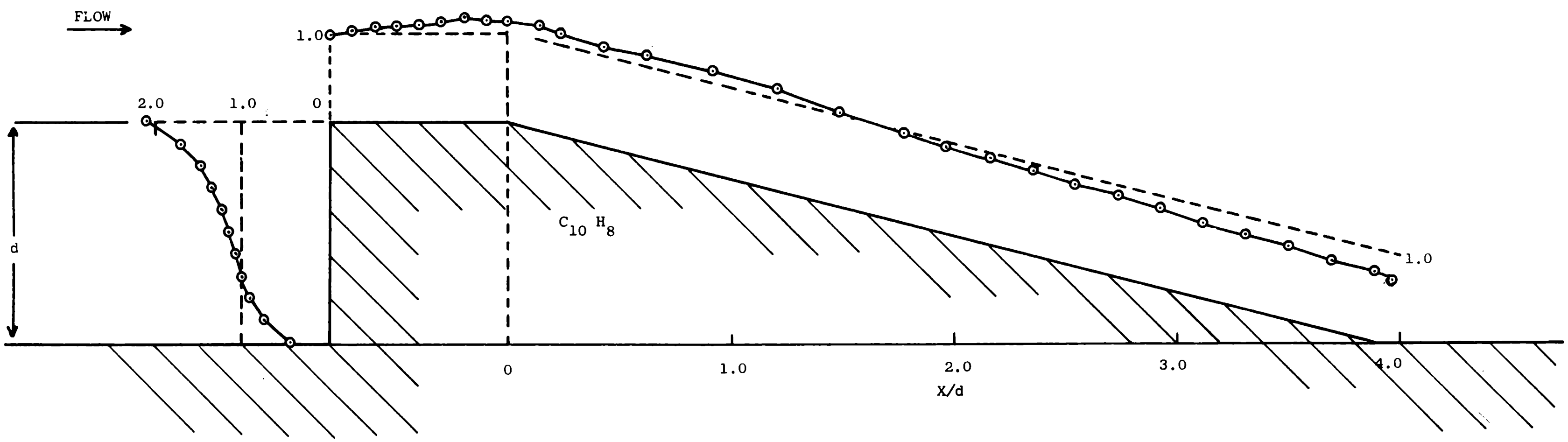


FIGURE 7:19

MASS TRANSFER TEST NUMBER 7 NORMALIZED TRANSFER COEFFICIENT*

ANNULAR FLOW - CIRCULAR FINS ON INNER SURFACE

DIA. OF INNER SPACE	:	2.50" → 0.250" EQUIVALENT
ANNULAR SPACE	:	0.500" → 0.050" EQUIVALENT
FIN HEIGHT, d_1	:	0.125" → 0.0125" EQUIVALENT
FIN PITCH, X_1	:	2.500" → 0.250" EQUIVALENT
RAMP LENGTH	:	0.516 → 0.0516" EQUIVALENT



* NORMALIZED WITH RESPECT TO FRONTAL, TOP, AND RAMP SURFACES.

FIGURE 7:20

MASS TRANSFER TEST NO. 8 NORMALIZED TRANSFER COEFFICIENT

ANNULAR FLOW - CIRCULAR FINS ON INNER SURFACE

DIA. OF INNER ROD	=	2.50" ⟶ 0.250"	EQUIVALENT
ANNULAR SPACE:	=	0.500" ⟶ 0.050"	EQUIVALENT
FIN HEIGHT, d_1	=	0.125 " ⟶ 0.0125"	EQUIVALENT
FIN PITCH, x_1	=	2.500" ⟶ 0.250"	EQUIVALENT
RAMPLENGTH	=	0.920" ⟶ 0.092"	EQUIVALENT

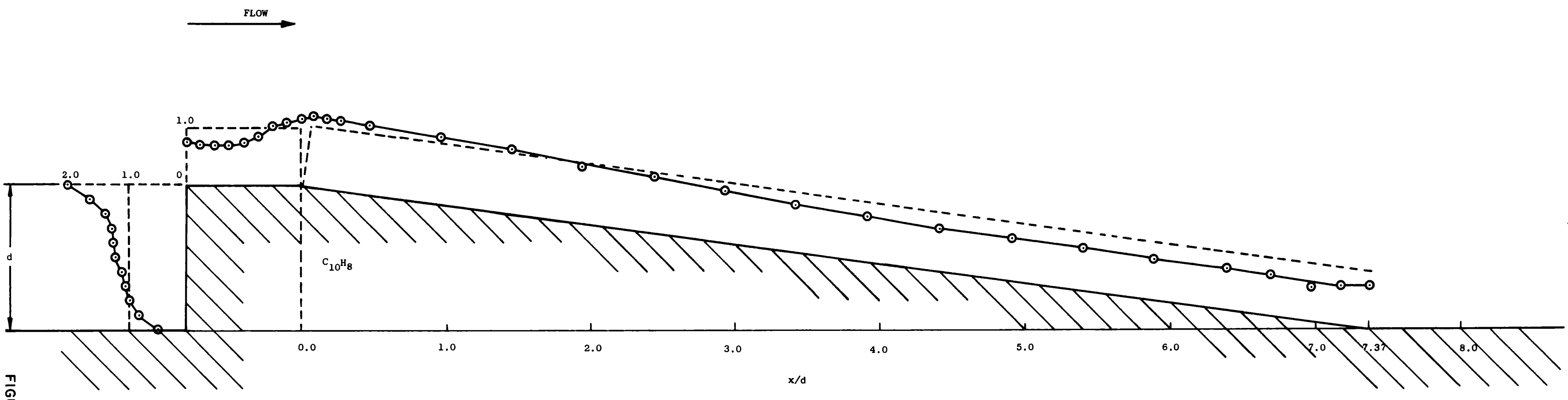


FIGURE 7:21

* NORMALIZED WITH RESPECT TO FRONTAL, TOP AND RAMP SURFACES.

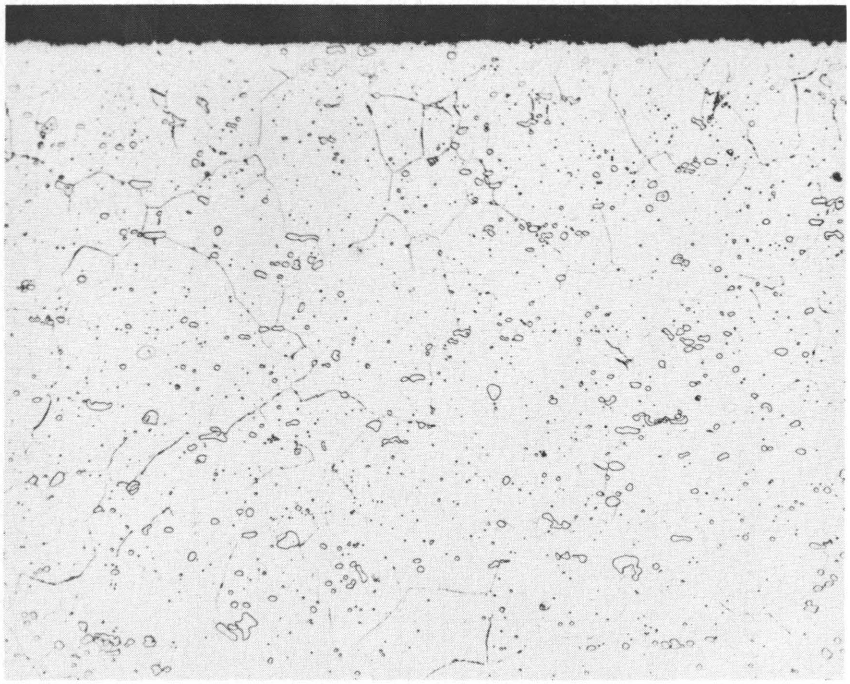


FIGURE 7:22. HASTELLOY-X SOLUTION HEAT TREATED (AS RECIEVED) X250

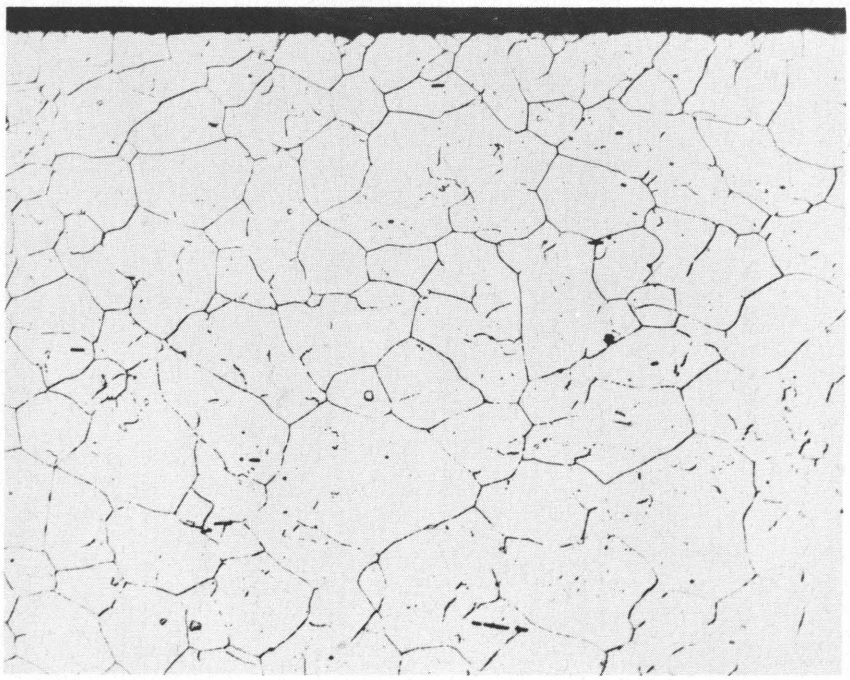


FIGURE 7:23. INCONEL ANNEALED (AS RECIEVED) X250

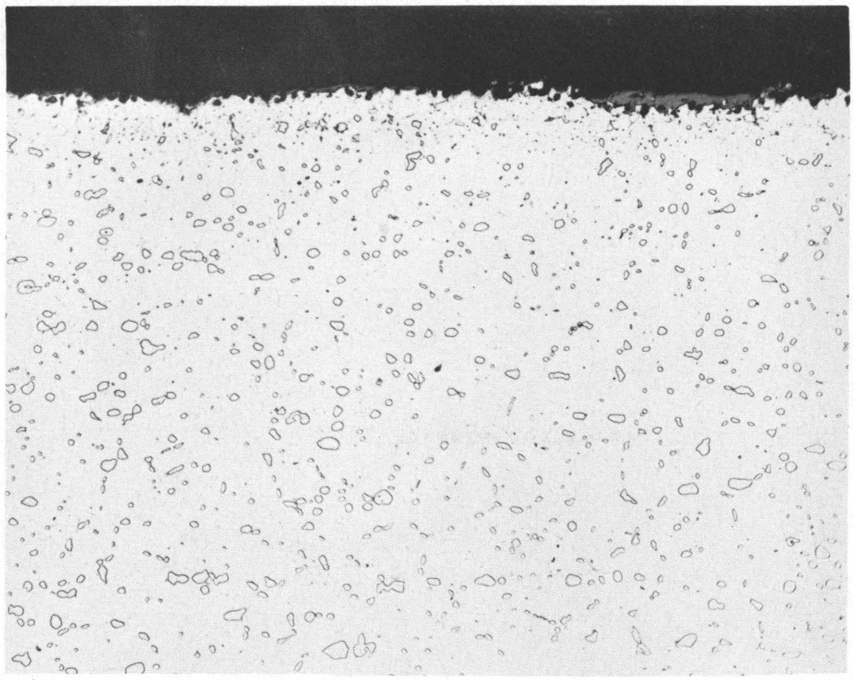


FIGURE 7:24. HASTELLOY-X: 5,000 HOURS AT 1750°F IN. 99.5 VOL% N_2 + 0.5 VOL% O_2 X250

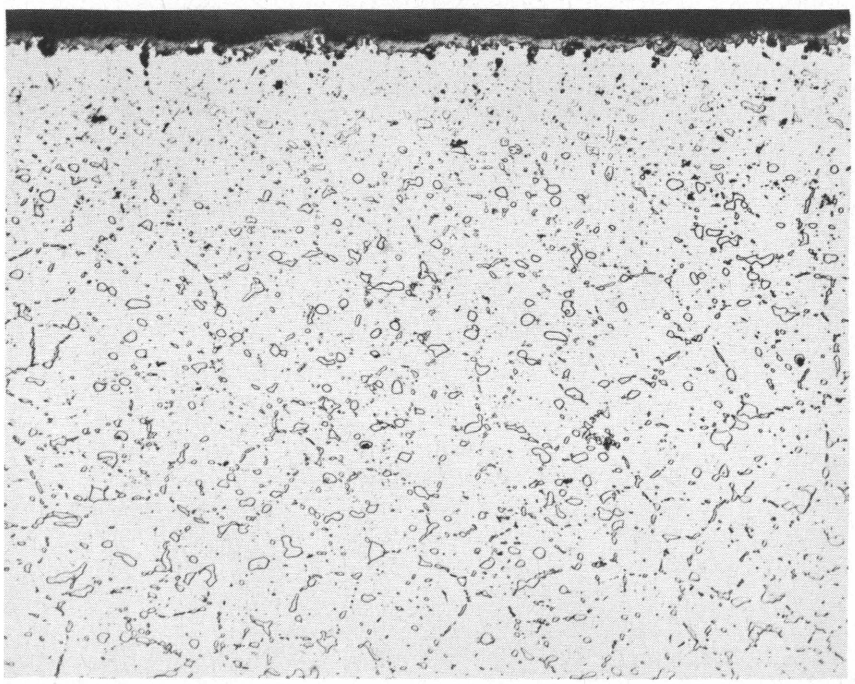


FIGURE 7:25. HASTELLOY-X: 5,000 HOURS AT 1750°F AIR X250

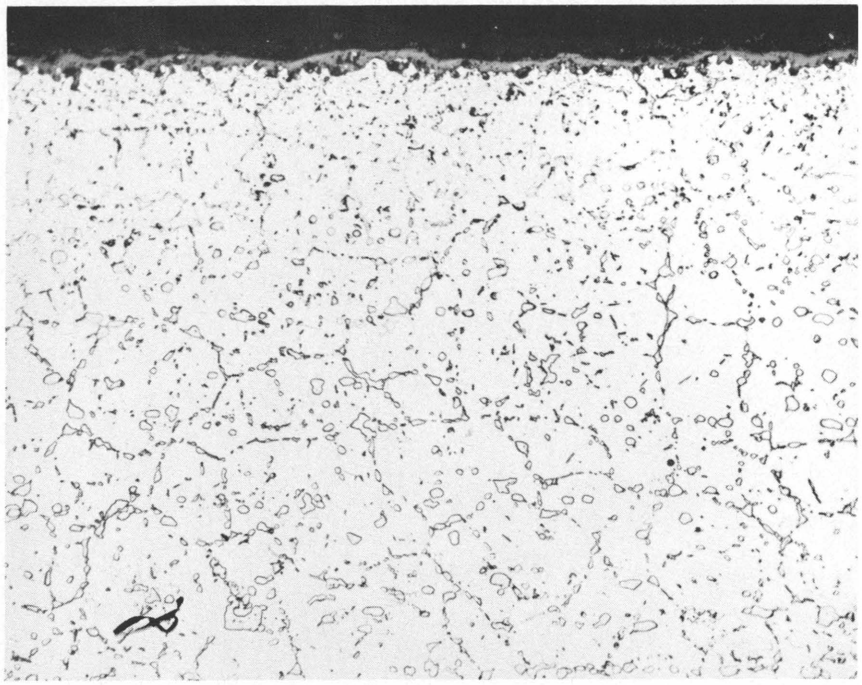


FIGURE 7:26. HASTELLOY-X: 10,000 HOURS AT 1750°F IN. 99.5 VOL% N_2 + 0.5 VOL% O_2 X250

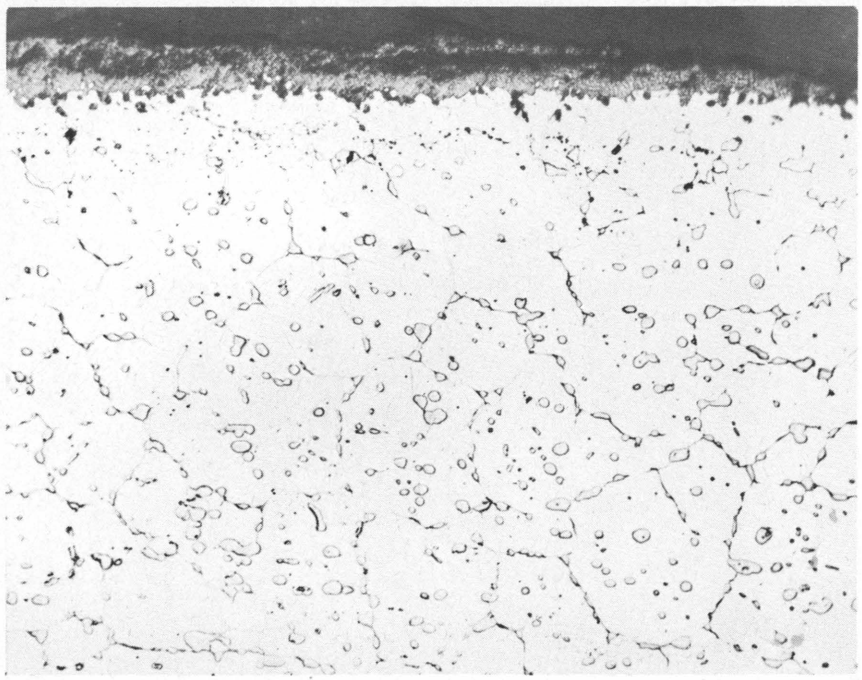


FIGURE 7:27. HASTELLOY-X: 10,000 HOURS AT 1750°F IN. AIR X250

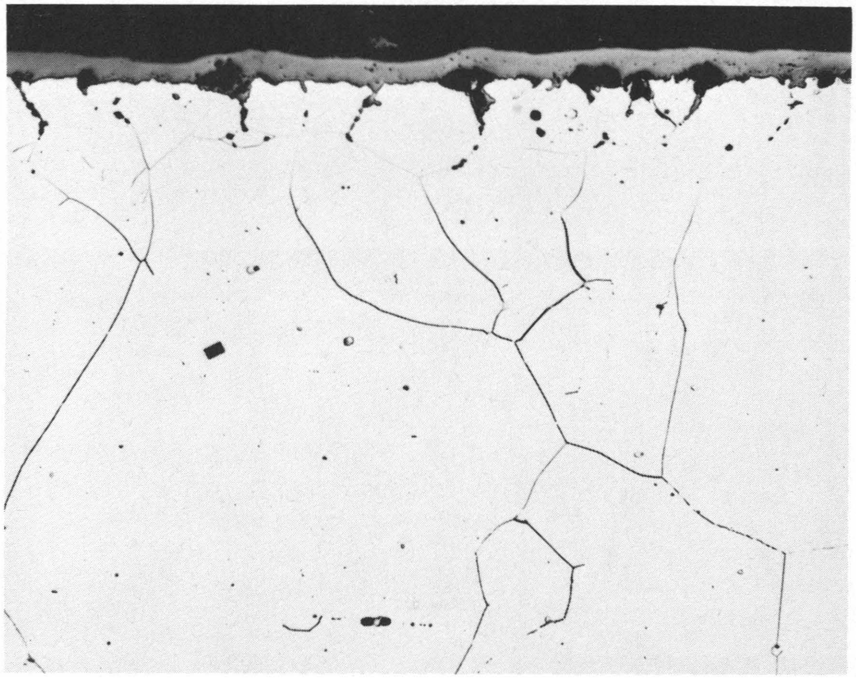


FIGURE 7:28. INCONEL: 5,000 HOURS AT 1750^{O}F IN. 99.5 VOL% N_2 + 0.5 VOL% O_2 X250

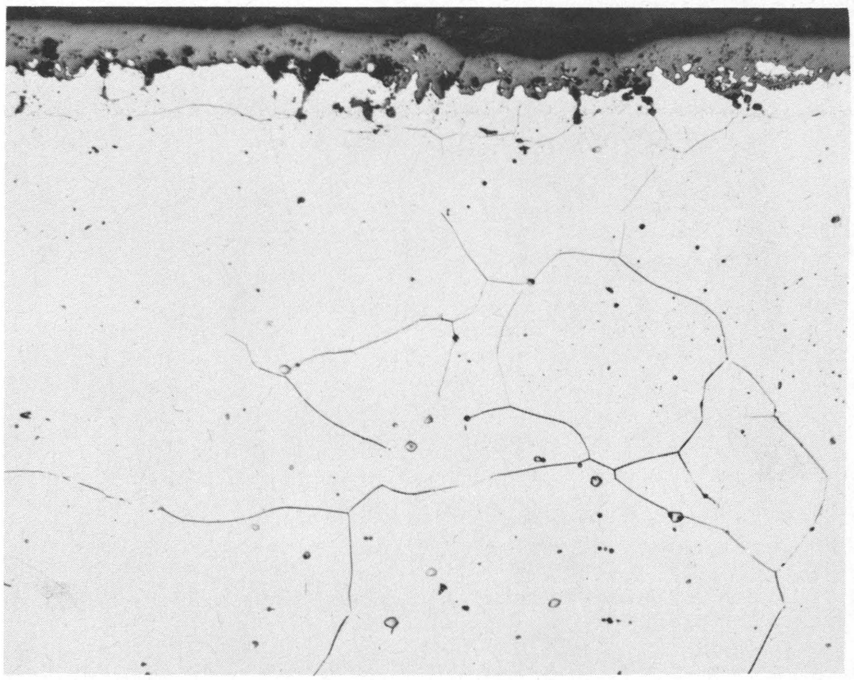


FIGURE 7:29. INCONEL: 5,000 HOURS AT 1750^{O}F IN. AIR X250

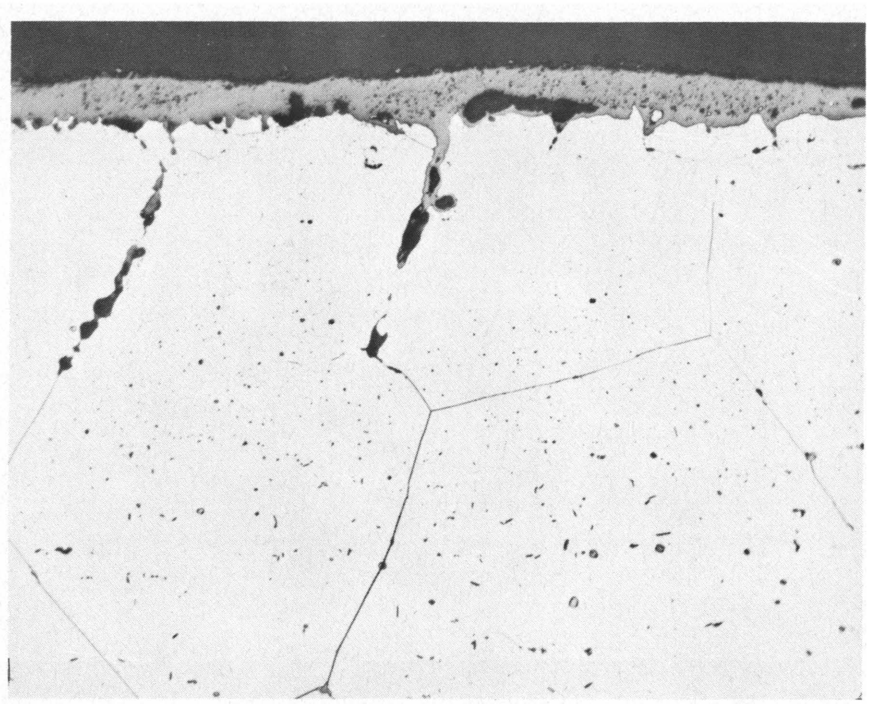


FIGURE 7:30. INCONEL: 10,000 HOURS AT 1750°F
IN. 99.5 VOL% N_2 + 0.5 VOL% O_2 X250

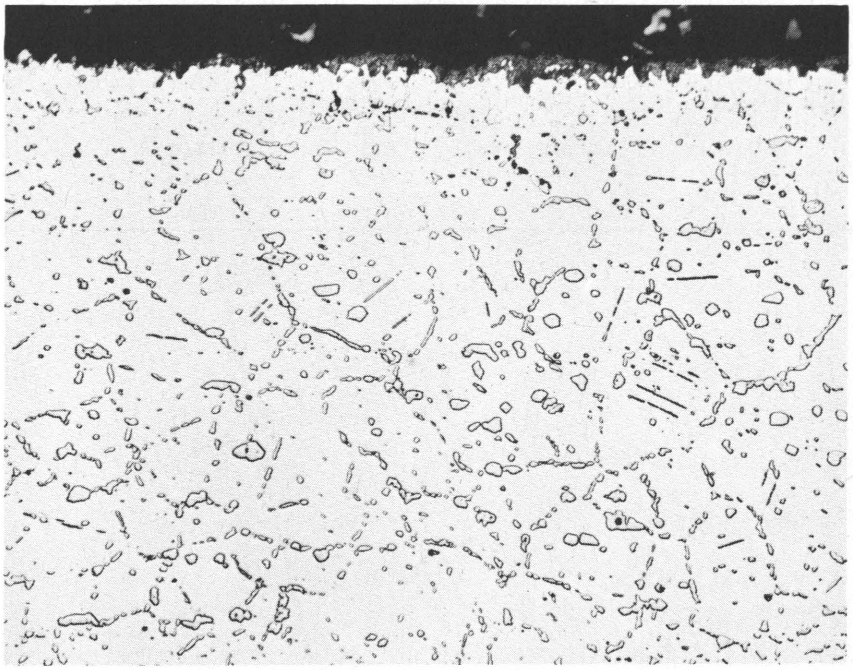


FIGURE 7:31. LOW COBALT HASTELLOY-X: 5000 HR @ 1750°F IN. 300 psi REFERENCE GAS X250

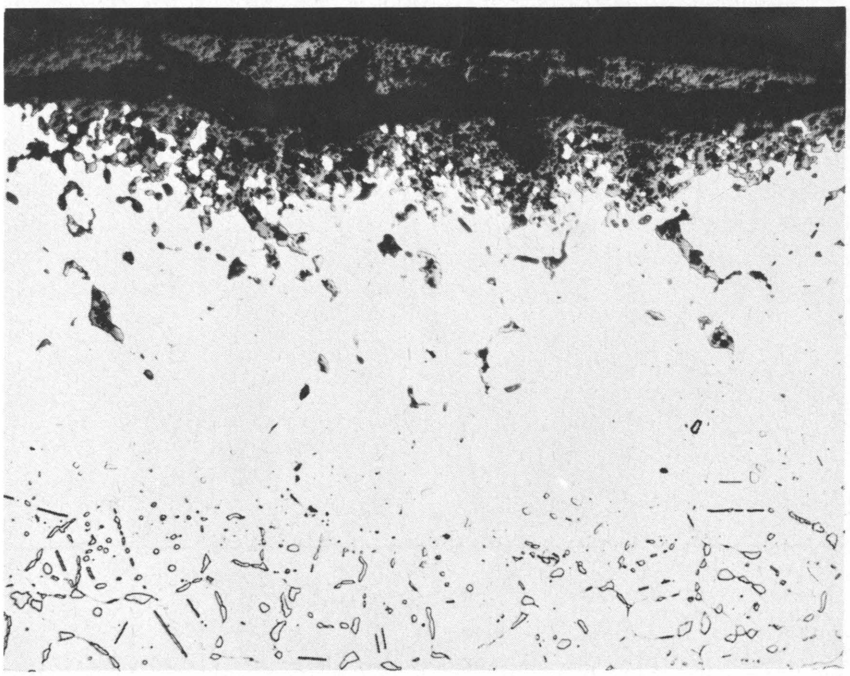


FIGURE 7:32. LOW COBALT HASTELLOY-X: 5000 HR @ 1750°F IN. 300 psi AIR X250

SECONDARY CREEP RATE VERSUS STRESS FOR HASTELLOY-X AT 1750° F

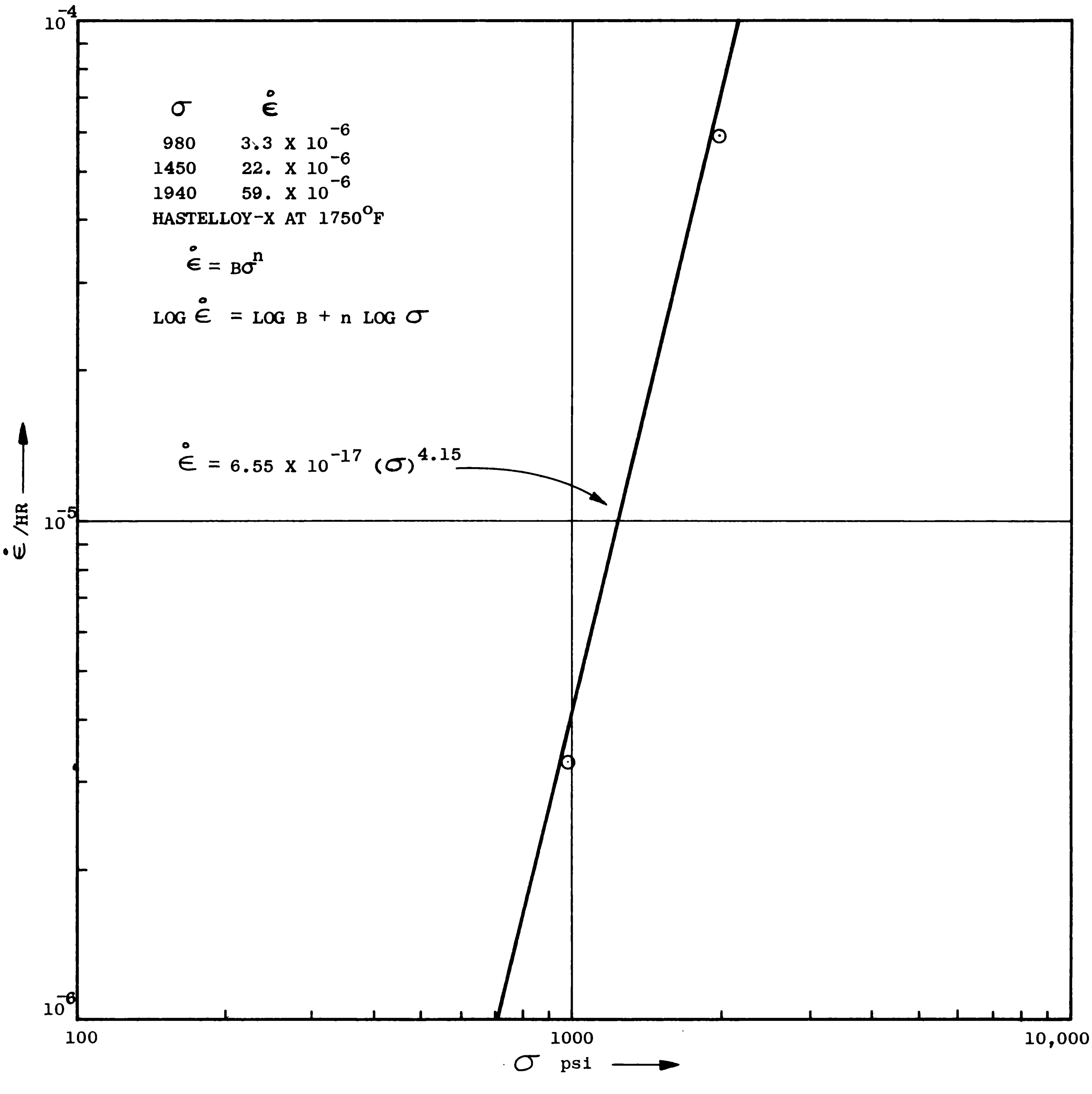


FIGURE 7:33

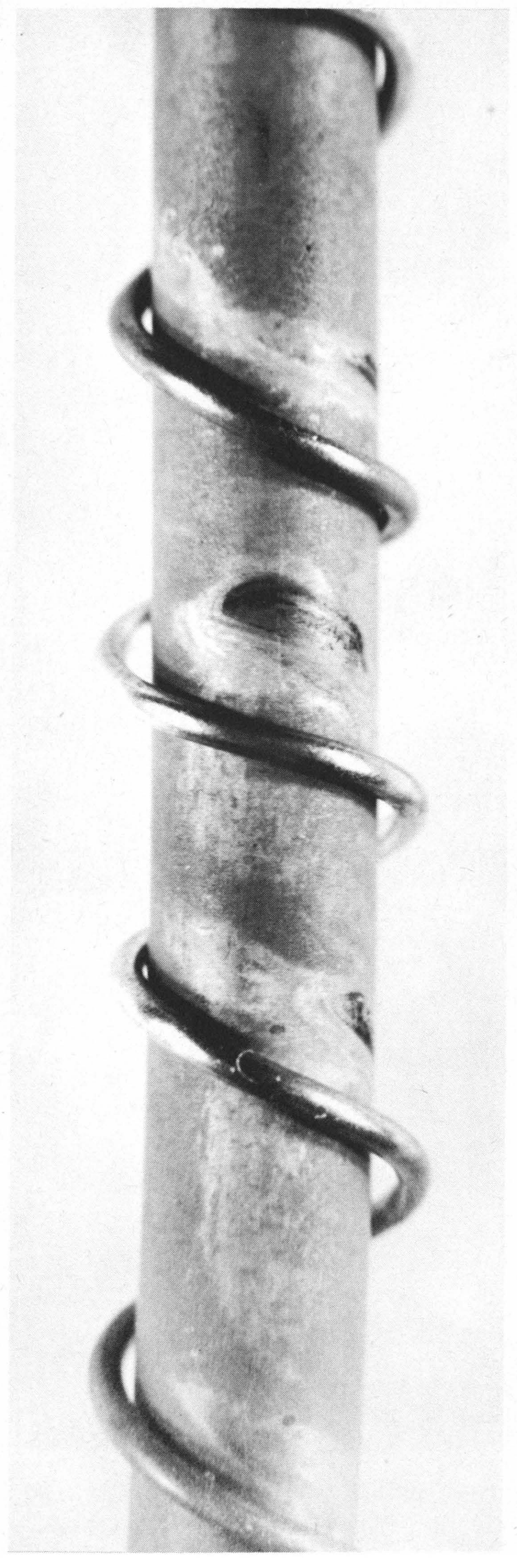


FIGURE 7:34. APPEARANCE OF HASTELLOY-X TUBING
WITH SPIRAL WIRE SPACER AFTER TEST 5X

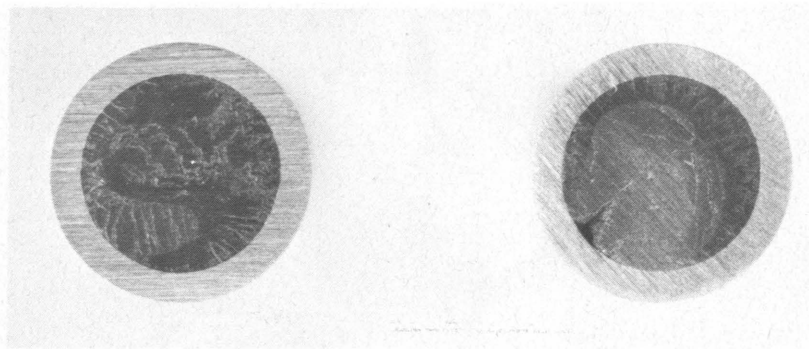


FIGURE 7:35 SECTION OF THE IB-7T OUT-OF-PILE CONTROL SPECIMEN MADE AT THE DEFECT.

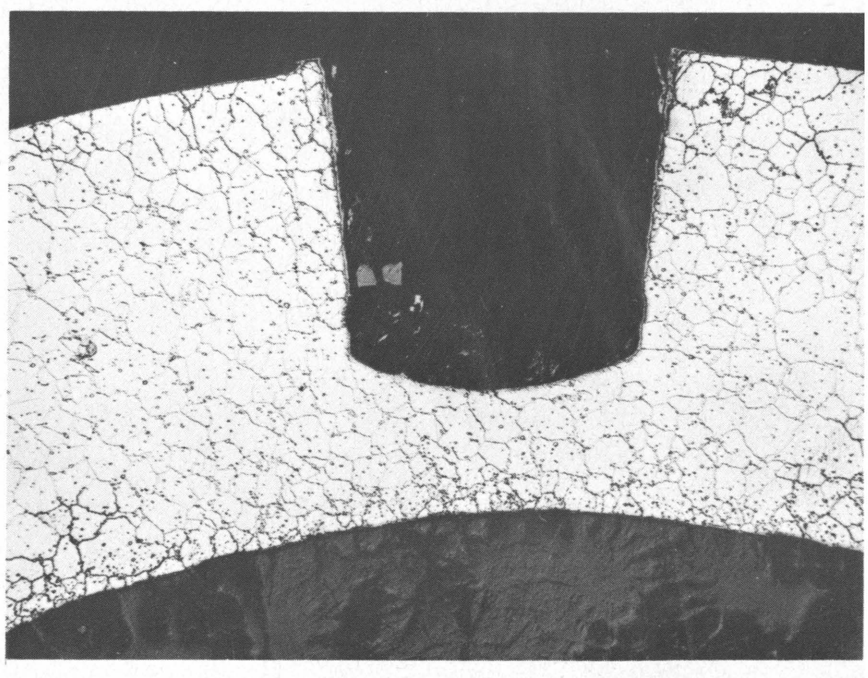
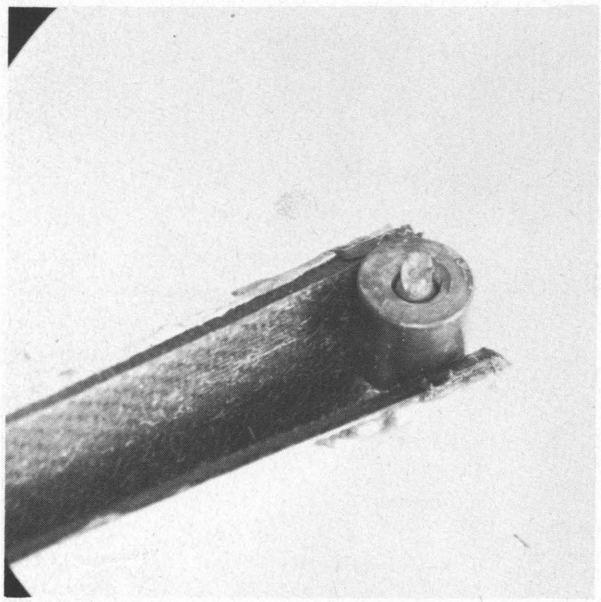
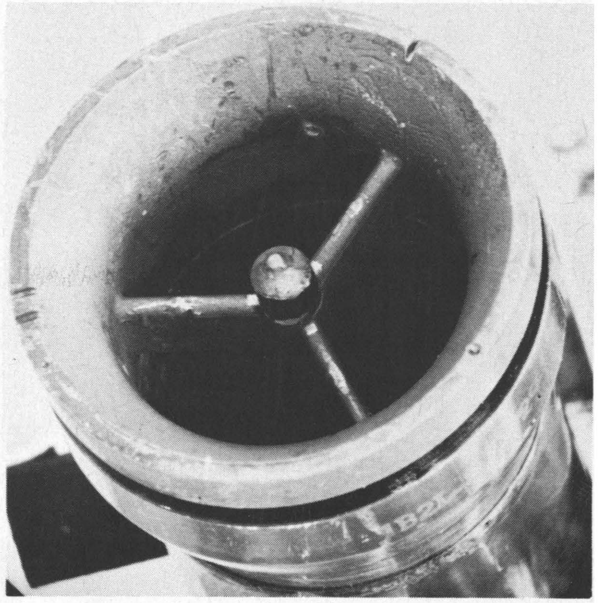


FIGURE 7:36 MICROSTRUCTURE OF THE HASTELLOY-X CLADDING OF THE IB-7T OUT-OF-PILE CONTROL SPECIMEN TAKEN NEAR THE DEFECT. THE DEFECT IS BEHIND THIS CROSS SECTION.

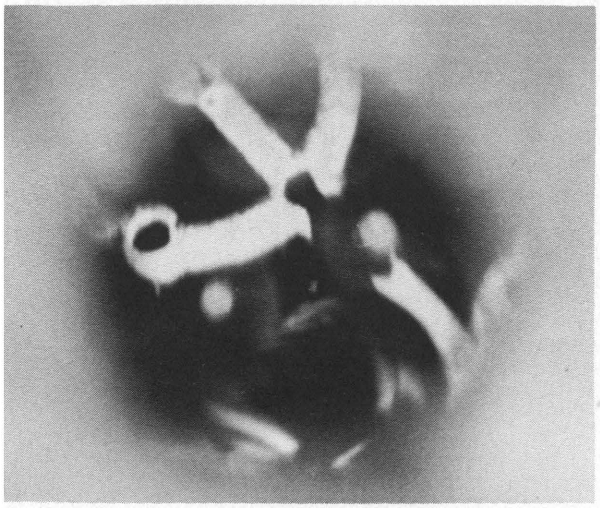
EXAMPLES OF DAMAGE IN IB-2L ELEMENTS



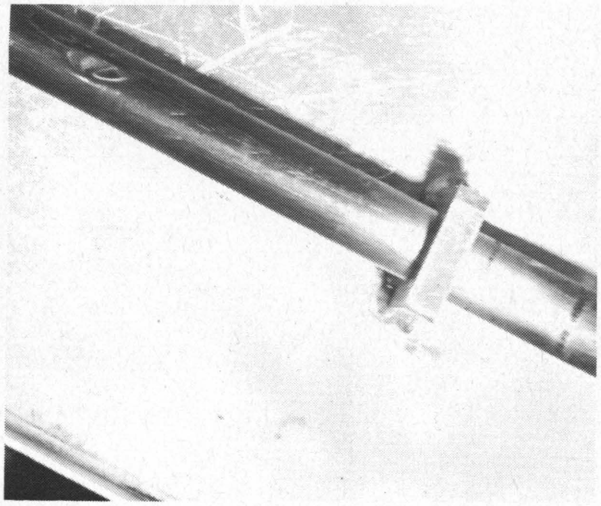
NUT-PIN SUPPORT



SEPARATED HOUSING



BROKEN SPIDER, IB-2L-2



LINER DENTS

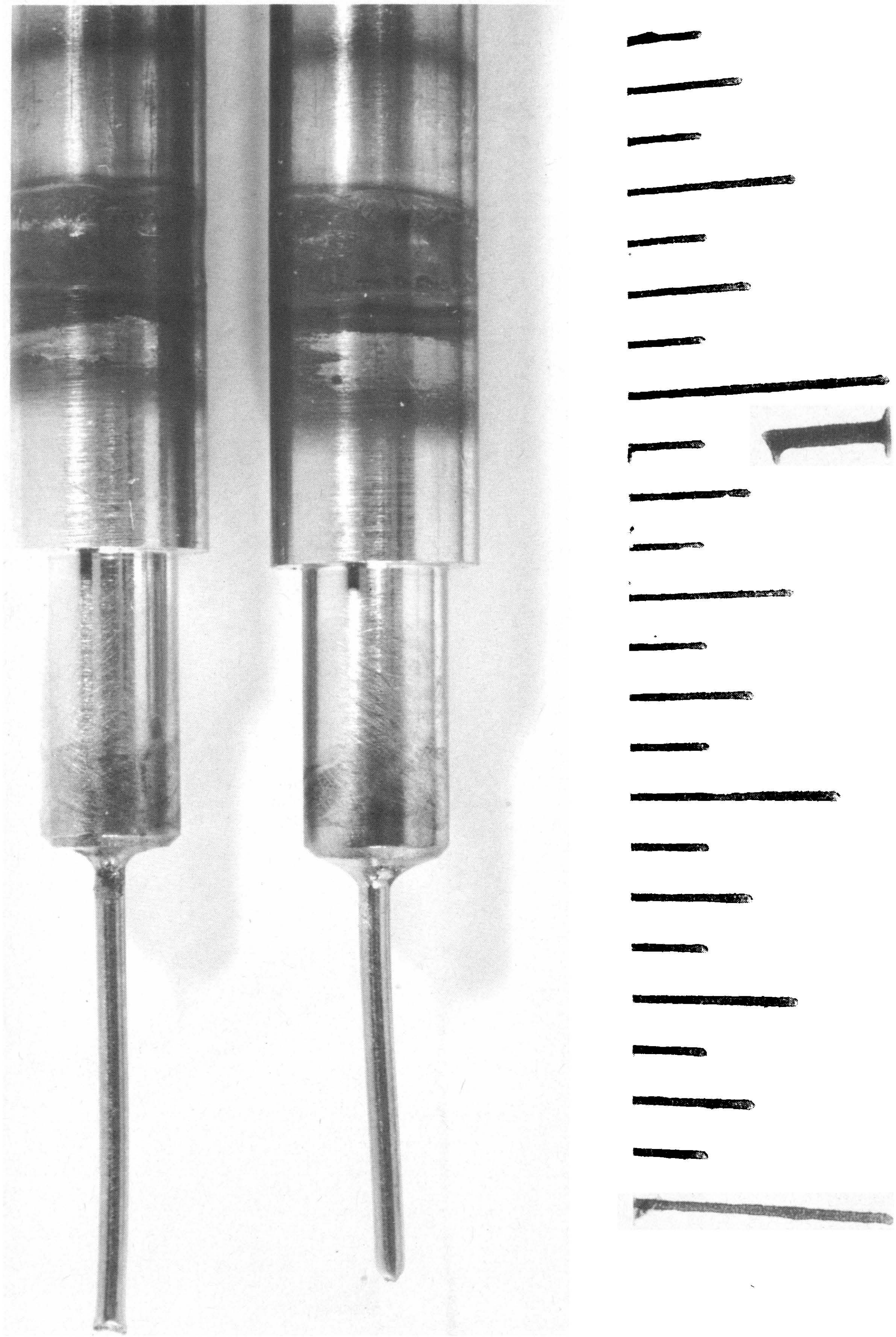
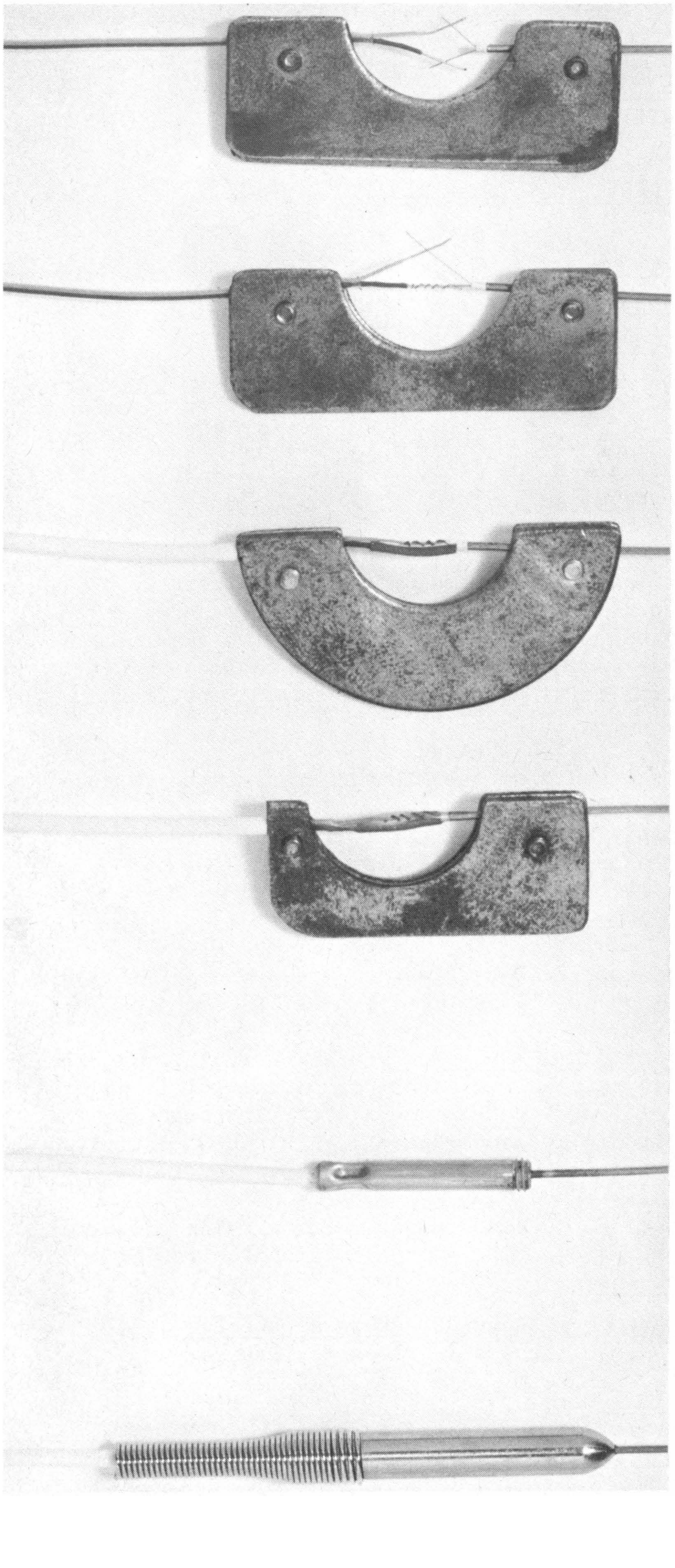


FIGURE 7:38 DEVELOPMENT THERMOCOUPLE BRAZE AND UPPER WELD JOINT.

THERMOCOUPLE SPLICING



a. THERMOCOUPLE WIRES READY FOR JOINING

b. JOINING THERMOCOUPLE WIRES

c. INSULATING JOINED THERMOCOUPLE WIRES

d. POTTING JOINED THERMOCOUPLE WIRES

e. INNER SPLICE CAN

f. OUTER SPLICE CAN

FIGURE 7:39

8.0 ML-1 FUEL IRRADIATIONS (Task 15-1XX)

Review - January through May:

a. BRR-GCR-3 (Solid UO_2 Fuel): Capsule irradiation continued in the Battelle Research Reactor with the peak specimen operating at about 1720°F. The capsule was discharged from the reactor on 1 May and post-irradiation hot cell examination began 8 May. Peak burnup was estimated to be 3.2 atom percent U-235.

All specimens were intact although measurements indicated the four central specimens swelled slightly (approximately 0.001- to 0.0015-in.). All specimens were punctured to collect fission product gas. The gas is decaying so that activity can be counted to determine the volume. Dosimetry and gamma-scanning for burnup calculations were performed; specimens were shipped to CPP-NRTS, Idaho, for isotopic analysis. Metallography is being performed on the two hottest specimens and the coldest specimen. The ends of all specimens were removed to expose the fuel for macro-examination. X-ray diffraction also will be performed on the fuel. Macro-observation of the irradiated fuel showed it to be cracked as expected. No central melting was detected in any specimen.

b. MTR-GCR-3 (70 and 80 wt% UO_2-BeO): Capsule irradiation continued in the MTR until 5 April when the capsule was removed from the MTR and transmitted to AREA for examination. Burnup at this time was estimated to be 13.1 atom% U-235. Examination was delayed and the capsule was transferred to the BMI hot cell. A similar examination to that performed on BRR-GCR-3 is planned.

Accomplishments - June:

ML-1 fuel irradiations, either completed or planned, are shown in Table 8-1 on the following page.

a. Irradiation Capsule BRR-GCR-3 (Solid UO_2 Fuel): Preparation of this capsule was described earlier.* Six Hastelloy-X clad specimens containing solid high density, fully enriched pellets were placed in this capsule for irradiation. The irradiation was performed in the Battelle Research Reactor (BRR) in an estimated flux of 0.4×10^{14} neut/cm^{2}sec. Actual irradiation began 7 September 1960.

Irradiation proceeded with specimen surface temperatures varying slightly between cycles because of reactor operating temperatures. Sample operating temperatures are tabulated on the following page.

*Army Gas-Cooled Reactor System Program Semiannual Progress Report for July through December 1960, IDO-28567 - Aerojet-General Nucleonics, San Ramon, California, February 1961.

TABLE 8-1 - ML-1 FUEL IRRADIATION

Capsule Number	Specimens, Description of	Irradiation Schedules	Irradiation Duration	Irradiation Clad Temp, °F	Total Burnup a% U-235 (est)
BRR-GCR-3	Six solid highly-enriched UO_2 pellets clad in 0.030-in. thick Hastelloy-X	Start 9/6/60 End 5/1/61	138 days	1720	3.2 (9100 hr ML-1 equiv.)
All specimens were intact. Slight diametral swelling measured. Fuel had cracked, but not excessively.					
MTR-GCR-3	Four 70 wt% UO_2-BeO pellet-type specimens clad with 0.030-in.-thick Hastelloy-X	Start 9/14/60 End 4/5/61	163 full power days; 10 MTR cycles	1550	13.1 (13,500 hr ML-1 equiv.)
Capsule enroute to BMI hot cell for examination.					
BRR-GCR-4	Six 60 wt% UO_2-BeO pellet type specimens clad with 0.030-in.-thick Hastelloy-X	Start late in 1961	undetermined	1600 to 1650	9.2
Irradiation of IB-3L, ML-1(II) reference fuel to 10,000 hr equivalent burnup.					

TYPICAL CAPSULE OPERATING CONDITIONS
CAPSULE BRR-GCR-3

Average Specimen Clad Surface Temp. (°F)

Specimen Number

BRR Cycle	1 (1)	2 (5)	3 (6)	4 (8)	5 (10)	6 (blank)
65	1550	1600	1600	1640	1580	1435
67	1550	1625	1680	1640	1565	1410
70	1590	1610	1710	1680	1600	1445
72	1600	1620	1720	1690	1610	1440

Irradiation was terminated 1 May. Hot cell examination began 8 May. Visual examination in the hot cell showed all specimens to be sound and apparently unchanged by the exposure. No fission product gases were found within the capsule, although quantities (still undetermined) were removed from each fuel specimen. Exact volumes of fission product gases could not be determined because of high specimen activity. Dimensional evaluation of the specimens indicated a slight increase in both diameter and length of the hottest specimens. Preliminary values are tabulated on the following page.

DIMENSION CHANGES OF SPECIMENS CAPSULE BRR-GCR-3
SPECIMEN NUMBER*

	1	5	6	8	10	Blank
			Diameter (in.)**			
Pre-Irradiation	0.2110	0.2100	0.2110	0.2115	0.2110	0.2115
Post-Irradiation	0.2113	0.2116	0.2123	0.2138	0.2130	0.2118
			Length (in.)			
Pre-Irradiation	1.618	1.624	1.613	1.604	1.611	1.630
Post-Irradiation	1.618	1.624	1.621	1.613	1.611	1.630

* Compare with chart above for operating temperature
**Taken around a point midway between specimen ends

Specimens were sectioned to permit examination of fuel and cladding. Ends were removed from all specimens and photographs made. Additional sections were made of specimen six (highest operating temperature, greatest burnup), five (next highest operating temperature and burnup), and blank specimen (lowest operating temperature and least burnup). Specimens six and blank had isotopic burnup specimens, metallographic specimens, and X-ray diffraction specimens removed from them. Figure 8:1 shows pre- and post-irradiation macrophotographs of a specimen and of the UO_2 fuel.

Macro-examination of other specimens showed the fuel was cracked in a similar fashion. No central fuel melting was observed, and none had been expected.

Estimated peak burnup achieved in the fuel (specimen 6) totalled 3.1 atom% uranium. Dosimeter evaluation and isotopic burnup data are being obtained to more accurately determine the burnup reached in specimen 6 and the blank specimen.

X-ray diffraction examination of the fuel to ascertain the degree of damage sustained by the fuel is planned. This effort was delayed by high activity of specimens from short-lived species.

In summary the fuel behaved as expected. No reaction was observed between cladding and fuel, although some cladding swelling was detected. Burnup analyses, fission product gas release determinations, and diffraction analysis remain to be completed.

b. Irradiation Capsule MTR GCR-3 (70 and 80 wt% UO_2-BeO Fuel): This capsule is identical to the BRR-CGR-3 capsule described above. The history of this capsule was described earlier.*

Operating temperatures for this capsule were estimated to be 100° to 150°F below the specified peak (1750°F). Difficulties with thermocouples eliminated the possibility of moving the capsule. Heavy expenditures of auxiliary heat were used to maintain the temperatures of specimens.

*Ibid (IDO-28567)

Capsule irradiation began on 14 September in a reactor flux estimated at 0.85 x 10^{14} neut/cm^2sec and was terminated 5 April. The capsule was sent to the AREA hot cells for disassembly and examination. The capsule was transferred because of scheduling to the BMI hot cell in early June for hot cell examination.

An examination similar to that performed on the BRR capsule was initiated on this capsule. Preliminary examination revealed that one of the 80 wt% UO_2 specimens had ruptured, and all others were intact. Fission product gas, detected inside the capsule originated from the failed specimen.

Dimensional micro- and macro-examinations were performed.

Anticipated Accomplishments - July:

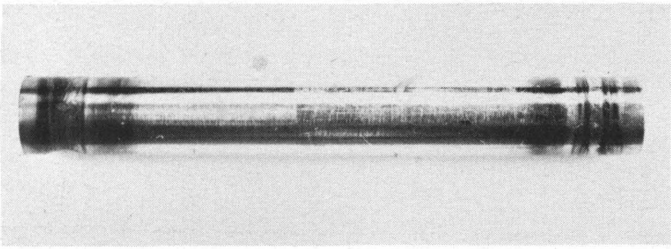
a. BRR-GCR-3: Post-irradiation examination will be completed with the possible exception of isotopic burnup analyses. These analyses are being performed at NRTS.

Preparation of a final report will begin. Completion of this report depends upon the availability of the isotopic burnup analyses.

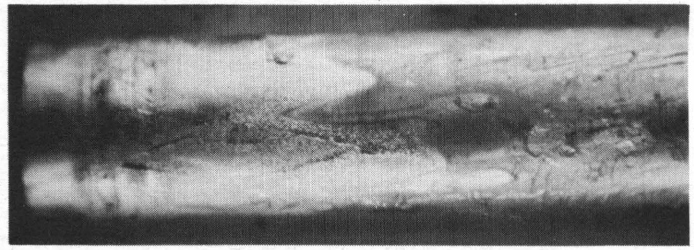
b. MTR-GCR-3: Post-irradiation examination of this capsule will be completed, again with the possible exception of isotopic burnup analyses. The cause of specimen failure will be reviewed and the effect upon ML-1 evaluated.

Preparation of a final report on this irradiation also will be initiated.

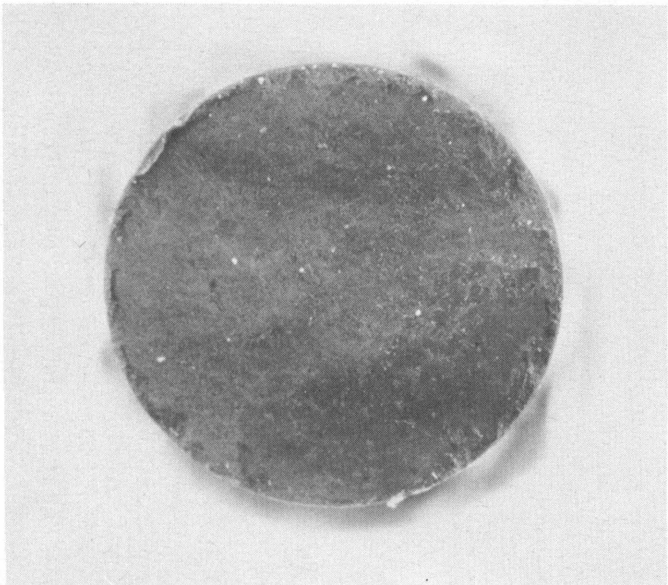
PHOTOGRAPHS OF SPECIMENS BEFORE AND AFTER IRRADIATION



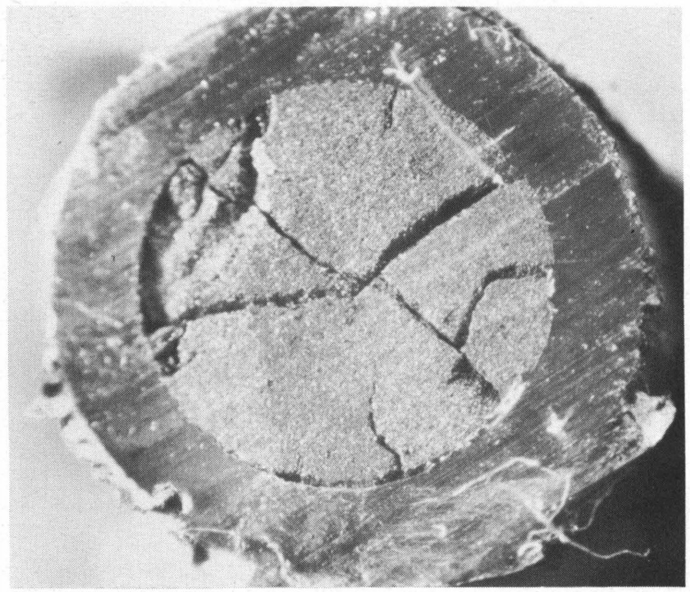
BRR-GCR-3 SPECIMEN BEFORE IRRADIATION



BRR-GCR-3 SPECIMEN AFTER IRRADIATION



SPECIMEN BEFORE IRRADIATION



SPECIMEN AFTER IRRADIATION

FIGURE 8:1

9.0 IN-PILE TEST PROGRAM

9.1 IB-2T Fabrication and In-Pile Test (Task 17-2XX)

Review - January through May:

The IB-2T-1 element was disassembled and examined in the MTR hot cell at NRTS. Before disassembly the pin bundle appeared to be in excellent condition except for a deposit of white powder and some separation of spacer wires (Figure 9:1).

After removal of the spacer wires, each fuel pin was scraped to obtain a sample of the white deposit near the top of the bundle. The analysis of the white powder indicated that this powder is similar to that found on the IB-2T-1 in-pile test element comprised of stainless steel components and silicon.

Individual fuel pins photographed against a grid show essentially no bowing or distortion.

Fission gas samples were obtained by puncturing each pin and the samples were analyzed. The results show lower fission product release than had been assumed in the fuel element design. Pin 14 contained a high percentage of nitrogen gas and was, thus, assumed to have been responsible for the fission leak during operation. Each pin was subjected to a helium "soak" before puncturing to locate the faulty pin. After puncturing, pin 14 also was subjected to a leak check utilizing liquid nitrogen and alcohol. These tests failed to detect a leakage source on the cladding, and showed the leak could only have been through the thermocouple of the brazed thermocouple seal.

Gamma ray scans of the 19 pins were obtained during the hot cell examination.

Accomplishments - June:

Metallographic specimens from the IB-2T-1 were examined at the MTR hot cell at NRTS. Metallurgical sections taken through the hottest locations on three fuel pins (pins 5, 14 and 15) and one section taken through the end plug area of pin 14 were examined in both the unetched and etched conditions.

Pin 5 appeared to have operated at the highest surface temperature. An oxide scale, 0.0003-in. maximum thickness, was found on the outside of the cladding. No evidence of intergranular or internal oxidation was observed. The tubing had completely and uniformly collapsed onto the fuel pellets. Numerous defects were observed along the inside of the tube. These defects are believed to have occurred during fabrication of the tubing and are not believed to be due to irradiation. The microstructure of the metal disclosed extensive and uniform carbide precipitation similar to that observed in out-of-reactor corrosion tests. The smaller precipitates were spherical in appearance.

Pin 15 was similar to pin 5 except that the outside was slightly less oxidized and this section of the tubing had only partially collapsed. A 0.0025-in.-deep dendritic defect was observed on the inside of the tubing. Again, this is believed to have been formed during fabrication.

Pin 14 had not collapsed and showed the thinnest oxide scale. An unidentified phase was formed along the inside of the tubing which extended intergranularly into the matrix. This phase resembles that detected upon exposure of Hastelloy-X to high purity nitrogen in out-of-reactor tests and is believed due to the presence of nitrogen in the fuel pin.

The section through the end plug of pin 14 disclosed that a fairly large void was present in the braze joint. Similar voids were observed in examination of other braze joints. These voids never were continuous and would not result in the observed leak. The inside of this void was not oxidized which further indicates the void had not provided the leakage path. The side of the stainless steel thermocouple sheath and the thermocouple wires were severely oxidized.

Anticipated Accomplishments - July:

Photomicrographs are to be prepared by PPCo and a complete summary of the hot cell examination of the IB-2T metallographic specimens will be prepared by Aerojet. This summary will include burnup data which has not yet been received from PPCo.

9.2 IB-7T Fabrication and In-Pile Test (Task 18-1XX)

Review - January through May:

The in-pile test capsule and the operating console were completed. The capsule was installed in the GETR and irradiation of the defective UO_2 pin started on 7 May. The apparatus performed with only minor difficulties.

A typical set of conditions at startup were:

Gas inlet	$800^{o}F$
Gas outlet	$1250^{o}F$
Max. cladding temp.	$1460^{o}F$
System power	2.2 kw
System pressure	310 psig
Coolant	Nitrogen

The fission gas release at equilibrium was measured at 31 millicuries as against a calculated value of 29 millicuries. The coolant was changed to reference gas and the activity in the loop dropped to about 3 millicuries in 13 days.

Accomplishments - June:

The IB-7T-1 was removed from the reactor after 683 hr of irradiation. The test section was cut out of the capsule and transferred to the General Electric Vallecitos hot cells. Post-irradiation examination showed that the cladding did not swell from oxidation of the UO_2 pellets. There was no external evidence of any change in material surrounding the defect (hole). Samples were removed from the vicinity of the defect for metallographic examination. The plate-out strips were scanned for fission product plate-out, but any activity present was completely masked by the activation products of the plate-out strips; the strips were at a radiation level of approximately 300 mr/hr at contact. The plate-out strips were leached and then rescanned, but no difference was apparent.

The IB-7T-2 was completed and inserted in the GETR on 5 June.The motor burned out during the reactor startup so the capsule was removed and transferred to the RML facilities for repair.

The construction of a small pressurized container to check motor and pump for the IB-7T capsule was completed.

Anticipated Accomplishments - July:

The IB-7T-2 will be repaired, and irradiation will begin. Hot cell examination of IB-7T-1 will be completed. Construction of the IB-7T-3 capsule will be started.

9.3 IB-8T Fabrication and In-Pile Tests (Task 18-2XX)

Review - January through May:

The IB-8T in-pile test operated through GETR cycles 20, 21, 22 and 23.

Data were recorded from the five remaining element surface thermocouples out of the eight original thermocouples. In addition, power and fluid flow parameters are being recorded. Normal operating conditions for the test are 800°F inlet coolant temperature, 1200°F outlet coolant temperature, and 55 kw power generation.

The test elements successfully withstood the irradiation except for the loss of thermocouples. Surface temperatures on the lower portion (outlet end) of the instrumented element showed an unexpected increase after re-fueling (mid-cycle 22). However, the increase is attributed to fouling as a result of accidental introduction of powdered material from a molecular sieve into the main loop. The temperature returned to normal when the source of the material was removed. Element pressure drop fluctuates with the operating conditions and may be increasing slowly with time not, however, to an important extent.

There was a GETR scram caused by a seismic disturbance on 8 April at 2323 hours. The clad temperatures after startup increased regularly and the facility tube filter radiation levels also increased regularly until mid-cycle shutdown for re-fueling on 12 April. On the subsequent startup, the clad temperatures were still high and so the mass flow rate was increased to 2000 lb/hr and the inlet temperature was controlled to hold the maximum measured clad surface temperature below 1700°F. Operation at these conditions was maintained until the end of cycle 22 on 30 April. It was discovered during shutdown that the loop nitrogen purifier molecular sieve material had powdered and some had been introduced accidentally into the loop. This unit was valved out of the system. GETR was started up for cycle 23 on 7 May. Normal operation of the test resumed after initial early cycle power peaking. The temperatures of the clad surface were well within the normal loop operating alarm points. The thermocouple AGN-1 has been the highest reading thermocouple since the incident, and it is expected to remain so. The surface temperature and loop activity history after the 8 April scram are shown in Figure 9:2.

Accomplishments - June:

The IB-8T in-pile test operated through GETR cycle 23. Cycle 24 is scheduled to terminate on 9 July. A summary of the test operating conditions is given in Table 9-1 on the following page. It was discovered during the GETR cycle 24 shutdown that the labyrinth oil seals of the two operating blowers had failed. The seals had operated for approximately 3700 hr. One of the two blowers has been overhauled, and the second is a non-operating standby.

Anticipated Accomplishments - July:

The GETR will finish cycle 24 on 9 July and begin cycle 25 on 10 July. The second loop blower will be overhauled during the cycle 25 shutdown.

Computing machine codes will be prepared to reduce experimental pressure drop data and to plot element thermodynamic conditions as a function of time.

9.4 IB-13T Fabrication and In-Pile Tests (Task 18-3XX)

Review - January through May:

(Note: Work on this task was begun in May.)

The design of the IB-13T test element and the procurement of element parts were initiated. The IB-13T test element will be a prototype of the ML-1 production element, designated IB-3L. The IB-13T will be tested in the GETR-AGN Nitrogen Loop at reference ML-1 conditions.

The IB-13T test is to have the same mechanical configuration as the IB-3L element and is to have the same pin power production ratio. Due to the large radial flux gradient in the GETR and a slower neutron spectrum it may be necessary to vary the IB-13T pin fuel loading to simulate the power of the constant pin fuel loading of the IB-3L. A total of 19 pins will be loaded in the IB-13T and IB-3L elements.

The exit gas of the test element will be measured by a temperature probe located downstream from the test element.

TABLE 9-1 - IB-8T IN-PILE TEST SUMMARY

Irradiation initiated 2 December 1960. About 2920 hr logged by 30 June 1961.

		IB-8T-1	IB-8T-2
Power, kw			
Maximum (average over cycle)		57.6	54.9
Minimum (average over cycle)		48.2	52.4
Average (total)		52.4	53.2
Temperature, °F			
Inlet gas		795	805
Outlet gas		1160	1175
Clad AGN #10 X/L = 0.295 outer		1160	
# 6 X/L = 0.750 outer		1310	
#12 X/L = 0.750 outer		1430	
#13 X/L = 0.750 inner		1520	
# 1 X/L = 0.900 outer		1620	
Flow Rate, lb/hr		1725	1730
Element ΔP, psi		12.7	12.6
Loop Pressure, psig	300		
Gas Analysis			
O_2	0.5%		
H_2O	115 ppm		
CO_2	90 ppm		
Combustible carbon	200-370 ppm		
Radioactive species	320 dpm/ml (A^{41})		

The element thermocouples, the exit gas thermocouples, and the uranium powder were ordered.

Accomplishments - June:

Engineering analysis was initiated for the IB-13T. The IB-13T is to be a prototype test of the IB-3L reactor core.

An exit gas temperature probe will be installed in the loop piping when the IB-13T is installed. The design of the modified facility tube that will accept the temperature probe was completed by GE.

Anticipated Accomplishments - July:

Element analysis will continue using latest design parameters of the IB-3L.

Assembly and machine drawings of the temperature probe will be initiated.

FIGURE 9:1. IB-2T-1 PIN BUNDLE

TEMPERATURE RISE NOTED IN IB-8T

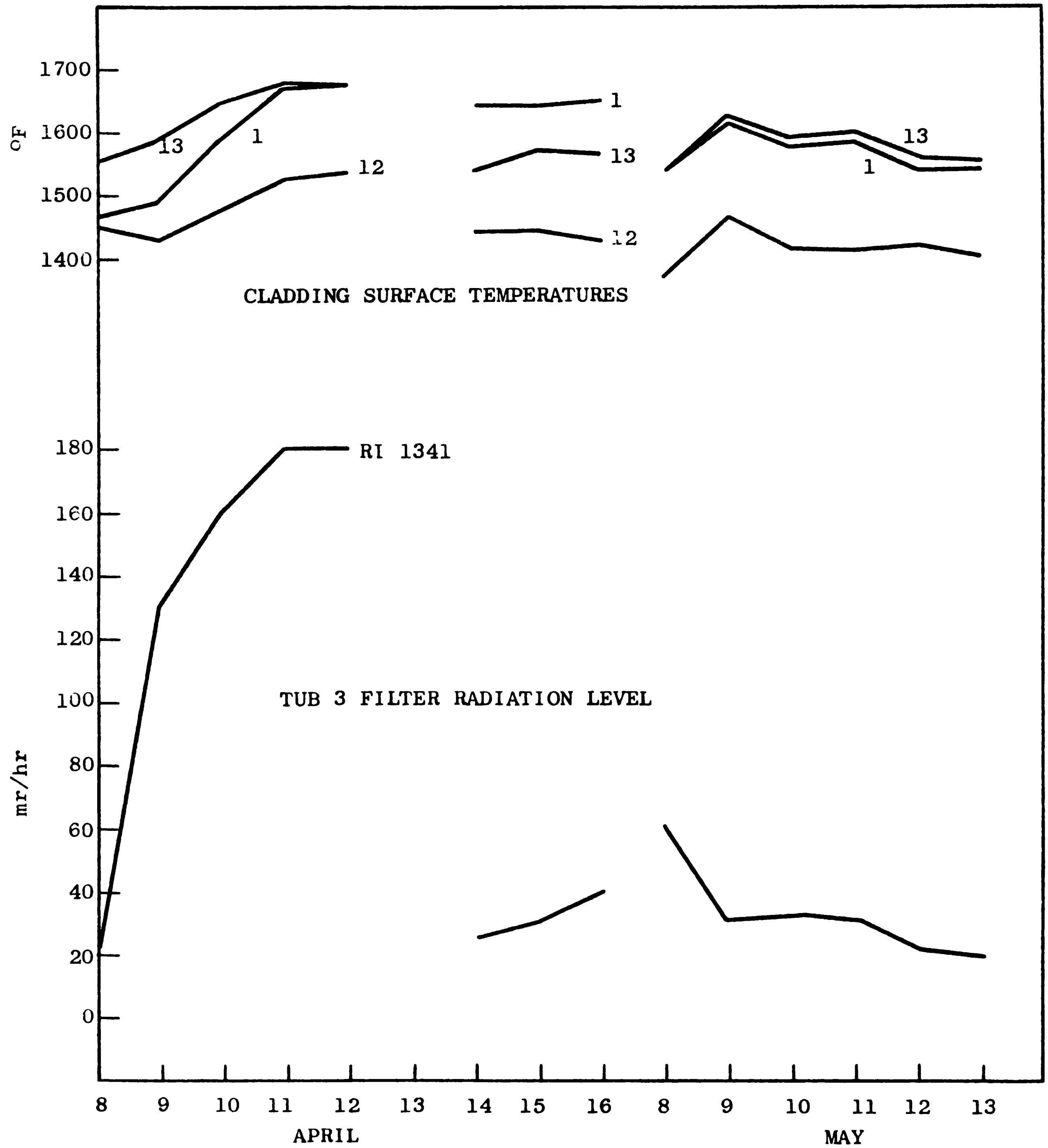


FIGURE 9:2

10.0 FUEL ELEMENT ANALYSIS

10.1 Fuel Analysis (Task 21-1XX)

Review - January through May:

a. GCRE Operational Assistance: The effects of conduction and gamma heating on the temperature error in the ΔT probe are negligible. However, radiative heat transfer causes the ΔT probe in the lower plenum to read 10 to 40 F degrees less than the actual coolant temperature. This range of temperatures results from uncertainties in the probe emissivity and the plenum wall temperature.

During calibration of the ΔT probe thermocouples, one hour was required to equalize the probe thermocouples to the surrounding gas temperature. Calculations validated the time lag. An additional thermocouple was installed on the external surface of the probe to measure gas temperatures during transients.

An expression was derived to relate GCRE total nuclear power to the measured coolant enthalpy rise. The expression includes the effects of heat loss to the moderator water and heat generation in the moderator and shield.

The exit coolant temperature from position E-2 was observed to be 150 F degrees higher than the other channels, and this position has limited reactor power. The observed indentation of the liner is insufficient to explain this effect. A check showed that the orifice diameter for this position was smaller than specified.

The GCRE orifice pattern was refined in January as a result of the availability of additional operational data. The actual radial power distribution was found to be flatter than was assumed in the choice of the original orifice pattern. The refinements in orifice pattern decreased the outlet coolant temperature variation for each fuel element to $\pm$ 30 F degrees and lowered the pressure drop in the core.

The relative power of each fuel element normalized to average was determined by the following methods:

1) Calculated from x-y two-group PDQ;

2) Measurement of power at six core positions with the IB-9ØR-2 element;

3) Two sets of heat balance data during the initial IB-2L power ascension with uniform orifices in all channels; and,

4) Three sets of heat balance data during operation of the IB-2L orificed core.

The agreement between the various methods is quite good and the power map of the core is estimated to be accurate within 10%. The PDQ method gives results as accurate as any other method and with minimum expenditure of effort.

b. GCRE Data Analysis: The coolant flow meter was observed to be reading 30% higher than the flow calculated from the pressure drop measured by the P probe. The discrepancy reduced to 10% after instrumentation maintenance was completed.

Steady-state operational data indicated that the mixed mean coolant outlet temperature, as measured by the outlet thermocouples on individual fuel element, is 80 F degrees greater than the ΔP probe outlet thermocouples. A portion of this discrepancy can be attributed to the previously mentioned radiation heat loss in the probe. The possibility that the outlet thermocouples on individual elements are not reading true mixed mean temperatures is also being considered.

Analysis of temperature data from GCRE operation during November and December 1960 led to the following conclusions:

1) Center pin temperatures on the IB-9R-2a and IB-9R-3a instrumented elements are in good agreement with prediction.

2) Liner and disc thermocouples from the IB-9R-2a and IB-9R-3a deviate by 40 to 150 F degrees from prediction. These deviations introduce an error into the data reduction of the shutdown cooling experiment of November 1960.

3) All except two of the thermocouples on fueled pins failed soon after insertion of the IB-9R-3b element. The two operative thermocouples gave poor agreement with HECTIC prediction (in one case, 100 F degrees higher and in the other, 50 F degrees lower than prediction).

Based on operational data obtained during January and February 1961, relations were developed between core pressure drop and compressor speed and coolant flow rate.

Skewing factor and pin-to-pin power ratio data were obtained from the IB-9ØR-2 experiment and applied to maximum nominal fuel pin temperatures in the IB-2L core. The estimated temperatures varied from 1370° to 1430°F as a function of core position for full flow, 2 Mw operation.

c. Instrumented Fuel Element in GCRE: The IB-9R-3b element is available for insertion into position G-5 of the IB-2L core. This element will be used to obtain temperature data during the following experiments:

1) Effect of shim rod position on pin temperatures

2) Shutdown cooling

3) Steady-state full power operation with a maximum intracell power skew

The IB-9R-3c element will be available for insertion in core position D-5 when the IB-9R-3b experiments are completed. This element will monitor steady-state pin temperatures during IB-2L core operation and furnish data on the pin axial temperature profiles.

The IB-14R element is a pilot model of the IB-3L (turbulence promotor pins) fuel element. This element will be inserted in position F-5 and is expected to furnish data on the axial temperature profile and the structural integrity of this new design concept.

<u>d. Shutdown Cooling Experiment:</u> Data reduction of the November 1960 shutdown cooling experiment was completed. The measured effective conductance from the inner liner to the moderator agreed within $\pm$ 25% with the calculated value. The measured effective conductance from the fuel pins to the inner liner is roughly twice the calculated value. It was hypotesized that convective effects during the experiment caused the measured increase in the conductance.

Measured temperatures following a shutdown were compared with HTR prediction. Although the experimental data were limited, there was close agreement with prediction, but HTR generally predicted slightly high.

The original experiment was hampered by a paucity of temperature data. This experiment will be re-run after the new ΔP probe, the IB-9R-3b, and two additional moderator water thermocouples are inserted into the core.

The effects of coolant flow decay, pellet-cladding temperature equalization, control rod insertion rate, and coolant de-pressurization are being evaluated for inclusion in the transient temperature analysis.

Extrapolations from old HTR problems gave the following maximum pin temperatures after a coolant loss accident.

	Hot Spot Case, $^{\circ}$F	Nominal Case, $^{\circ}$F
ML-1	2020	1860
IB-3L	1930	1790

The following assumptions were made in the analysis:

1) Loss of coolant occurs instantaneously with no allowance for convective cooling.

2) The central fuel element at the point of maximum power generation was considered.

3) The pin and pellet were assumed to reach a mixed temperature instantaneously.

4) The minimum amount of reactivity (-3.8% $\delta k/k$) was assumed available for insertion.

Maximum pin temperatures were reached 75 to 100 sec after coolant loss with the delayed neutrons contributing 50% of the energy produced during this time.

e. ML-1 Operational Assistance: Calculations based on ML-1 critical assembly data indicate that full insertion of a shim blade pair decreases the power of a fuel element adjacent to the blades by 30%. The power of an element one row away from the blade decreases by 18% following full blade insertion. The full insertion of a blade pair requires that the power of elements more than two rows away from the blade pair be increased 7.5% to maintain constant reactor power. This effect increases the maximum pin temperature by 50 F degrees for full insertion of a blade pair.

A correlation was derived to statistically relate ML-1 maximum fuel pin temperature to the thermocouple readings on the ten instrumented elements.

The presence of 28 silver-plated shims in ML-1 will decrease maximum pin temperatures by 10 to 20 F degrees. Variations in the method of heating the ML-1 upper reflector in the PDQ model result in 25 F degrees variations in maximum pin temperatures.

Calculations of the temperature of fuel pins, pressure tube, and control blades after moderator draining were made for various operational conditions.

Planning procedures for ML-1 orificing were completed. All the necessary flow data are available. These data will be combined with the flux element data and the results of x-y PDQ problems to specify the ML-1 orifice pattern.

f. IB-3L Fuel Element Design Analysis: A comparison of the smooth-pin IB-3L design with IB-2L showed that the net advantage of the IB-3L design is quite small. It was decided to pursue the turbulence promoter approach for IB-3L and to attempt to fullyutilize the potential 100 F degree reduction in maximum pin surface temperature. The turbulence promoters tend to break up the boundary layer and produce an axial variation in the heat transfer coefficient. Preliminary calculations indicated that the resulting pin temperature variation is not severe, but the variation is about 20 F degrees.

Hand calculations, based on experimental heat transfer and fluid flow tests and the criterion of pressure drop equivalent to ML-1, yielded the following dimensions for the IB-14R instrumented element (IB-3L prototype):

Fin tip diameter	0.260-in.
Fin root diameter	0.238-in.
Minimum pin wall thickness	0.020-in.
Finned length	13.5-in.

Further experimental data showed that the IB-14R reference design is within 5 F degrees of optimum. The expected pin temperature reduction is 80 F degrees taking into account the 20 F degrees variation between fins.

The calculated IB-14R axial temperature profile is shown in Figure 10:1 for the hottest pin and the coolant adjacent to the hottest pin. In Figure 10:2, the fin pitch-to-height ratio is plotted against a parameter proportional to the film drop. The figure shows that temperature reduction is unaffected by minor dimensional variations.

Calculations indicate that the heat transfer coefficients on the turbulence promoters are higher than for adjacent smooth surfaces. These calculations were experimentally verified by the mass transfer technique.

Preliminary data from a mockup of the IB-3L insulation package show that the effective thermal conductivity from the fuel pin liner to the moderator water agrees closely with calculation. The data also indicate the subcooled nucleate boiling on the pressure tube surface will not occur at ML-1 operating conditions.

Accomplishments - June:

a. GCRE: Data from the IB-2T fuel pin puncture test were adjusted for the effect of power, temperature, and pellet density. The outer ring pins (UO_2 diluted with U-238) release four times the quantity of stable fission product gases as did the mid-ring pins (UO_2). In all cases, the release rates were small and comparable to releases expected from recoils. Similar puncture tests will be made during the IB-2L-2 hot cell examination and will give initial data on the release characteristics of $BeO-UO_2$ fuel operated at reference conditions.

A temperature analysis indicates that the observed dents in the IB-2L outer liners will not increase the maximum fuel pin temperatures in these elements.

A test request was made for GCRE compressor coastdown with simultaneous depressurization. Since not all of the IB-2L fuel elements have pressure equalization holes in the liner, further consideration is being given to the possible effect of fuel element damage during the proposed depressurization.

b. ML-1: The silver-plated reactivity control shims in ML-1 are located between the outer liner and the pressure tube. The following table gives the maximum shim temperature for various conditions.

MAXIMUM SHIM TEMPERATURES

Condition	Pressure Tube Temp, °F	Outer Liner, Temp, °F
Steady state, full power operation	220	600
Normal shutdown	230	650
Coolant loss accident	240	850
Maximum credible accident	260	1150

During the maximum credible accident postulated in the ML-1 hazards report, all the fuel cladding and most of the fuel melts. The reactor reaches prompt critical during the excursion and then goes subcritical as the fuel melts. There is a remote possibility that the inner liner could melt, the insulation fall out and the silver eventually melt. However, it is considered impossible for the foregoing events to occur quickly enough (milliseconds) for the removal of the silver to bring the reactor back to a critical condition.

Expressions were formulated and solved for external loop activity (resulting from Hastelloy-X scaling) following ML-1 shutdown. The use of 2 wt% cobalt in Hastelloy-X increases the ML-1 truck cab shutdown dosage by 12 mr/hr after 10,000 hr operation with the following assumptions:

1) Power conversion skid gives an attenuation factor of 7.

2) 6.5×10^{-4} gm/cm^2 of scale is lost in 10,000 hr (0.0005-in. average thickness lost).

3) Cobalt content of the scale is depleted to one-fourth.

4) Scaling loss is linear with time.

For 3000 hr operation, the activity from the Ni-58 (n,γ)Co-58 reaction exceeds that from the Co-59 (n,p) Co-60 reaction.

Further study of scaling corrosion and mode of scale deposition is recommended.

Preliminary hot spot temperature analysis indicates maximum ML-1 fuel pin temperatures of 1600^{o}F. The effect of several additional factors will increase the initial estimate. A detailed report is being written on this work.

Ten of the ML-1 fuel elements have a thermocouple on the unloaded center pins. The calculated time constant of these thermocouples is 7 seconds. As a result of gamma heating in the steel rod surrounding these thermocouples, the thermocouples tend to read 25 to 35 F fegrees high. The temperature error due to axial conduction in the rod is negligible.

The HECTIC code was modifed to permit varying the axial power distribution of individual fuel pins. Preliminary ML-1 flux data indicated the advisiability of having this option available when calculating the orifice pattern for the ML-1.

The effect of mixing on fuel pin temperatures for the ML-1 system was evaluated as follows:

YED (HECTIC Mixing factor)	Maximum Fuel Pin Temperature (nominal conditions)^{o}F
0 (no mixing)	1450
1 (theoretical)	1442
5 (assumed value based on dye tests)	1420
10 (large amount of mixing)	1404

c. IB-3L Design: Maximum burnup in the IB-3L fuel element was calculated for 10,000 hr exposure at 3 Mw. In all cases, a peaking factor of 1.7 was used.

Case	Burnup
IB-3L (37 kg U-235, $P_3/P_2 = 1.5$)	1.75×10^{21} fissions/cc UO_2
IB-3L (37 kg U-235, $P_3/P_2 = 1.8$)	1.80×10^{21} fissions/cc UO_2
ML-1 (49.5 kg U-234, $P_3/P_2 = 1.1$)	1.76×10^{21} fissions/cc UO_2

(P_3/P_2 = ratio of power per pin in outer ring to power per pin in mid-ring)

Anticipated Accomplishments - July:

The calculated and experimental ML-1 power distributions will be completed and the majority of the ML-1 orifice pattern calculations will be completed.

The ML-1 hot spot work will be completed and edited.

All the data and knowledge concerning fuel pin wall thickness will be assembled preparatory to the decision on wall thickness for the IB-3L fuel pin.

Thermal calculations will be continued in support of GCRE and ML-1.

10.2 IB-14R Fuel Element (Task 21-4XX)

Review - January through May:

The IB-14R is the pilot model of the IB-3L fuel element, and is instrumented to obtain engineering as well as mechanical performance data in the GCRE. The design (Figure 10:3) incorporates temperature improvement features for the IB-3L, and mechanical improvements to eliminate the problems found in the IB-2L (see Section 7.4, Task 11-4XX). The improvements include elimination of the center support, dowel pins substituted for roll pins, larger fuel pin joints, and the expansion joint modified and relocated from the 1200^{o}F to the 800^{o}F zone. Modification to the expansion joint includes slitting the inner tube to reduce circumferential rigidity, thus reducing galling.

The IB-14Ø is a flux mapping element to be used in conjunction with the IB-14R.

The drawing of the IB-14R instrumented fuel element was completed during the period. The drawing of the IB-14Ø was 95% completed, and the modified IB-9R-2 drawing was 80% completed. Procurement for these elements was 60% completed by the end of the period.

Accomplishments - June:

The IB-14Ø flux element drawings were released for fabrication.

The drawings for the modified IB-9R-2Ø element were completed and checked, but minor changes are required before release. This flux element is similar to the IB-2L elements and operating data from this element will be used to calibrate and reduce the data from the IB-14Ø element.

The inner and outer liners were received for the two models of this element (the M-1 and M-2). All parts now are available. These two models will be integrated into the development and testing task (Section 7.1, Task 11-1XX), and will not be reported under this task.

Assembly work on the IB-14R instrumented element was begun.

Anticipated Accomplishments - July:

The modified IB-9R-2Ø drawings will be released for fabrication, and fabrication will be about 60% completed.

Fabrication of the IB-14Ø flux element will be about 80% completed.

10.3 Fuel Design (Task 21-6XX)

Review - January through May:

The IB-9R-3b instrumented fuel element was designed, fabricated, and sent to the GCRE site.

An engineering evaluation of the failures (roll pin failure and retainer nut separation) in some of the IB-2L power elements concluded primary cause of failure was shock loads on the element during the re-orificing operation. Those elements with this deficiency were removed from the reactor for repair.

Since the expansion joint froze in experiments this effect may contribute to the failure of the roll pins. Methods of modifying the upper support were studied. These methods would free the inner liner to expand if the expansion joint seizes.

The IB-3L conceptual design was begun and was continued in the IB-14R design. The design is compared with the ML-1 in Table 10:1 on the following page.

Accomplishments - June:

The design work for the IB-3L fuel element continues to be the same as for the IB-14R.

Anticipated Accomplishments - July:

Conceptual design work for the IB-3L core will begin.

10.4 Reactor Physics (Task 21-7XX)

Review - January through May:

a. ML-1 Criticality: The criticality of the ML-1 and subsequent experiments permitted a comparison of predictions with experimental results. Some predictions were based on theoretical calculations and others were based on the extrapolation of data from the ML-1-IB critical assembly. Several items of interest are compared in the table at the bottom of the following page.

The poison shim liners significantly distort axial flux distribution in the ML-1. The effect of this distortion on control rod worth was estimated. The revised control rod worth were 1.5% and 0.4% $\delta k/k$ for the shim and regulating blades, respectively.

TABLE 10-1 - IB-14R VS. ML-1-I FUEL ELEMENT

Fuel Pin	ML-1-I As-Built	IB-14R 1 June 1961
Type	Smooth	Smooth and finned
Material	Hastelloy-X (0.07% Co)	Hastelloy-X (~2.0% Co)
Outside diameter	0.241 in.	0.260 in.
Inside diameter (in.)	0.180	0.198
Clad thickness (in.)	0.030	0.020 and 0.030
Fin height (in.)	---	0.012
Fin length (in.)	---	13.5
Core Loading (kg)	49	36.4
Inner Liner		
Material	Hastelloy-X	Hastelloy-X
Inside diameter (in.)	1.426	1.530
Thickness (in.)	0.010	0.101
Outer Liner		
Material	AISI Type 316 SS	AISI Type 316 SS
Outside diameter (in.)	1.648 to 1.686	1.698 to 1.686
Inside diameter (in.)	1.666 to 1.670	1.666 to 1.670
Insulation		
Material	Thermoflex	Thermoflex
Direction of fibers relative to heat flow	Perpendicular	Perpendicular
Thickness (in.)	0.111	0.056

COMPARISON OF PREDICTIONS WITH EXPERIMENTAL RESULTS

Item	Theory	Extrapolation	Experiment
Critical loading, element	46	48	46.5
Shim liners required	25	--	28
Tungsten baffle worth, % $\delta k/k$	+0.28	--	+0.17
Shim rod worth (max), % $\delta k/k$	--	-1.8	-1.4
Regulating rod worth (max), % $\delta k/k$	--	-0.5	-0.45
Flooding worth, % $\delta k/k$	--	+5.5	+3

The predicted values listed above generally are in good agreement with experimental results. The most significant deviation occurs in the reactivity worth of flooding the gas passages of the core. The most probable reason for this error is that the relative worth of the shim liners is greater in the flooded core than in the dry core. This increase in relative worth would be caused by the shift in the intracell flux distribution when the core is flooded. The validity of this hypothesis will be investigated in the future.

b. ML-1 Power Distributions: Power distributions in the ML-1 core were calculated, using the PDQ code on the IBM-7090. (PDQ is a two-dimensional diffusion theory code.) The problems were run using two neutron energy groups and in both x-y and r-z geometry. Due to the three-dimensional nature of the ML-1 core the results of several problems were combined to synthesize the predicted power distribution.

The radial power distributions calculated for various cases are given in Figure 10:4. The figure also shows experimental data from the critical assembly. The final synthesized power distribution is given in Figure 10:5. The radial reflector of the ML-1 contains tungsten over a 180° segment. The effect of the maximum anticipated skew due to the tungsten is also shown in Figure 10:5. Typical axial power distributions are given in Figures 10:6 and 10:7. The distortion caused by the silver-plated poison shim liners is quite noticeable.

Power mapping experiments to be performed in the ML-1 will provide a check on the validity of these calculations.

c. Reactivity Lifetime of ML-1 and IB-2L: Both the ML-1 and the IB-2L core in GCRE use burnable poisons to reduce changes in system reactivity during core life. The burnable poison requirements were based on one-group perturbation theory analysis and inadequate flux distribution data. Two-group hand calculations were performed using better flux distribution and cross-section data. These calculations indicated that the burnable poison will burn out faster than desired giving a marked increase in system reactivity. The calculated curves of reactivity versus operating time are shown in Figure 10:8.

The maximum increase in system reactivity is 0.8% and 1.5% for the ML-1 and IB-2L, respectively. A limited amount of data from GCRE operation is shown in Figure 10:9. A change in the system reactivity of about 0.2% is seen in about 400 hr of operating time. This is in fair agreement with calculations.

This problem will be studied in more detail using the BURP code. BURP is a two-dimensional, two-group perturbation theory code for calculating burnup. The code soon should be ready for production use.

d. IB-3L and ML-1-II Fuel Element Design: The IB-3L and ML-1-II fuel elements will have 19 uniformly loaded fuel pins according to current plans. These fuel pins will be slightly larger than the present ML-1 pins and will contain about 65 wt% UO_2 in a BeO matrix. The ratio of the power produced in an outer pin to that produced by a mid-ring pin was calculated to be about 1.5. The maximum surface temperature will occur on the outer fuel pins. As the fuel burns out, this effect will decrease the maximum surface temperature. Variations in the pin to pin power distribution have a relatively small effect on the maximum surface temperature (Figure 10:10). Since the power distribution is a function of fuel loading, this insensitivity permits greater flexibility in selecting the fuel loading. Calculations indicate that the total loading of the ML-1-II can be reduced from 49 to 36 kg of U-235.

The IB-14R instrumented fuel element was designed along these lines and will be run in the GCRE. A flux and power mapping element (IB-14Ø) will be irradiated before the IB-14R is inserted. This experiment will provide information which may be used in conjunction with the power distribution and criticality calculations.

e. Advanced Calculational Techniques: The 2DXY code is a two-dimensional, multigroup transport theory code for the IBM-7090 which uses the S_n approximation in x-y geometry. This code is being used in trial calculations of thermal flux distribution in ML-1 type fuel elements. Preliminary results are encouraging, but not conclusive.

If this code proves to be satisfactory the need for experimental flux measurements will be greatly reduced.

f. ML-1-IIC Experiments: A series of experiments were planned for the ML-1 to obtain additional experimental data for use in the design of advanced fuel elements. Special test elements were designed and fabricated to provide power distribution and reactivity data over a range of pin sizes and fuel loadings. The data from these experiments will be used with theoretical calculations in the final design of the IB-3L and ML-1-II fuel elements.

g. Miscellaneous Calculations: The GCRE shows an increase in reactivity following a short shutdown (Figure 10:9) rather than the expected decrease due to xenon buildup. Calculations showed that for low flux (less than 10^{13} n/cm^2-sec) reactors, the xenon poisoning decays within an hour after shutdown. The calculated xenon decay was in good agreement with observed change in reactivity.

Both the ML-1-IB critical assembly and the IB-2L core in GCRE have positive moderator temperature coefficients of reactivity and also show an increase in reactivity due to flooding. This implies that either removal of hydrogen from the moderator region or the addition of hydrogen to the gas passages will increase system reactivity. Calculations were performed to determine the cause of this apparent anomaly. It was concluded that the dominant reactivity effects were quite different in the two cases. Increasing the moderator temperature flattens the intracell flux distribution. This increases the thermal utilization, thereby increasing system reactivity. Flooding of the gas passages reduces fast leakage and increases the fraction of the neutrons that are thermalized. This also increases the system reactivity.

Low cobalt Hastelloy-X alloys do not appear to be as oxidation resistant as the alloys with normal (approximately 2.0%) cobalt content. It was calculated that an increase in cobalt content to 2% corresponds to a 1 kg increase in the design U-235 loading of any future core.

A large number of IB-2L fuel elements separated at the upper hanger. This separation caused the fuel pins to move upward about 1/8 in. relative to the rest of the fuel element. The net effect of this motion was to add a 1/8 in. water reflector at the bottom of the core. The reactivity increase was found to be 0.05% $\delta k/k$, if every element in the core had moved up 1/8 in.

Multi-group hand calculations were performed to find the relative absorption of various control rod materials in the GCRE neutron spectrum. It was found that 0.020-in. of silver laminated in stainless steel would be virtually identical from a neutronic standpoint with the present 0.090-in. tungsten alloy control rods.

Various materials and geometries for burnable poisons were studied in detail. Lumped poisons, for example, appeared to have better burnout characteristics than the present poison foils. Additional study will be required, however, to find the proper combination to give the desired reactivity variation (less than 0.3% $\delta k/k$) during the life of future cores.

Accomplishments - June:

The prediction of reactor nuclear properties depends upon the ability to properly homogenize a unit cell of the reactor. This is accomplished for the thermal neutron group by using the P-3 method of solving the transport equation to obtain the flux distribution throughout the cell, and then using this result to properly weigh the cross-sections. A nuclear code, I-2, previously was used for these calculations, but this code is not adaptable to the IBM-7090 machine. Consequently, work was started to modify an existing P-3 code, IDIOT for the IBM-7090 and add an input and output routine to the code. These additional routines will calculate the proper cross-sections to be used for a specified material and, after the P-3 calculation, find the equivalent homogeneous cell cross-sections. The resulting code, named BLOT, will also be able to use the "source-sink" method of correcting for neutron streaming between pins. All work of writing and assembling of the code is now complete and the code is being checked.

Continued work using the 2DXY transport code to predict fluxes throughout the reactor cell produced good results. This code, which does not need the normalization to experimental data necessary in the corrected P-3 calculations, utilizes the solutions of the S_n equations in an x-y geometry. Results of a test problem have yielded pin power ratios within 15% of those obtained experimentally. Continued effort is being expended in further checks and in understanding this method.

The predicted power distributions in the ML-1 core were modified by considering a more advanced and detailed analysis than undertaken previously. The problem arises in the use of predicted values from the symmetrical r-z two-dimensional calculations which do not consider a partially filled ring of elements with shims, and the x-y calculations that do not consider the axial power distribution changes when shims are present. It thus is necessary to superimpose the results of a series of these calculations. Figure 10:11 shows the new predicted values. These values will be compared to experimental results.

Anticipated Accomplishments - July:

BURP, a burnup code using two-group perturbation theory, will be finished and preliminary results obtained for the GCRE-IB-2L and the ML-1 cores. This method will give reactivity variations and power shifts as a function of time.

The experimental power distribution in the ML-1 core will be compared to theoretical values. Any gross discrepancy will be considered as a sufficient reason for reviewing and modifying calculational techniques so that future predictions will be closer to the true power generations.

Analysis to predict the nuclear characteristics of flooded cores will start. The experimental results available from the GCRE, ML-1, and the two critical experiments provide cases which must be predicted correctly before any method (to be chosen in this analysis) can be accepted and used to predict future flooded cores.

BLOT, a P-3 cell code, will be finished and available for use in standard cell analysis problems.

10.5 ML-1-II Replacement Experiments (Task 21-8XX)

Review - January through May:

a. ML-1-IB Critical Assembly: A series of critical experiments, designated ML-1-IB, was completed in the previous period at Battelle Memorial Institute. The data was reviewed at Aerojet. (The final report, BMI-1501, was issued by BMI.)

b. ML-1-IIC Power Ratio Experiment: Design of the ML-1-IIC power ratio and replacement reactivity elements was completed, and the drawings released for fabrication. This experiment will be performed in ML-1 during low power operation this year.

Ten of the twelve elements are designed to use fuel pins from the ML-1-IB critical assembly at BMI. These pins were shipped from BMI to the GCRE site. The hardware for these elements was fabricated at Aerojet, San Ramon, and will be shipped to GCRE where the fuel elements will be assembled.

Two of the elements contain $BeO-UO_2$ pellets of a different size than the other ten. Pellet and hardware fabrication and assembly were completed.

A holder for normalizer capsules was completed.

A test plan was prepared for the ML-1-IIC experiments.

Accomplishments - June:

Capsule fabrication was completed.

Anticipated Accomplishments - July:

Dismantling of the ML-1-IB experimental structure will be discussed with BMI.

BIBLIOGRAPHY

1. Rickey, C.R., "IDIOT, A Lattice Parameter Code for the IBM-709," HW-63411, 7 January 1960.

IB-14R AXIAL TEMPERATURE PROFILE

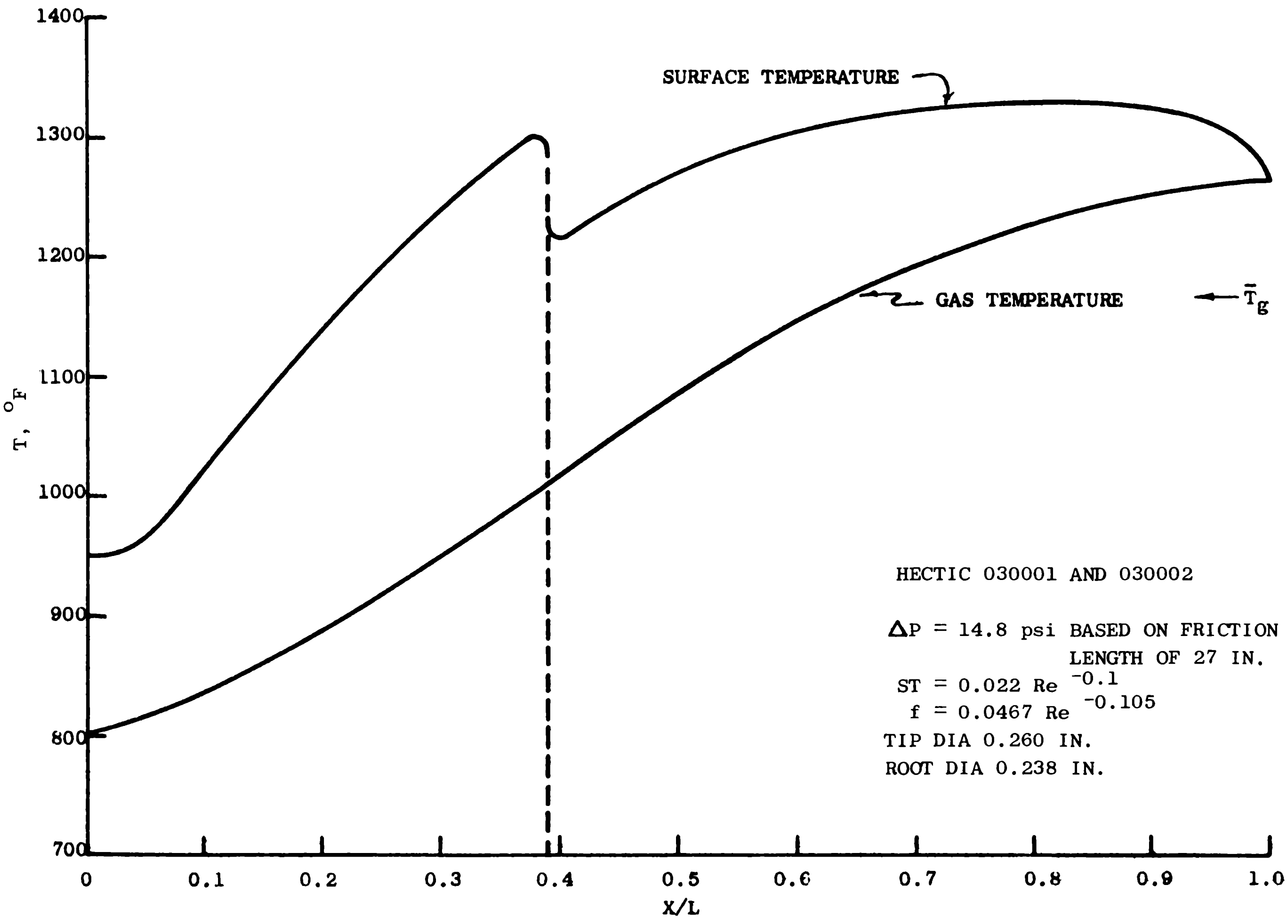


FIGURE 10:1

CHOICE OF HEAT TRANSFER SURFACE

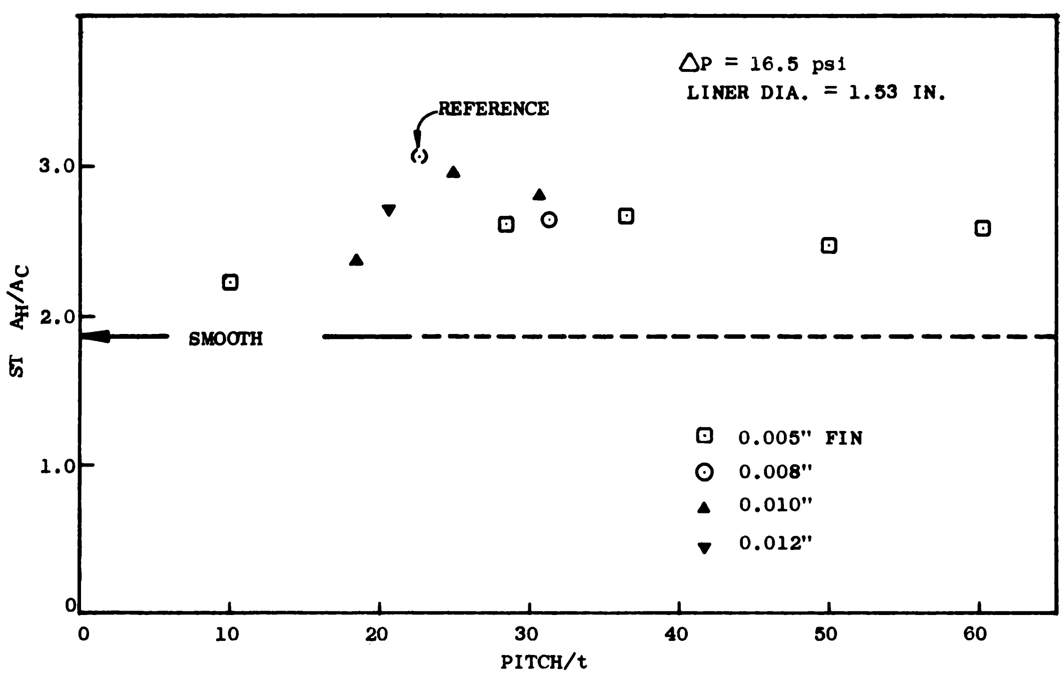


FIGURE 10:2

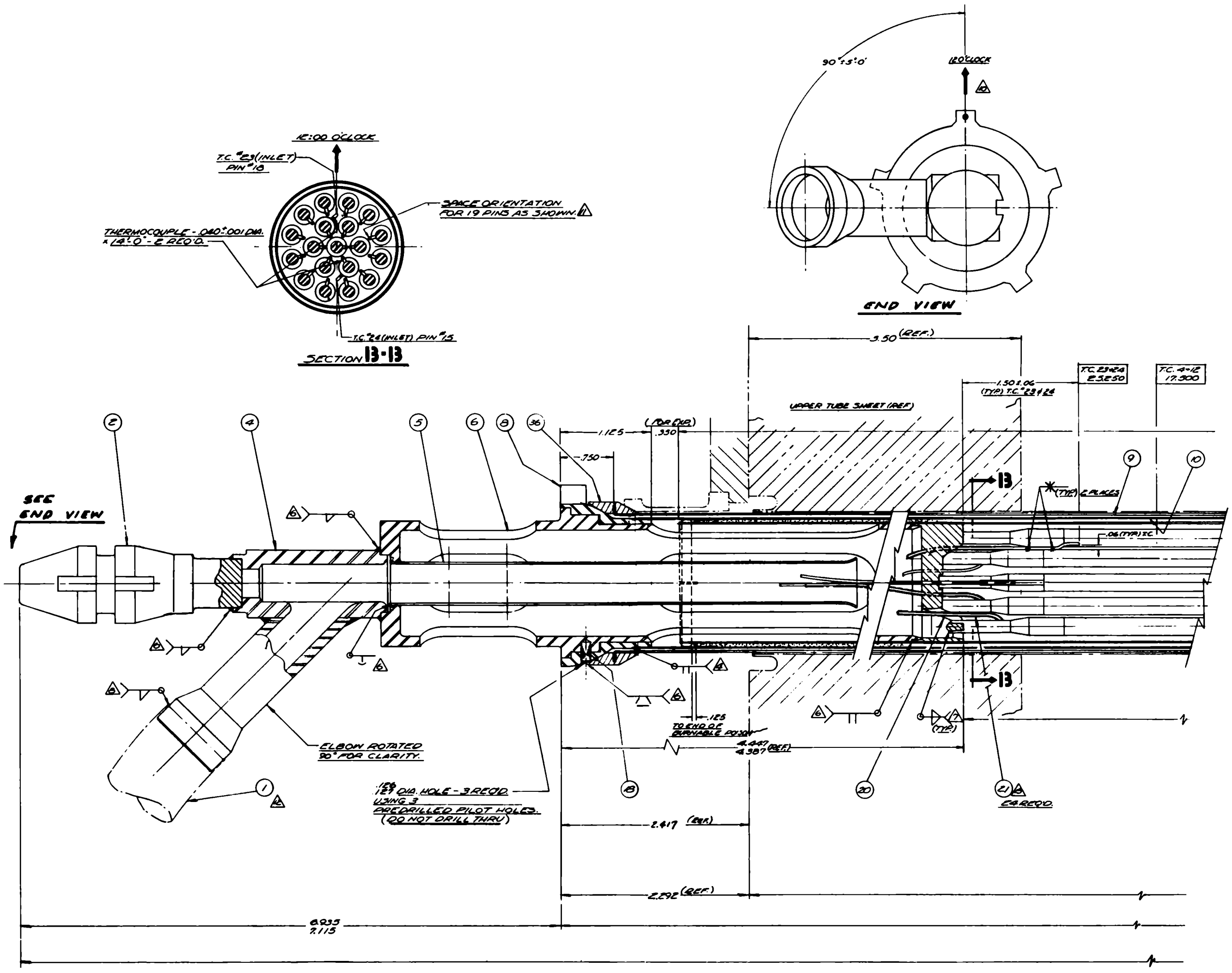
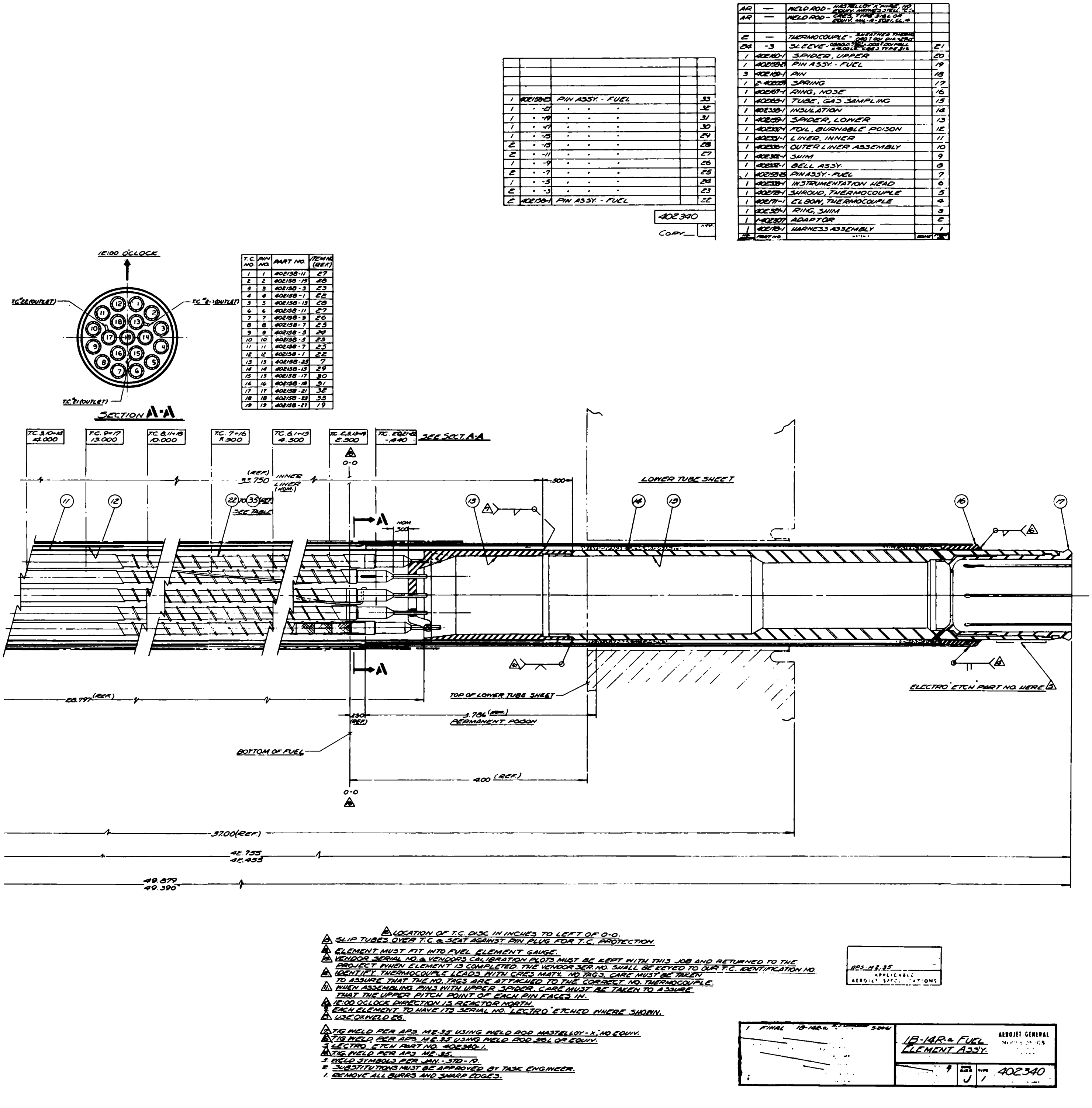

12:00 O'CLOCK
T.C. #23 (INLET) PIN #18
SPACE ORIENTATION FOR 19 PINS AS SHOWN
THERMOCOUPLE - .040 ±.001 DIA. x 14'-0" - 2 REQ'D.
T.C. #24 (INLET) PIN #15
SECTION B-B
12 O'CLOCK
END VIEW
3.50 (REF.)
UPPER TUBE SHEET (REF.)
SEE END VIEW
ELBOW ROTATED 90° FOR CLARITY.
PREDRILLED PILOT HOLES.
(DO NOT DRILL THRU)
TO END OF BURNABLE POISON
2.417 (REF.)
2.292 (REF.)
6.935
7.115

FIGURE 10:3



T.C. NO.	PIN NO.	PART NO.	ITEM NO. (REF.)
1	1	402158-11	27
2	2	402158-13	28
3	3	402158-3	23
4	4	402158-1	22
5	5	402158-13	28
6	6	402158-11	27
7	7	402158-9	26
8	8	402158-7	25
9	9	402158-5	24
10	10	402158-3	23
11	11	402158-7	25
12	12	402158-1	22
13	13	402158-25	7
14	14	402158-15	29
15	15	402158-17	30
16	16	402158-19	31
17	17	402158-21	32
18	18	402158-23	33
19	19	402158-27	19

1	402158-23	PIN ASSY. - FUEL		33
1	" -21	" " "		32
1	" -19	" " "		31
1	" -17	" " "		30
1	" -15	" " "		29
2	" -13	" " "		28
2	" -11	" " "		27
1	" -9	" " "		26
2	" -7	" " "		25
1	" -5	" " "		24
2	" -3	" " "		23
2	402158-1	PIN ASSY. - FUEL		22

QTY	PART NO.			ITEM NO.
AR	—	WELD ROD - HASTELLOY X WIRE, NO EQUIV. HAYNES STELL. CO.		
AR	—	WELD ROD - CRES, TYPE 316L OR EQUIV. MIL-R-5031, CL. 8		
2	—	THERMOCOUPLE - SHEATHED THERMO .080 ± .001 DIA. 250		
24	-3	SLEEVE - .0580 O.D. ± .001 x .005 ± .001 WALL x 9.00 LG. CRES TYPE 316		21
1	402160-1	SPIDER, UPPER		20
1	402158-27	PIN ASSY. - FUEL		19
3	402159-1	PIN		18
1	2-402057	SPRING		17
1	402167-1	RING, NOSE		16
1	402165-1	TUBE, GAS SAMPLING		15
1	402338-1	INSULATION		14
1	402159-1	SPIDER, LOWER		13
1	402337-1	FOIL, BURNABLE POISON		12
1	402331-1	LINER, INNER		11
1	402336-1	OUTER LINER ASSEMBLY		10
1	402322-1	SHIM		9
1	402152-1	BELL ASSY.		8
1	402158-25	PIN ASSY. - FUEL		7
1	402339-1	INSTRUMENTATION HEAD		6
1	402173-1	SHROUD, THERMOCOUPLE		5
1	402171-1	ELBOW, THERMOCOUPLE		4
1	402321-1	RING, SHIM		3
1	1-402307	ADAPTOR		2
1	402178-1	HARNESS ASSEMBLY		1

ML-1 RADIAL POWER DISTRIBUTION

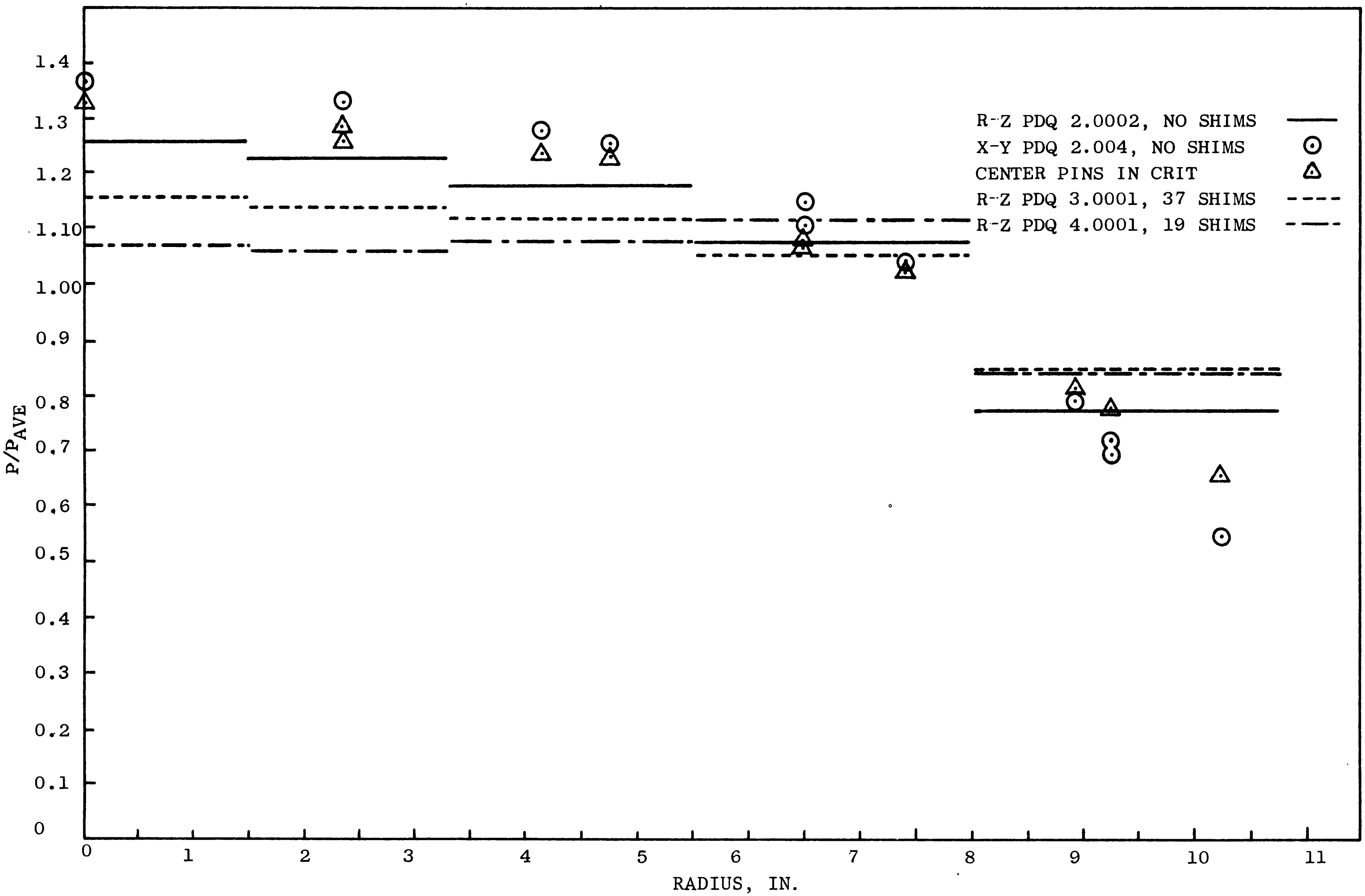
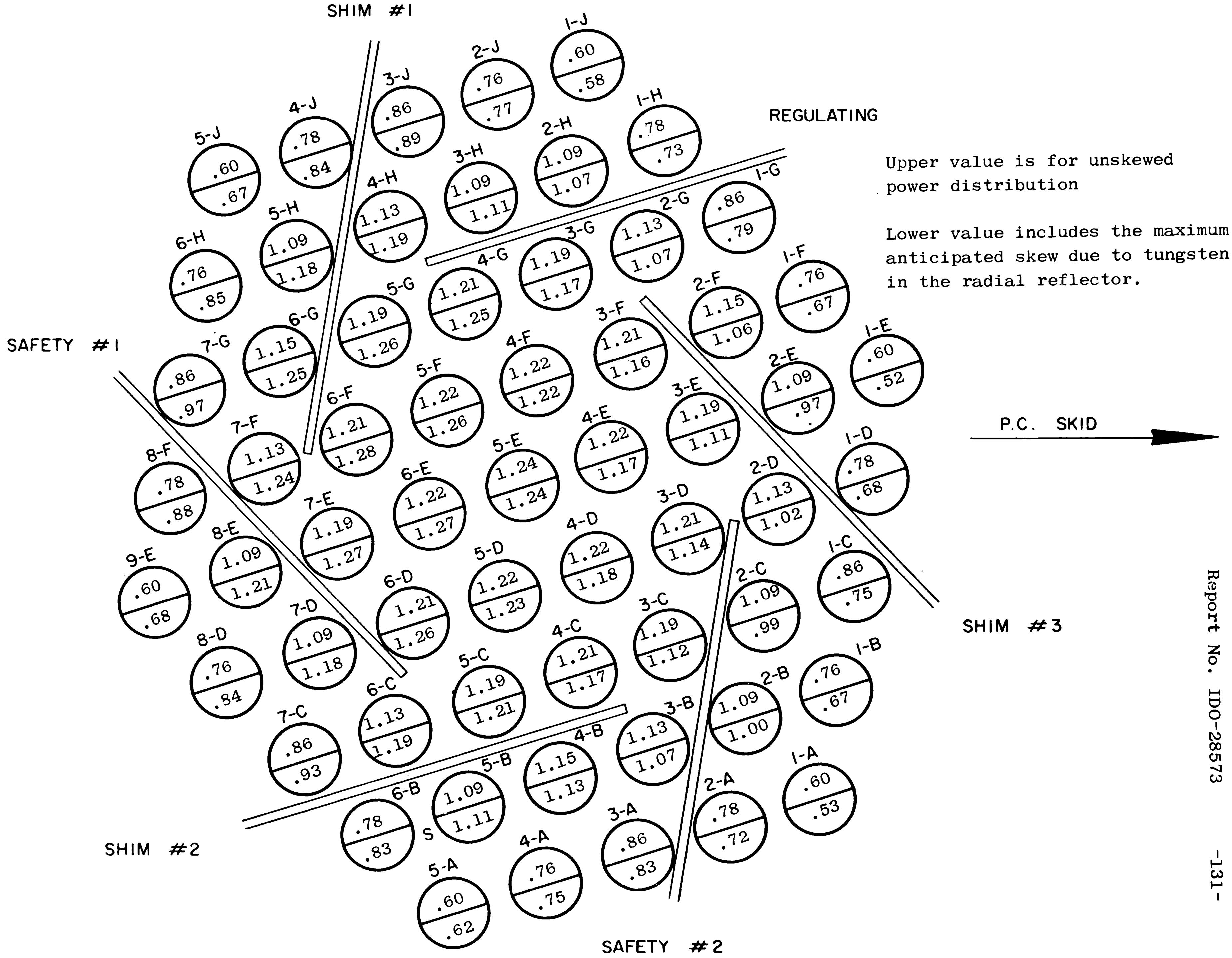


FIGURE 10:4

RELATIVE POWER DISTRIBUTION WITH 28 SHIMS INSERTED



Upper value is for unskewed power distribution

Lower value includes the maximum anticipated skew due to tungsten in the radial reflector.

FIGURE 10:5

AXIAL POWER DISTRIBUTION IN THE ML-1 WITH 19 SHIMS

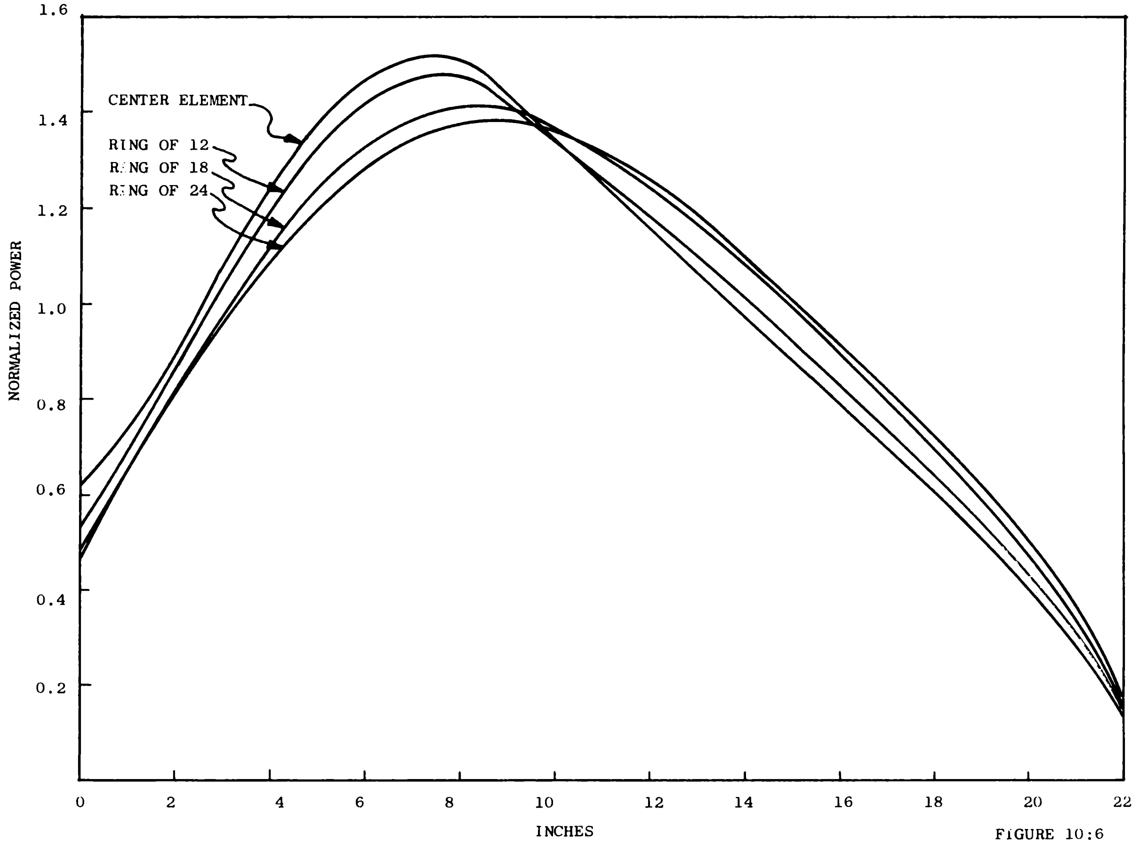


FIGURE 10:6

AXIAL POWER DISTRIBUTION IN THE ML-1 WITH 37 SHIMS

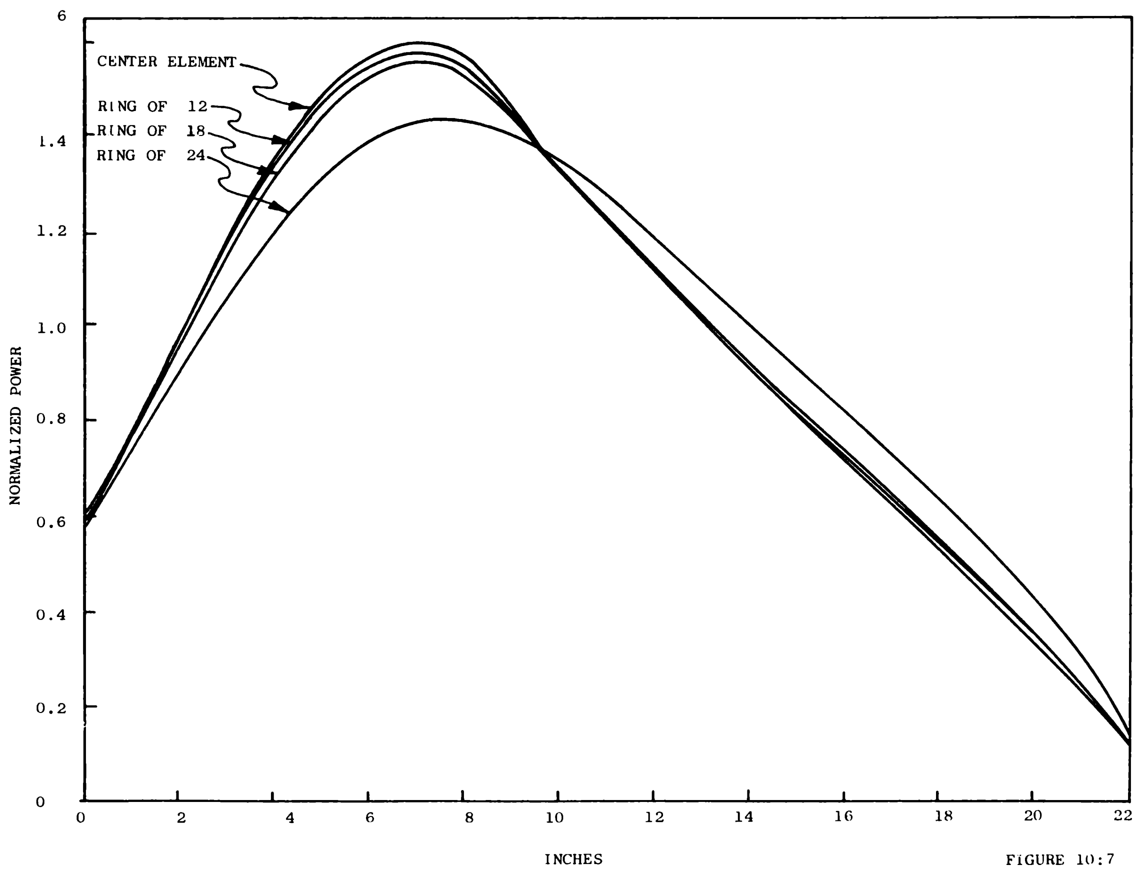


FIGURE 10:7

REACTIVITY LIFETIME ML-1 AND IB-2L

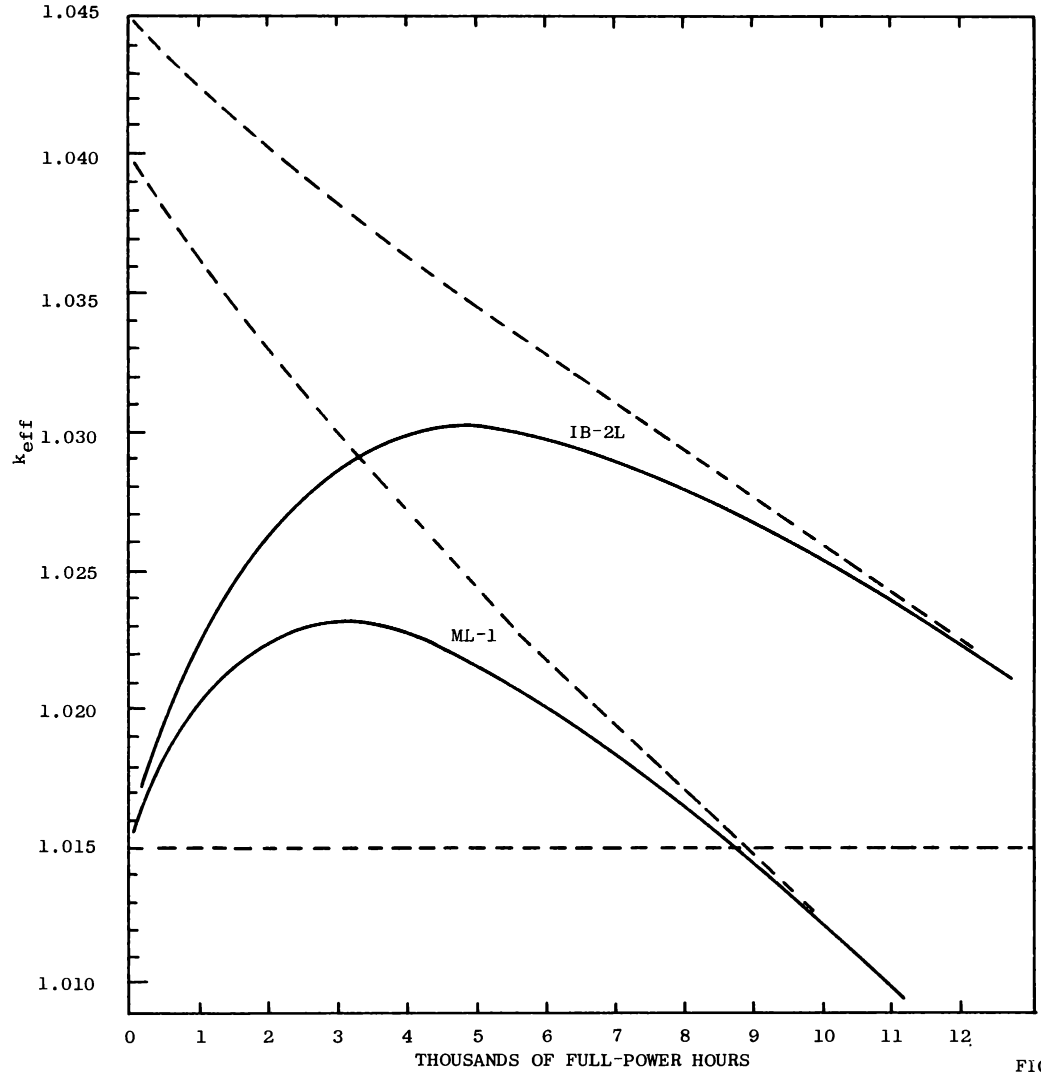


FIGURE 10:8

IB-2L EXCESS REACTIVITY

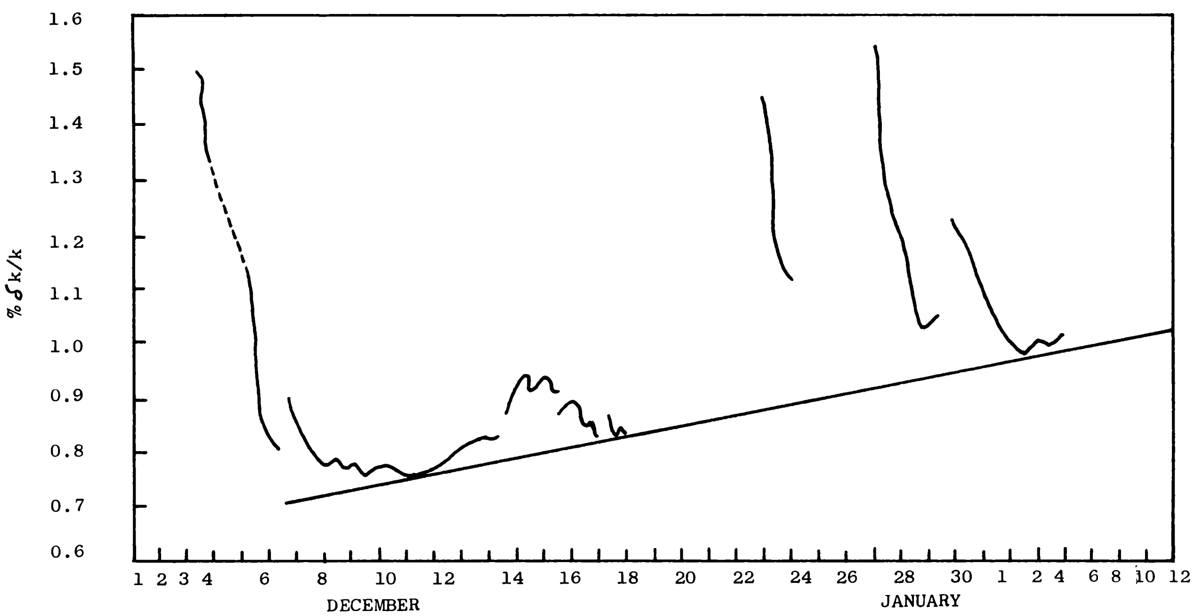


FIGURE 10:9

NOMINAL MAXIMUM SURFACE TEMPERATURE
Pin-Type Fuel Elements (Without Fins)

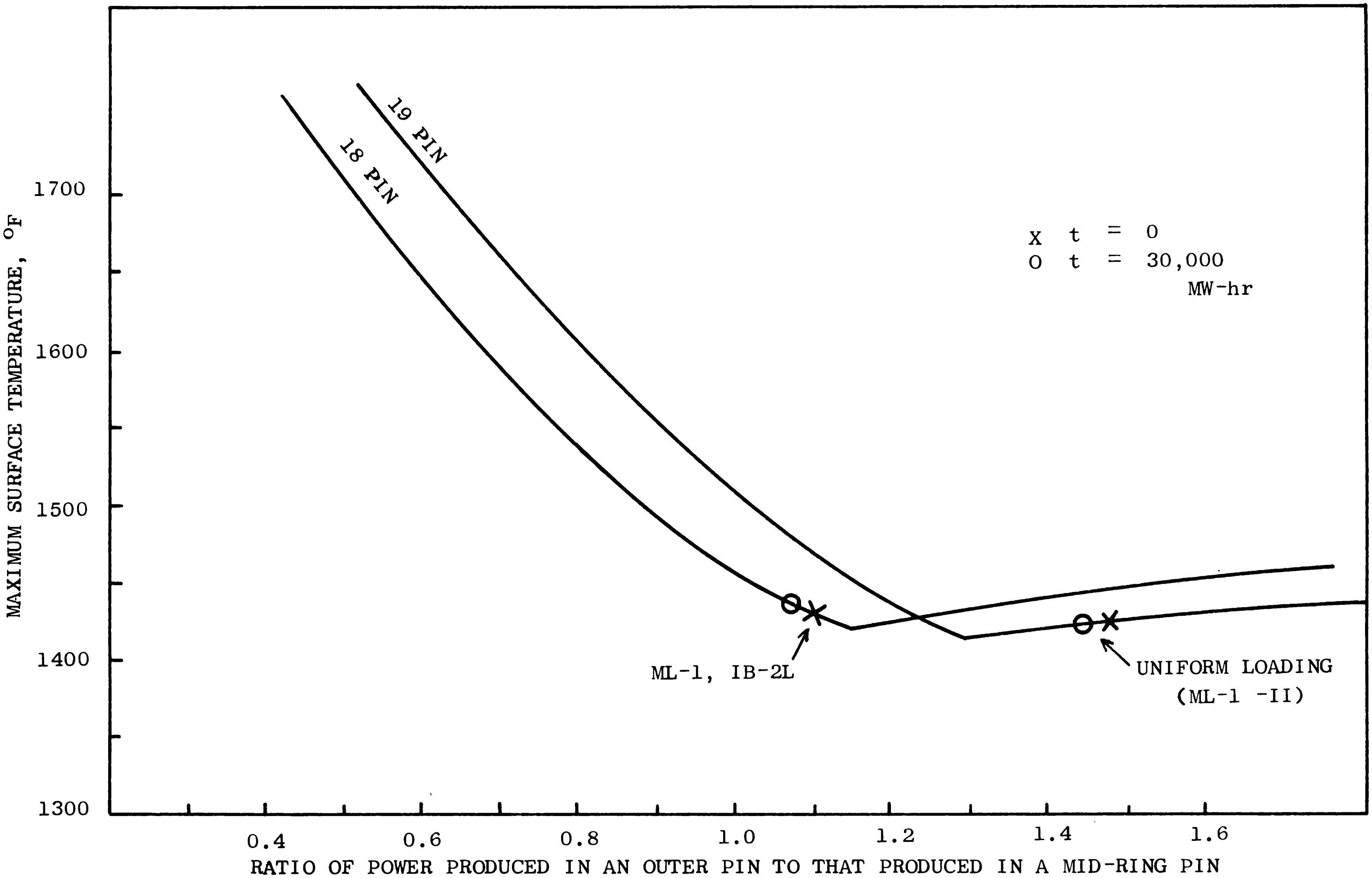
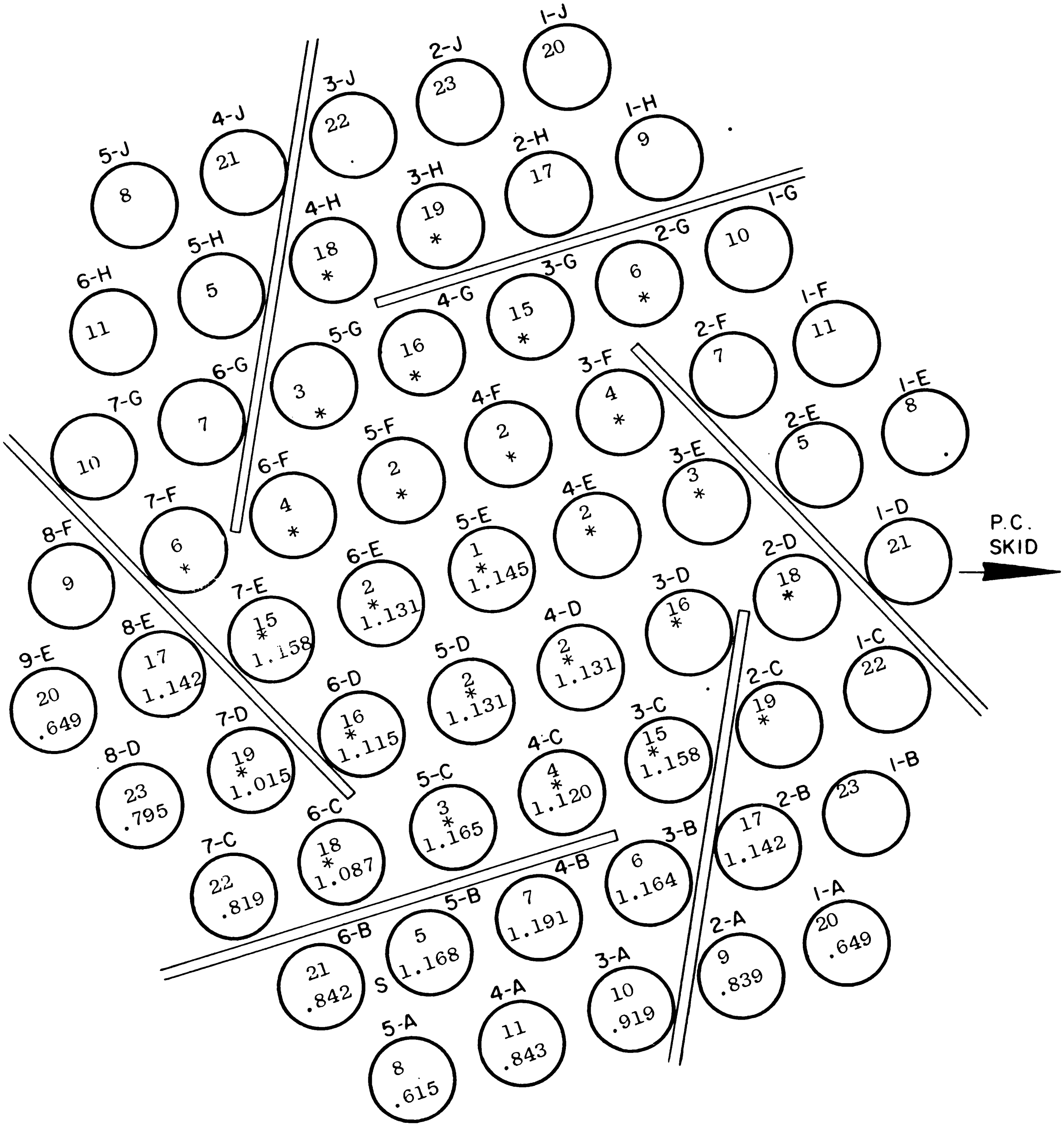


FIGURE 10:10

ML-1 I POWER DISTRIBUTION AND FUEL ELEMENT ORIENTATION
(28 SILVER SHIMS)



NOTES:
1. AVERAGE INTEGRATED VALUES OF ELEMENTS IN A 120° SECTOR ARE SHOWN.
2. AVERAGE POWER PER ELEMENT = 1.
3. * ELEMENTS WITH .005 IN. SILVER SHIM.
4. NUMBERS OUTSIDE ARE ML-1 I CORE DESIGNATIONS.

FIGURE 10:11

11.0 ML-1-I CORE PRODUCTION (Task 22-1XX)

Review - January through May:

The core was completed in February. Fifty-eight power and eleven instrumented ML-1-I fuel elements with shims and orifices, and three flux elements with 250 capsules were shipped to the GCRE test site.

The task was completed in February.

12.0 CORE PRODUCTION

12.1 IB-2L Core (Task 62-1XX)

Review - January through May:

Sixteen fine-variable size orifices were machined and sent to the GCRE test site with eight spare fuel elements.

Accomplishments - June:

Disposition of IB-2L tooling, spare parts, and materials was completed.

The design work and procedure for repair of the IB-2L fuel elements were completed.

Anticipated Accomplishments - July:

Tooling and parts for the repair of the IB-2L core will be completed and trial repairs will be made.

12.2 IB-3L Core (Task 62-2XX)

Review - January through May:

The specifications and requisitions were prepared for the IB-3L fuel pins was initiated.

Accomplishments - June:

The fuel pin requisitions and specifications were sent out for quotation.

Anticipated Accomplishments - July:

The quotations for the IB-3L fuel pin tubing will be reviewed and submitted to IDO for approval.

IV. THE GAS TURBINE TEST FACILITY

(Note: The Gas Turbine Test Facility, Fort Belvoir, Virginia, is of interest to the AGCRSP insofar as work under Contract DA-44-192-ENG-8 will affect completion of the ML-1 and contribute to the design of power conversion equipment compatible with the ML-1 system. The complete report on GTTF activities is made under the relevant contract.)

Review - January through May:

The TCS-560 (a turbine-compressor set built by Stratos) was being repaired by the vendor until March when it was reassembled. The cold seal run-in tests were performed on 29 March, and the loop reassembled. One major experiment was conducted in April to provide for Government acceptance of this t-c set. The experiment was not completed due to failure of the turbine shaft bearing at 13,700 rpm. Disassembly of the turbine was completed on 24 April. The vendor completed repair of the t-c set in June, and testing will resume early in July.

Technical work was completed on the GTTF-1A Summary Design Report in February and the report was published in March. The design of the operating and analysis instrumentation was virtually completed when all design effort on the GTTF-1A was stopped in May at the direction of the Contracting Officer.

Quotations were solicited for the replacement recuperator for the GTTF in February. Quotations were received from four prospective vendors in May. The quotations were evaluated, but additional effort will not be expended in this area until the revised design conditions are received from the Contracting Officer.

A contract modification was received in April for the replacement recuperator.

APPENDIXES

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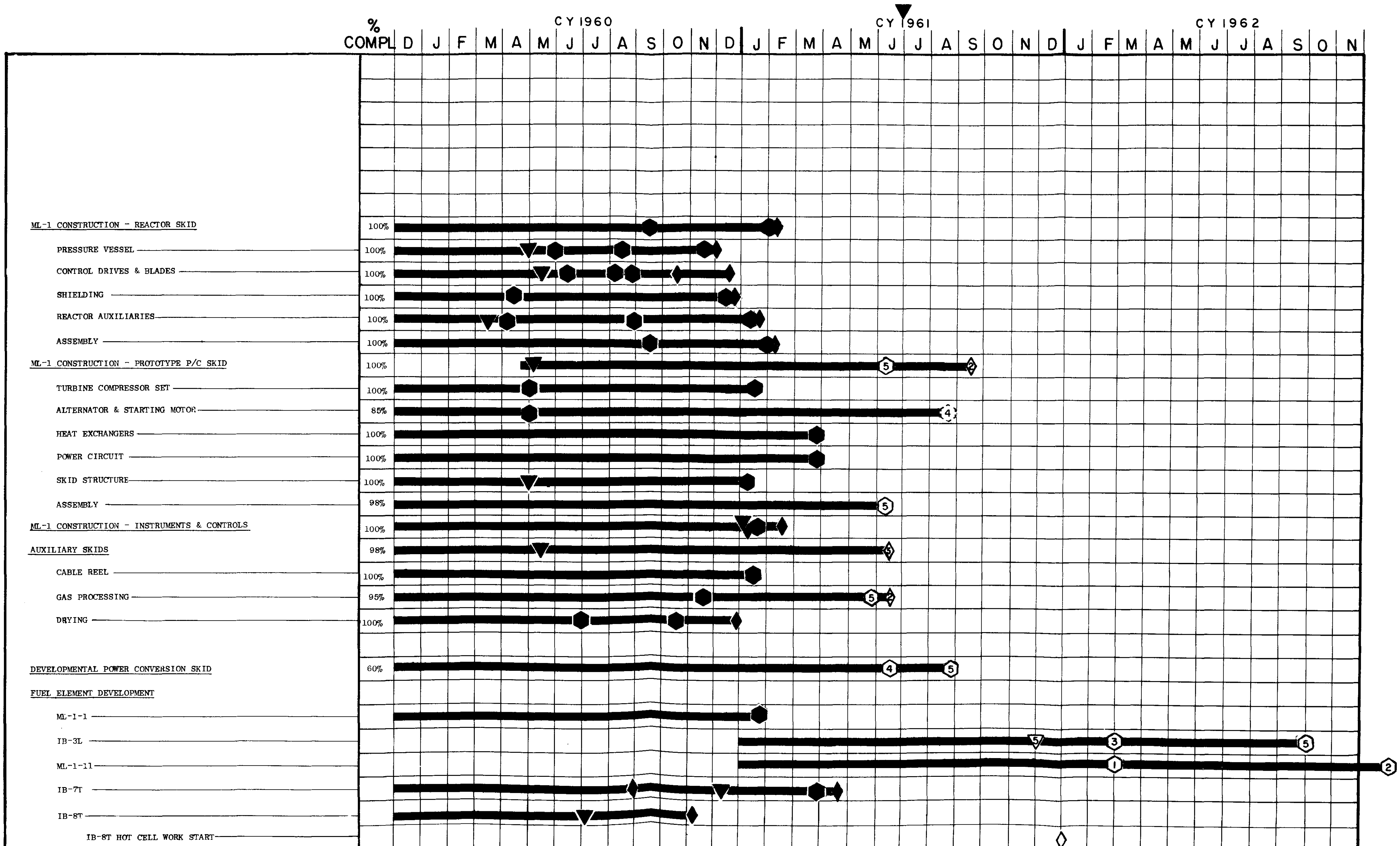
APPENDIX A	THE AGCRSP MASTER SCHEDULE	143
APPENDIX B	ML-1 PLANT CHARACTERISTICS	147

LEGEND

SYMBOL	TYPE OF PROJECT: DESIGNS STUDIES & REPORTS	TYPE OF PROJECT: PROCUREMENT OR FABRICATION OF "HARDWARE"	TYPE OF PROJECT: OPERATING OR TESTING
▽ 1	CONCEPTUAL DESIGN APPROVED OR SCOPE OF STUDY OR REPORT APPVD.		
▽ 2	PRELIMINARY DESIGN APPROVED OR STUDY INITIATED		
▽ 3	COMPLETION OF INTERIM REVIEW OF DESIGN OR STUDY REVIEW		
▽ 4	APPROVED LAYOUT DRAWING RELEASED OR INITIATION OF DETAILED DESIGN OR REPORT ROUGH DRAFT		
▽ 5	RELEASE OF ALL DRAWINGS COMPLETED OR STUDY COMPLETE OR REPORT PUBLISHED		
▽ 6	SPECIFICATIONS APPROVED		
▼	MILESTONE ACHIEVED		
⬡ 1		COMPONENT PROCUREMENT INITIATED	
⬡ 2		COMPONENT PROCUREMENT COMPLETED	
⬡ 3		COMPONENT FABRICATION INITIATED	
⬡ 4		COMPONENT FABRICATION COMPLETED	
⬡ 5		ASSEMBLY FABRICATION COMPLETED	
⬢		MILESTONE ACHIEVED	
◇ 1		COMPONENT ACCEPTANCE TESTING COMPLETE	
◇ 2		ASSEMBLY ACCEPTANCE TESTING COMPLETE	
◇			OPERATION OR TESTING TARGET DATE
◆			OPERATION OR TESTING TARGET DATE ACCOMPLISHED

APPENDIX A AGCRSP MASTER SCHEDULE



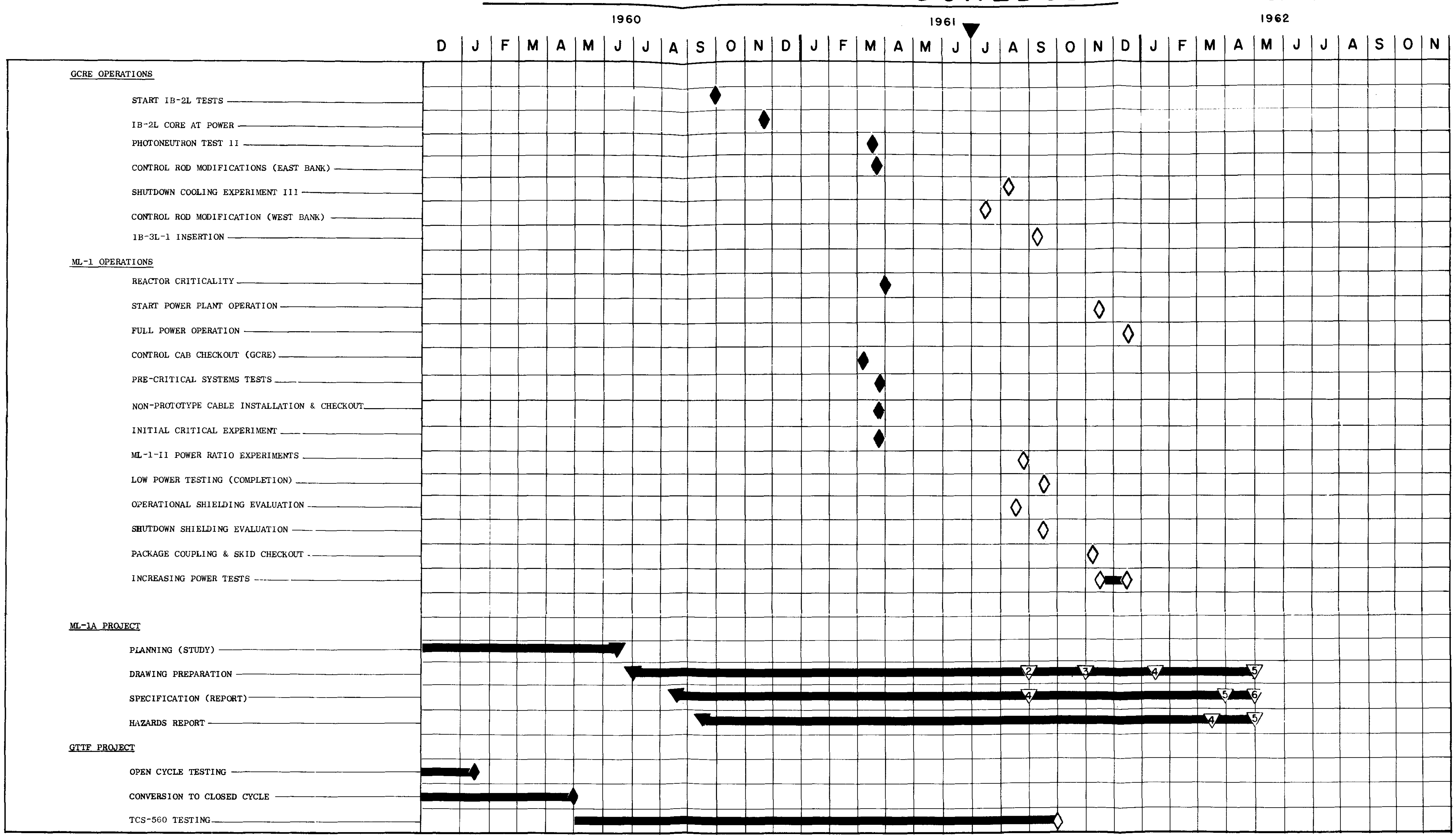
KEY (see legend facing page): ▽ DESIGNS, STUDIES, AND REPORTS ⬡ PROCUREMENT OR FABRICATION OF "HARDWARE"; ◇ COMPONENT, ASSEMBLY TESTING; ▼⬢◆ MILESTONES ACHIEVED ▽⬡◇ MILESTONES NEW OR CHANGED

LEGEND

SYMBOL	TYPE OF PROJECT		
	DESIGNS STUDIES & REPORTS	PROCUREMENT OR FABRICATION OF "HARDWARE"	OPERATING OR TESTING
▽1	CONCEPTUAL DESIGN APPROVED OR SCOPE OF STUDY OR REPORT APPVD.		
▽2	PRELIMINARY DESIGN APPROVED OR STUDY INITIATED		
▽3	COMPLETION OF INTERIM REVIEW OF DESIGN OR STUDY REVIEW		
▽4	APPROVED LAYOUT DRAWING RELEASED OR INITIATION OF DETAILED DESIGN OR REPORT ROUGH DRAFT		
▽5	RELEASE OF ALL DRAWINGS COMPLETED OR STUDY COMPLETE OR REPORT PUBLISHED		
▽6	SPECIFICATIONS APPROVED		
▼	MILESTONE ACHIEVED		
⬡1		COMPONENT PROCUREMENT INITIATED	
⬡2		COMPONENT PROCUREMENT COMPLETED	
⬡3		COMPONENT FABRICATION INITIATED	
⬡4		COMPONENT FABRICATION COMPLETED	
⬡5		ASSEMBLY FABRICATION COMPLETED	
⬢		MILESTONE ACHIEVED	
◇1		COMPONENT ACCEPTANCE TESTING COMPLETE	
◇2		ASSEMBLY ACCEPTANCE TESTING COMPLETE	
◇			OPERATION OR TESTING TARGET DATE
◆			OPERATION OR TESTING TARGET DATE ACCOMPLISHED

AGCRSP MASTER SCHEDULE

SHEET 2



KEY (see legend facing page): ▽ DESIGNS, STUDIES, AND REPORTS; ⬡ PROCUREMENT OF FABRICATION OF "HARDWARE"; ◇ COMPONENT, ASSEMBLY TESTING; ▼⬢◆ MILESTONES ACHIEVED ▽ ⬡ ◇ MILESTONES NEW OR CHANGED

30 JUNE 1961

APPENDIX B

ML-1 PLANT CHARACTERISTICS

1. GENERAL

Design performance at 100°F		
Gross electrical output	400 kw	
Net electrical output	330 kw	
Reactor thermal power	2.9 Mw to gas; 3.3 Mw total	
Cycle efficiency	13.3%	
Plant thermal efficiency	10%	
Coolant flow	92,000 lb/hr	
Dose rate at control cab @ 500-ft during full power operation	5 mr/hr (with expedient shielding as needed)	
Dose rate at 25 ft, 24 hr after shutdown (direction of transport vehicle driver with P-C skid in place)	15 mr/hr	
Overall plant dimensions	279 x 113 x 93 in. high	
Overall plant weight and dimensions	Weight	Dimensions (in.)
Reactor package	30,000 lb	111 x 110 x 93 high (plus ion exchange column on end)
Power conversion package	30,000 lb	168 x 113 x 93 high
Control cab	5,000 lb	145 x 82 x 81 high
Auxiliary equipment	11,000 lb	- - - - - - - - - -
Operating supplies (startup and 90 day operation):		
Demineralized water	2900 gal	
Nitrogen (with 0.5 vol% oxygen)	1800 scf	
Oxygen	200 scf	
Anhydrous boric acid (B_2O_3)	1200 lb	
Mixed bed ion exchange resin	900 lb max.	

Lubricating oil	180 gal
Filter elements	6
Plant startup time	12 hr
Auxiliary power requirements	
Pre-startup	30 kw max.
Normal startup	45 kw max.
Normal shutdown	45 kw max., 3 kw ave
Emergency shutdown	none
Reactor drying	45 kw max.

2. REACTOR THERMAL CHARACTERISTICS

Power density	700 kw/ft^3
Maximum heat flux	137,500 Btu/hr/ft^2
Average heat flux	80,500 Btu/hr/ft^2
Heat transfer surface	126.5 ft^2
Maximum: average heat flux ratio	1.71
Maximum fuel center temperature (including hot spot factors)	2240^{o}F
Maximum moderator temperature	200^{o}F
Maximum surface temperature of fuel cladding (nominal, average)	1441^{o}F
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1750^{o}F

3. REACTOR NUCLEAR CHARACTERISTICS

Average thermal neutron flux (fuel)	1.9 x 10^{12} neut/cm^2-sec
Average fast neutron flux (fuel)	1.7 x 10^{13} neut/cm^2-sec
Maximum: average thermal flux ratio (fuel)	3.9
Hydrogen to U-235 atom ratio	36
Core buckling	0.0053 cm^{-2}
Fermi age	92 cm^2
Square of thermal diffusion length, L^2	2.56 cm^2
Thermal utilization, f	0.82
Infinite multiplication factor, k	1.70
Neutron lifetime	2.4 x 10^{-5}
k_{eff}, cold, clean core; no shims or burnable poison	1.081

k_{eff}, cold clean core, with shims, no burnable poison	1.040
k_{eff}, cold, clean core, with shims and burnable poison	1.015
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.6% in 10,000 hr
Prompt temperature coefficient, $\triangle k/k$-^{o}C	$+3 \times 10^{-6}$ @ 0^{o}C $+2 \times 10^{-6}$ @ 90^{o}C

4. REACTOR VESSEL

Materials	
Tube sheet	Stainless steel, Type 304, 2.94 in. thick
Pressure tubes	Stainless steel, Type 321
Source tube	Stainless steel, Type 321
Gas ducts, plenums and baffle	Stainless steels, Types 304-L, 321 and 347
Outside diameter	30.960 in. max. (exclusive of upper flanged connection)
Overall height	79.5 in.
Pressure tube length	24 in. between inside surfaces of tube sheets
Design pressure	345 psia
Design temperature	400^{o}F
Wall thicknesses	Tubes 0.020 in. Plenum 2.12 in. min
Source tube	0.020 in. wall thickness; 0.500 in. OD

5. REFLECTOR

Composition, top	2 in. H_2O; 4.5 - 5.0 in. stainless steel;1.5 in. W
bottom	3-4 in. stainless steel; 3 in. W
radial	1.8 in. Pb; 2 in. W; 180^{o} segment 4 in. Pb; 180^{o} segment
Total heat generation	6×10^{5} Btu/hr
Maximum power density	360 Btu/hr-in.^{3}

6. BIOLOGICAL SHIELDING

Composition	3-1/2 to 4 in. lead plus 30 in. of borated water (10 wt% boric acid)

7. CORE (EXCLUDING REFLECTOR)

Diameter	22 in. equivalent
Height	22 in.
Number of fuel elements	61
Number of coolant passages	61
Number of coolant passes	1
Type of geometry of fuel elements	Cluster of 19 pins (18 fueled)
Cold, clean critical mass, U-235 no shims, no burnable poison	25 kg
U-235 loading	49 kg
Enrichment, inner 6 pins	93% U-235 as UO_2
outer 12 pins	31 vol% UO_2, 93% U-235 69 vol% BeO

Core composition

Materials	Volume %
UO_2	4.3
BeO	3.3
Stainless steel	3.6
Hastelloy-X	7.0
H_2O	58.6
Insulation	7.0
Gas void	16.2
Total	100.0

8. FUEL ELEMENT

Dimensions	1.72 in. OD x 32 in.
Fuel material	UO_2
Number of pins per element	19
Pin outside diameter	0.241 in.
Pin cladding material	Hastelloy-X
Pin cladding wall thickness	0.030 in.

Pin spacer	0.040 in. OD Hastelloy wire
Heat transfer material	He
Pellet diameter	0.176 in (nominal)
Type burnable poison	Cadmium
Reactivity worth of burnable poison	2.2% at startup

9. CONTROL ELEMENTS

Type	Tapered blades
Location	Moderator
Number: Shim blades	3 pairs (3 actuators)
Safety blades	2 pairs (2 actuators)
Regulating blades	1 pair (1 actuator)
Absorber material: Safety and shim blades	5 wt% Cadmium- 15 wt% Indium- 80 wt% Silver
Dimensions (each blade)	4 x 10 x 0.25 to 0.62 in.
Regulating blades	Stainless steel
Dimensions (each blade)	4 x 10 x 0.25 to 0.62 in.
Cladding material	none
Reactivity worth of control elements:	
Safety and shim blades	0.050 $\Delta k/k$
Regulating blades	0.005 $\Delta k/k$
Total	0.055 $\Delta k/k$
Actuating time for regulating blade:	
Drive	13.3 sec for full insertion or withdrawal
Scram	0.35 sec for full insertion from signal
Safety and shim actuator:	
Drive	4.0 min for full insertion or withdrawal
Scram	0.35 sec for full insertion from scram signal

10. MODERATOR

Type	Water
Reactor inlet temperature	180^{o}F

Reactor outlet temperature	190°F
Pressure	32.5 psi max.
Flow rate	300 gpm
Type of flow circulation	Forced
Purity:	
Total solids	1 ppm
Resistivity	10^5 to 10^6 ohm-cm
Total heat removal rate	1.5 x 10^6 Btu/hr

11. REACTOR WORKING FLUID FLOW

Working fluid	99.5 vol% N_2 + 0.5 vol% O_2
Reactor inlet temperature	800°F nominal
Reactor mixed-mean outlet temperature	1200°F max.
Average velocity in core	160 ft/sec
Maximum velocity	180 ft/sec
Inlet pressure	315 psia (max.)
Core ΔP	15 psi
Reactor ΔP	22 psi

12. POWER CYCLE

Type	Brayton cycle with regeneration
Total volume of working fluid system	120 ft^3
Total system working fluid inventory full load at 100°F	52 lb
Working fluid transit time	2.0 sec

Cycle characteristics:

Ambient temperature	100°F	0°F	-65°F
Net power, kw	330	330	330
Reactor inlet, °F	791	597	597
Turbine inlet, °F	1200	990	990
Compressor inlet, °F	132	24	24
Compressor inlet, psia	117	93	93
Compressor outlet, psia	320	294	294
Reactor inlet, psia	313	288	288

13. TURBINE-COMPRESSOR SET

	Radial Flow Compressor	Axial Flow Compressor
Speed, rpm	18,338	22,000
Turbine stages	2	2
Turbine rotor material	Incoloy 901	Incoloy 901
Turbine blade material	Inco 713	N 155
Turbine stator blade material	Inconel	N 155 or 19-9DL
Expansion ratio	2.38	2.38
Compressor stages	2	11
Compressor material	Al 355 T71	403 stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compressor ratio	2.72	2.72
Case material	304 stainless steel	304 stainless steel
Seals		
at journals	Buffered labyrinth	Buffered labyrinth
interstage	Plain labyrinth	Plain labyrinth
shaft	Buffered labyrinth	Double "L" ring seal oil buffered
Bearings		
journal	Tilting pad	Plain babbitt
thrust	Kingsbury type (in low press. area)	Kingsbury type (in low press. area)
Support	Overhung turbine	Turbine and compressor supported between bearings

14. ALTERNATOR

Output	60 Cycle Operation	50 Cycle Operation
Rating	500 KVA 3 Ø	417 KVA 3 Ø
Voltage	2400/4160 V	2000/3467 V
Rotor shaft speed	3600 rpm	3000 rpm
Case		
Diameter, without water jacket	39 in.	
Diameter, max, with water jacket, at starting motor	40.6 in.	

Length, without starting motor	26.8 in.
Length, with starting motor	29.4 in.
Weight, alternator only (including water jacket)	4700 lb
Starting motor	360 lb
Temperature, operating (hot spot)	275°F internal max.

15. RECUPERATOR

Length (including insulation)	81 in.
Outside diameter (including insulation)	49.25 in.
Headers	
High pressure inlet	8 in.
High pressure outlet	8 in.
Low pressure inlet	20 in.
Low pressure outlet	14 in.
Effectiveness	79%
Pressure loss	
High pressure $\Delta p/p$	2.24%
Low pressure $\Delta p/p$	1.21%
Type	Shell and tube regenerator
Tubes	4 passes x 840 tubes
Shell	1 pass
Surface	External fins
Materials	300 series stainless steel

16. PRE-COOLER, MODERATOR COOLER AND OIL COOLER ASSEMBLY

Dimensions:	
Length, overall	166 15/16 in.
Pre-cooler	122 5/16 in.
Moderator cooler	32 1/8 in.
Oil cooler	11 5/16 in.
Width	113 in.
Thickness, overall	32 in.
Core	15 in.
Fans and plenums	17 in.

Materials	
Tubes and fins	Series 1100 aluminum
Headers	Series 2219 aluminum
Weight	6500 lb
Pre-cooler:	
Header, inlet	One, 14 in.
Header, outlet	One, 10 in.
Effectiveness	92.01%
Total $\Delta p/p$	1.65%
Air flow	247,500 lb/hr
Type	Fin fan air-to-gas exchanger
Tubes	1105 tubes, single pass
Surface	Internal and external fins
Moderator cooler:	
Headers, inlet and outlet	4 in.
Total Δp	2.77 psi
Water temperature	
In	190°F
Out	180°F
Airflow	73,250 lb/hr
Type	Fin fan air-to-water exchanger
Tubes	88 tubes per pass, three passes
Surface	External fins
Oil cooler:	
Connections, inlet and outlet	1 1/2 in.
Total Δp	9.38 psi
Oil temperature	
In	180°F
Out	150°F
Oil flow	18,900 lb/hr
Air flow	27,500 lb/hr
Type	Fin fan air-to-oil exchanger
Tubes	45 tubes, 2 passes
Surface	Internal and external fins

L E G A L   N O T I C E

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NOTE: This is the fiftieth in a series of Research and Development Progress Reports. The preceding reports in this series are Nos. IDO-: 28501, 28502, 28504, 28515, 28516, 28517, 28518, 28519, 28520, 28521, 28523, 28524, 28525, 28526, 28527, 28528, 28529, 28531, 28532, 28533, 28535, 28536, 28538, 28539, 28541, 28542, 28543, 28544, 28545, 28546, 28548, 28549, 28551, 28553, 28554, 28556, 28557, 28558, 28559, 28562, 28563, 28565, 28566, 28567, 28568, 28569, 28570, 28571 and 28572. The information herein is regarded as preliminary and subject to further checking, verification and analysis.