Report No. IDO-28558
AEC RESEARCH AND
DEVELOPMENT REPORT
UC-81: "Reactors -Power"
TID-4500 (15 Edition)
Contract AT(10-1)-880

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

SEMIANNUAL PROGRESS REPORT
1 January through 30 June 1960

31 July 1960

Aerojet-General NUCLEONICS
A SUBSIDIARY OF AEROJET-GENERAL CORPORATION
SAN RAMON, CALIFORNIA

L E G A L N O T I C E

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NOTE: This is the thirty-seventh 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, and 28557. The information herein is regarded as preliminary and subject to further checking, verification and analysis.

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The Engineering Division
Aerojet-General Nucleonics
San Ramon, Calif.
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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

SEMIANNUAL PROGRESS REPORT

for

1 January through 30 June 1960

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Report No. IDO-28558

THE ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

SEMIANNUAL PROGRESS REPORT

1 January through 30 June 1960*

ABSTRACT

This report contains the significant highlights of the work performed during the first six months of calendar year 1960 in connection with the Army Gas-Cooled Reactor Systems Program. The Program includes the Gas-Cooled Reactor Experiments I and II, the ML-1 (a prototype mobile, gas-cooled nuclear power plant) and the Gas Turbine Test Facility. Status and progress of each project is reported, as is information concerning associated tests and data evaluation, and status of fabrication of experimental and prototype components.

PREFACE

The Army Gas-Cooled Reactor Systems Program (AGCRSP) includes three principal projects being conducted by Aerojet under Contract AT(10-1)-880: design, construction and operation of the GCRE-I; studies directed towards the design of an advanced backup experimental reactor, called GCRE-II; and design, development, construction and operation of the ML-1.

Operation of the GCRE-I at NRTS was begun in February 1960. The reactor is being operated to provide developmental and lifetime data on heterogeneous fuel elements, and dynamic and control characteristics for use in the ML-1 design.

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

The GCRE-II is planned as a gas-cooled graphite moderated, homogeneous fueled reactor system. It was originally conceived as an advanced backup effort to the GCRE-I project.

The ML-1 project is the main stream effort of the AGCRSP. Its objective is to produce a prototype mobile nuclear power plant suitable for military field use. Criticality of this prototype plant is scheduled for April 1961.

Included in the ML-1 project is the major effort to develop advanced fuel elements (FED). In view of the complexity of the FED project, a separate section of the report is devoted to its status.

Additional support to the Program is provided by Department of the Army Contracts DA-44-192-ENG-8 (design and fabrication of turbine-compressor sets for the ML-1) and DA-44-009-ENG-3252 (operation of the Gas Turbine Test Facility - GTTF). Reports on these contracts are included as background information.

Organization of this report follows this order: GCRE-I, GCRE-II, ML-1, FED, and GTTF. The detailed breakdown of the report is by task numbers. That is, work is reported under the task responsible. The work for each task is reported in three categories: work accomplished in the first five months of the period; work accomplished in June; and anticipated accomplishments for July. This task breakdown, although convenient, possibly is misleading in that materials development tests, for example, may be reported under several task numbers although conducted in one laboratory, perhaps by one person.

I. THE GAS-COOLED REACTOR EXPERIMENT I

A. SUMMARY

Expedient modifications to the tube bundle and control rods made possible the attainment of initial critical of the GCRE-I reactor early in February. The scheduled series of low power experiments was completed and the facility shut down in mid-April to permit the permanent modifications to the tube bundle, control rods and instrumentation. This work was completed late in June and the planned program of ascension to rated reactor power was initiated.

B. A/E SERVICES

The A/E resident engineer completed the activity associated with the construction work, and left the site 12 February.

C. IDAHO OPERATIONS

Narrative Summary: January through May:

Thorough evaluation of the design deficiencies of the GCRE-I brought to light during pre-operation testing in November 1959 showed the necessity of certain expedient modifications, as follows:

1) Tube Bundle: The aluminum tube bundle was repaired by removing the existing fusion seal weld between the pressure tubes and the tube sheet, and re-welding with a filler rod weld. It was not possible to make all welds leak tight. For several reasons it was decided to re-install the vessel with a small leak. These reasons include the limited schedule for reactor operations, and the limited pressures and temperatures at which the reactor was to be operated.

Consideration of the long-term changes in the structure of aluminum welds and the uncertainties in the corrosion rate of the aluminum bundle led to the decision early in January to proceed with fabrication of a replacement stainless steel tube bundle. The stainless steel bundle was completed in mid-May and shipped to the site for installation. A report detailing the design and operating history of the aluminum tube bundle and the design and fabrication history of the stainless steel tube bundle will be published shortly (AGN-TM-386).

2) Control Rods: Leakage through the chevron seals was the most persistent difficulty experienced with the GCRE-I fast control rods. Pressurizing the actuator housings made early operation possible with some reliability. With this modification, leakage was manifested by air passing out through the seals rather than by water penetrating into the actuator housing.

Other significant changes included re-mounting the drive mechanism and micro-switches in the actuator housings, providing bronze bearings adjacent to the chevron seals, and eliminating galling surfaces in several locations. A detailed report will be written on modifications to the rod actuators.

3) Instrumentation: Expedient modifications to the instrumentation consisted primarily of "de-bugging" this system and isolating sensitive circuits wherever possible.

These modifications were completed early in February. The initial critical experiment was then performed with the reactor in the flooded (most reactive) condition. Criticality was attained with a loading of 36 IZ-type fuel elements (11.25 kg U-235). The wet critical experiment was followed by the drying test and the dry critical experiment. The reactor attained criticality in the dry condition with a core loading of 56 IZ elements (about 17.5 kg U-235). Following these critical experiments, flux mapping, determination of control rod reactivity, and associated low power tests were run. These tests were terminated in April to modify the system so as to make extended full power operation possible.

The modifications for full power operation of the GCRE-I reactor included installation of the stainless steel tube bundle, re-work of the fast control rods, and further stabilization of instrumentation. By the end of May, the stainless steel tube bundle was about 50% installed, the modified control rods were being installed, and modifications to the instrumentation system were complete.

Accomplishments - June:

Modifications were completed, and the modified components installed early in June.

1) Shutdown Rods: The following significant improvements were incorporated: the magnets were replaced by modified ball-latch mechanisms; larger, more rugged switches were used to replace all micro-switches, and the chevron seals were replaced with U-cup rubber seals. In addition, the pistons were plated with a molecular coating of molybdenum to provide a lubricated surface. The dashpot housings were machined to provide optimum deceleration during scrams.

2) Safety Rods: The rear set of chevron seals were eliminated since they were not required to effect a seal. The forward chevron seals were replaced with U-cup rubber seals. A study of the damping characteristics of the safety rod showed that forces

of about 50 g were sustained during scramming. The dashpot housing was modified to provide a maximum of 25 g at a nitrogen driving pressure of 75 psig. The scram times following the modifications were 160 msec in water with a blade attached to the rod.

3) Tube Bundle: The replacement stainless steel tube bundle was installed in June. This bundle is geometrically similar to the aluminum bundle except for thickness of the pressure tube walls. The stainless steel tubes have walls 0.020-in.-thick compared to 0.058-in.-thick for the aluminum tubes. The most significant changes were in the tube-to-tube sheet joint and in the provision of cooling for the tube sheet. The latter modification was made because conduction from the heated nitrogen and gamma heating sets up prohibitive thermal stresses in the 3-in.-thick stainless steel tube sheet if auxiliary cooling is not provided.

4) Instrumentation: The most significant changes in the GCRE-I instrumentation were made to isolate sensitive circuits and to ensure that regulated power leads were not tied into non-regulated power. These efforts were all directed toward minimizing spurious signals in the nuclear instrumentation.

After the control rods were re-installed, each was cycled 20 times before they were accepted. The reactor attained criticality in the flooded condition on 13 June with a loading of 55 IZ-type elements (17.2 kg U-235). The full core flooded experiment, the drying test and the dry critical experiment were performed after the wet critical experiment with the stainless steel tube bundle. The reactor attained dry criticality with a core loading of 66 IZ-type elements (20.6 kg U-235). The core was then loaded with 71 IZ-type elements to provide the excess reactivity required for operations.

The IB-9Ø experiment was performed in anticipation of full power operation to determine relative flux levels for a pin-type element in various positions in the reactor.

Power ascension was initiated late in June with an instrumented plate-type element. Performance of this test was impeded by instrument instability.

Anticipated Accomplishments - July:

Power ascension (ANSOP 9210) will be completed during July. After demonstrating stable operation at full reactor power level, the reactor will be operated long enough to generate the gamma source for the photoneutron experiment. The reactor will then be shut down and flooded, and the photoneutron experiment performed. This experiment is to determine the level of neutron emission that might be expected in the ML-1 from the photoneutron effect of gamma rays on beryllium. It is anticipated that this experiment will take about three days, after which the core will be loaded with two instrumented IB fuel elements and one non-instrumented IB power element. After the core is dried, the reactor will be operated at power.

D. TEST PLANNING AND EVALUATION

Narrative Summary - January through May:

The two major changes made in the GCRE-I during the period were the design and installation of a stainless steel tube bundle, and the decision to replace the plate-type fuel element with the pin-type (ML-1) element. The tube bundle design and fabrication was monitored by this group, and the assembly installed under the supervision of this group. The pin-type core (designated IB-2L) design and fabrication were assigned to the Fuel Element Development (FED) group. This core is scheduled to be loaded in October 1960.

These core changes required revision of the GCRE-I Hazards Summary Report, IDO-28506. Addendum II was published in February and Addendum III in May.

Thermal and stress analyses of the tube sheet for the stainless steel tube bundle indicated that internal cooling would be needed to reduce thermal stresses to acceptable values. A pumping system and a manifold was designed and installed to provide this cooling.

The reactivity effect of the substitution of the stainless steel tube bundle for the aluminum tube bundle was calculated, showing a change in reactivity of -0.6%. The critical experiment conducted with this configuration determined that 66 fuel elements (20.6 kg U-235) constituted the critical loading. This is an increase of seven elements (2.4 kg U-235) over a previous experiment using the aluminum tube bundle with plate-type fuel elements. An analysis of the mathematical methods indicated that the codes used to evaluate the fast constants did not calculate a neutron age consistent with reported experiments. In addition, questionable methods were used to determine neutron temperature. The MUFT IV and SOFOCATE codes were used to recalculate the constants for the core with the aluminum tube bundle, and gave a k_{eff} of 1.023. The experimental value of k_{eff} was 1.01 and the previously calculated value was 1.065.

Fuel element handling tools were designed and fabricated for use with the pin-type fuel elements. A borescope was designed with forward and side viewing heads to permit internal inspection of pressure tubes. The nitrogen filter vessels in the main loop were modified to permit removal of filter elements from a remote location. Dummy plugs to block off unused fuel element positions in the core were re-designed, primarily by the addition of insulating material. The dummy plugs at the GCRE-I site were also modified in the same way. Additional plugs are being fabricated for use with the smaller IB-2L core.

Accomplishments - June:

Calculations were initiated on a core composed of IB-2L elements in a stainless steel tube bundle based on experimental values of cell flux distribution available from BMI experiments. Calculations using the I_2 cell code failed to give results compatible with the experimental distribution. Improved results were obtained by introducing pin self-shielding factors, but the mathematical methods were still considered unsatisfactory. A calculation is being made using the PDQ code (a two-dimension diffusion code).

Data from the IB-9Ø flux measuring experiment is being reduced.

Anticipated Accomplishments - July:

A preliminary schedule of experiments at nominal power will be prepared for the GCRE-I.

The fuel cask shielding analysis will be completed and design and fabrication initiated.

The IB-2L neutronic analysis will be continued.

Experimental procedures will be prepared and forwarded to the GCRE-I operations group covering system activity, experiment 511; moderator activity, experiment 512; irradiation data (instrumented elements), experiment 520; radiation damage (shock mount), experiment 533; and dose distribution, experiment 534.

II. THE GAS-COOLED REACTOR EXPERIMENT II

A. SUMMARY

Work in the GCRE-II area during the report period was limited to materials development and systems studies. These studies included mobile and portable power systems using homogeneous graphite reactors as well as modifications and improvements to the ML-1 system. The materials development effort was devoted to homogeneous graphite fuel materials.

B. SYSTEMS ANALYSIS (Task 47-300)

Narrative Summary - January through May:

1. ML-1 Improvements:

a. ML-1 Cycle Study and Weight Optimization: A cycle and weight optimization analysis of the ML-1 system resulted in the following conclusions:

Minimum plant weight and maximum power output per unit plant weight result from the use of a recuperator and pre-cooler with heat transfer effectiveness of 80 and 93%, respectively, and maximum system pressure of 375 psia. These heat exchanger effectivenesses are comparable to those in the ML-1; however, an increase in maximum system pressure to the optimized value could decrease the weight of the ML-1 power conversion system about 1400 lb and increase plant thermal efficiency by about 2.0 percentage points.

The maximum system pressure can be increased to about 525 psia without exceeding the nominal design weight of the ML-1 power conversion skid. This increase in pressure, used with the same turbine inlet temperature, will increase plant thermal efficiency by 3.9 percentage points, reducing the thermal requirements for a given power output by about 25%. The increased weights of plenum and tube sheet (made necessary by the higher pressure) are counterbalanced by the reduction in shielding weight made possible by the reduced core size and thermal power made possible by the increased pressure. In addition, the ML-1 core heat transfer characteristics can be maintained while reducing the total number of fuel elements from 61 to 46.

The net plant electrical output can be increased by 22 kw without exceeding the nominal design weight of the power conversion system if the weight saved by optimization for minimum weight is converted into additional plant capacity.

The ML-1 reactor now is limited to an outlet coolant temperature of 1200°F to maintain a maximum allowable hot spot fuel element surface temperature of 1750°F. Calculations were made to determine the gains possible through advancements in high temperature materials technology. The results showed that a 50°F increase in turbine inlet temperature would increase the plant thermal efficiency 0.75 percentage points and would decrease the weight of the power conversion skid by about 1000 lb. Calculations based on advancements in turbomachinery technology showed that a one percentage point change in turbine or compressor efficiency produces about a 0.6 percentage point change in cycle efficiency and a reduction in weight of the power conversion skid of 600 to 800 lb.

b. ML-1 with Inert Gases: The feasibility of operating the existing ML-1 nitrogen system with an inert gas was investigated. Certain model laws must be satisfied to operate a given machine with a gas other than that for which it was designed. Where compressibility effects are important, the Mach numbers (N_M) should be the same for both. For equal velocities and temperatures in the turbomachinery:

$$N_M \propto \sqrt{\frac{MW}{k}}$$

where MW is molecular weight, and
k is specific heat ratio

An inert gas mixture must be used to satisfy the specified conditions. The properties of two suitable mixtures are compared to nitrogen in the table below:

Gas (vol%)	Molecular Weight	Specific Heat Ratio
N_2 (100%)	28.01	1.36
71.1 A + 28.9 Ne	34.3	1.66
84.7 A + 15.3 He	34.4	1.664

The inert gas mixtures listed above require large volume fractions of argon, but argon has a relatively high neutron activation cross-section. Calculations indicate that dose rates on the order of 2×10^4 times tolerance would exist only two feet from unshielded coolant pipes after 10,000 hr operation. About five inches of lead would be required to attenuate the radiation to 300 mrad/week at the same dose point. Inert gases containing argon therefore are not suitable for use in an unmodified ML-1 reactor system.

2. An Advanced ML-1:

a. Dual Cycle - Helium/Air: A dual cycle system has the advantage over the single closed cycle system in that more conventional power conversion equipment can be used and fuel element lifetimes and temperatures may be increased by virtue of using helium in the primary loop. Feasibility studies were therefore initiated for a dual cycle power plant employing a helium primary system and an open cycle gas turbine plant.

Preliminary investigations now in progress will cover the ranges of turbine inlet temperatures to 1500°F and reactor outlet temperatures to 1950°F with the ML-1 power output. Optimum compressor pressure ratios were found for various turbine inlet temperatures using equations which account for the power requirements for the helium pump and auxiliaries. As was expected, the efficiency is greater in a recuperative cycle; however, the recuperative cycle is only about 2 to 3 percentage points more efficient than for the case without a recuperator because of increased pressure drop in the system due to the heat exchanger. Optimum compressor pressure ratios vary from 3 to 4 for the recuperative cycle, and from 6 to 8 for the non-recuperative cycle depending on the turbine inlet temperature.

Preliminary weight scaling relationships were developed for the power conversion equipment to compare the overall weights for the ML-1 and a dual cycle system. It was found that the dual cycle system would produce more net electrical output at a slightly higher system efficiency than with the ML-1 with the same power conversion skid weight, turbine inlet temperature, and maximum fuel element wall temperature.

b. Heat Exchanger Design: Since weight and size are at a premium, a mobile dual cycle power plant employing a helium primary system and an open cycle gas turbine requires a specially designed heat exchanger to transfer heat between loops. A pure counterflow heat exchanger, employing U-tubes and spherical heads, weighs less than other exchangers, and has the further advantage in that the exposed spherical plenums and U-tube shell can be kept relatively cool by internal insulation. The results of preliminary heat exchanger calculations are shown in the table below for various turbine inlet temperatures with various reactor outlet temperatures for an unfinned heat exchanger (0.25-in ID tubes); a primary system pressure of 500 psia; a primary and secondary side $\Delta p/p$ of 0.005 and 0.02, respectively; a net generator electrical output of 400 kw; and equal capacity rates on both sides of the heat exchanger.

RESULTS OF HEAT EXCHANGER CALCULATIONS

	Turbine Inlet Temperature, °F					
	1200		1400		1600	
Reactor Outlet Temperature, °F	1350	1650	1550	1850	1750	1900
Heat Exchanger Tube (Length in Feet)	19	7	19	7	19	10
Diameter of Heat Exchanger, Inches	19	15	15.5	12.5	13	11
Number of Tubes	1150	750	850	550	650	500
Weight in Pounds	6000	2300	4000	2000	3500	2000

A compact recuperator/heat exchanger design was completed and a weight calculation made for use as a normalization factor for weight scaling relationships in optimizing the complete dual cycle system. The recuperator is of the plate fin cross-flow design, rectangular in shape, 2.0-x 2.5-x 3.5-ft. A heat transfer effectiveness of 70% was obtained for a total weight of 2500 lb.

c. Data from Vendors: Design information is being gathered from industrial concerns that manufacture open cycle gas turbomachinery with capacities in the 300 to 3000 kw range. Performance data has been received from three vendors. The amount of experience and development associated with these engines, coupled with proven performance, suggests that open cycle turbomachinery offers a large degree of reliability at minimum dollar cost at this time.

A survey of compact heat transfer equipment is being conducted, since the output of a mobile plant is limited to a great extent by the weight of the heat exchanger. Preliminary information received from one vendor shows a reduction of 35% in weight and 60% in volume compared to conventional shell and tube designs.

3. Solid, Homogeneous Moderator Reactor Systems:

a. 3000 kw(e) Mobile System: A preliminary design and feasibility study was completed for a mobile nuclear power plant of 3000 kw net electrical output. This weight-optimized power plant consists of a nitrogen-cooled reactor and a regenerative closed cycle gas turbine power conversion system operating at 500 psia maximum system pressure. A net plant efficiency of 18.5% is achieved with a turbine inlet temperature of 1300 $^{\circ}$F and a sink temperature of 100°F.

The entire system is readily transportable since there are only seven packages, none of which weighs more than 15 tons. The total plant weight is estimated to be 100 tons, corresponding to a specific weight of 67 lb/kw of net electrical output. The design is intended primarily to supply electrical power at remote locations where logistics, economics or the exhaust fumes make diesel fuel impractical.

A preliminary estimate shows that three days time and 21-man-days of labor are required to set up the plant for full-power operation with a clean core. An economic analysis of this system showed a capital investment of $1038/kw(e) for an estimated power production cost of 35 mills/kw-hr.

Characteristics of a 3000 kw(e) Mobile Plant

Overall Plant Performance

Reactor thermal output	16.3 mw
Net electrical output	3000 kw
Net plant efficiency @ 100°F ambient temp.	18.4%

Reactor

Moderator	Graphite
Core length (active)	33-in.
Core equivalent diameter (active)	31-in.
Fuel loading U-235	25 Kg
Lifetime	10,000 hr
Core composition (vol %)	
Graphite	82
Metal	3
Void	15
C/U ratio	485
Control drums	
Diameter	5.0-in.
Number	12
Location	Side reflector
Poison	Rare earth oxide
Reflector	
Composition	BeO
Side thickness	5.0-in.
Top thickness (coolant outlet)	4.5-in.
Bottom thickness (coolant inlet)	6.0-in.

Fuel Element (Semi-Homogeneous)

Distance between hex flats	1.84-in.
Fuel rod diameter	0.875-in.
Fuel volume fraction in element	23%

Core Flow and Heat Transfer

Number of coolant holes (total)	2277
Diameter	0.25-in.
Coolant	Nitrogen
Mass flow rate	475,000 lb/hr
Heat transfer area	410 ft^2
Average heat transfer coefficient	348 Btu/hr-ft^2-^oF
Average film temperature drop	390^oF
Average heat flux	1.36 x 10^5 Btu/hr-ft^2
Maximum nominal coolant channel surface temperature	1595^oF
Maximum hot spot coolant channel surface temperature	1800^oF
Reactor pressure drop (orificed)	25 psi
Coolant inlet temperature	870^oF
Coolant exit temperature	1300^oF

Power Cycle

Pressure ratio	2.65
Recuperator heat transfer effectiveness	80%
Pre-cooler heat transfer effectiveness	93%

b. 3000 kw(e) Portable System: A feasibility study was completed for a 3000 kw(e) superheated steam power plant using a helium-cooled homogeneous graphite moderated reactor primary system. The plant was not fully optimized due to the lack of availability of current knowledge in the areas of costs, weights, fabrication and development times, and the operating parameters for each component over the range of interest. The principal characteristics and problems of heat transfer and cycle optimization were explored, however.

The proposed system provides high efficiency with moderate reactor gas outlet temperature. The system is portable in the sense that it can be packaged to allow air transportation by C-130A aircraft to the operating site. The estimated installation time and manpower requirement for application in continental United States is 32 days with a maximum crew of 20 men. Fifteen men are estimated to be needed for around the clock operation. The overall system weighs 217 tons, including equipment housings, is divided into 16 packages, none of which exceed the size and weight limits for the C-130A. An economic analysis of this system indicates that power could be produced for 31 mills/kw-hr with a capital investment of $970/kw(e).

The gas-cooled reactor concept appears to be one of the more promising means of obtaining superheated steams and affords a relatively light-weight primary system. The degree of superheat demanded by most modern high performance steam turbines can be met with relatively low primary system pressures and moderate reactor outlet temperatures. The low moisture levels at the turbine exit, typical of a superheated steam power plant, contribute to high performance and minimum turbine maintenance.

The power plant uses currently available equipment wherever possible and does not involve any major development work. The dual loop concept has the advantage of containing radioactive contaminants; thus routine maintenance may be performed on the secondary (steam) system. The use of an inert gas in the primary system greatly reduces corrosion problems at the high temperatures in the reactor fuel elements.

The primary loop includes the reactor, steam generator, helium blower, helium purification system, and the helium make-up system. The reactor employs a graphite, semi-homogeneous fuel element with a BeO reflector, and is shielded with water and expedient materials. The semi-homogeneous fuel element has a canned fueled graphite circular cylinder encapsulated in an unfueled graphite hexagon. The graphite hexagon has coolant slots, or holes, in its body. Coated fuel particles and silicon carbide coatings on the graphite surfaces help prevent release of fission products from the fueled graphite. The fuel can prevents the escape of fission products into the coolant stream. The graphite provides the structural strength.

The steam power plant uses one steam generator to supply steam to three 1.25 mw(e) turbine generator units in parallel. Partially expanded steam is extracted from an intermediate point in the turbine to heat the feedwater. The turbine generator sets are field assembled to the condensers to form integral units. These units reject their heat through an intermediate fluid to three air-cooled heat exchangers. An evaporative water system is provided with the steam plant to supply make-up water at the site.

CHARACTERISTICS OF THE 3000 kw(e) PORTABLE SYSTEM

Overall Plant Performance @ 100°F Ambient	
Reactor thermal output	13.3 Mw
Net plant heat rate	15,200 Btu/kw-hr
Net plant efficiency	22.5%
Net plant electrical output	3,000 kw(e)
Reactor: Graphite Moderated, BeO Reflected	
Active size of core	35.4-in. high x 28.25-in. dia
Fuel inventory	22.6 kg
Coolant	Helium at 900 psia
Coolant flow rate	65,000 lb/hr
Inlet/outlet/max nominal wall temp	580°F/1150°F/1650°F
Average heat flux	1.73×10^5 Btu/hr-ft^2
Power density	1.04 Mw/ft^3
Coolant hole equiv diameter	0.246-in.
Fuel element size across flats	2.19-in.
Void fraction	10.3%
Metal fraction	2.9%
Fueled graphite fraction	42.0%
Unfueled graphite fraction	44.8%
Power Plant - Superheated Steam	
Turbine inlet conditions	950°F, 800 psia
Steam flow rate	40,000 lb/hr
Condenser pressure	7.5 psia
Heat rejected	3.4×10^7 Btu/hr
General	
Total plant weight	217 tons
Number of packages	16
Estimated power cost	31 mills/kw-hr
Capital costs	$970/kw(e)

c. Neutronics: The effect on core loading of coolant volume fraction was investigated for a representative reactor assembly. Calculations were performed for the range of 10 to 30 vol% void in a beryllium-reflected, lead-shielded, cylindrical graphite assembly. The critical core loadings were found to increase two-fold when the void fraction was increased from 15 to 30%.

Further calculations were performed to evaluate trends in critical mass as a function of the length-to-diameter (L/D) ratio of the reactors evaluated. The L/D ratio yielding the minimum critical mass was found to depend on the core diameter. The minimum critical mass for a core 26-in. dia was found to occur at an L/D of 1.8, and for a 30-in. core at an L/D of 1.4.

Europium was selected as a representative resonance absorber material for evaluating the reactivity control afforded by such a poison material in reflector control drums. Criticality calculations indicate that sufficient reactivity might be controlled by this method for use in a graphite moderated reactor.

In the majority of criticality survey calculations performed, representative core assemblies were surrounded by an 11-cm beryllium reflector and a 24-cm lead shield. Evaluation of the lead shields of these assemblies indicated a reactivity contribution to the system on the order of 15%, due to the reflection of neutrons back into the cores.

Variations in the thickness of the beryllium reflector surrounding representative core assemblies indicated the worth to be on the order of 1 %/cm in the region of 10- to 15-cm beryllium reflector thickness. In all calculations the beryllium reflector contained 2 vol% NiCr to simulate coolant tubing and was enclosed in a lead shield 24-cm-thick.

d. Fuel Element: There are several fuel element configurations that will satisfy the heat transfer and flow requirements of the two 3000 kw systems. Two concepts appeared to warrant study. These were the semi-homogeneous element (a fueled graphite cylinder in a graphite can) and a homogeneous element (a fueled graphite cylinder in a metallic can). The latter element would be easier to fabricate, leads to lower build-up of fission gas pressure, and uses lower fuel density in the graphite; thus it is superior to the semi-homogeneous element. However, the metal used in the can must have a coefficient of thermal expansion near that of graphite, must have low strength at the operating conditions, and must remain ductile over the operating temperature range. Zirconium and its alloys are the only metals that meet these requirements. However, zirconium and its alloys exhibit poor oxidation resistance at the operating temperatures, and large dimensional instability when thermally cycled between the alpha and beta phases. For these reasons work on the homogeneous element has virtually ceased, and the materials group is carrying out basic materials developments so that the semi-homogeneous element can be fabricated.

e. Safety: A preliminary investigation was made of the safety characteristics of the homogeneous and semi-homogeneous fuel element. The homogeneous element consists of a canned, fueled graphite hexagon with coolant gaps around the periphery; the semi-homogeneous element consists of a homogeneous fueled graphite circular cylinder encapsulated in an unfueled graphite hexagon with coolant slots or holes in its body.

The can materials considered for the semi-homogeneous element were Zircaloy 2, Hastelloy X, Monel, "A" Nickel and platinum. Zircaloy 2 was considered for the homogeneous element. Reference parameters from the 3000 kw(e) mobile system feasibility study were used in the materials study.

The transient heat transfer characteristics for the fuel elements were found by solving an analogous R-C electrical network. In these calculations fuel capacities were lumped, the prompt temperature coefficient was neglected and the heat removal rate was assumed to be constant. The neutron lifetime was taken to be 125 M/sec. The reference conditions are listed below:

REFERENCE PARAMETERS FOR SAFETY CALCULATIONS

Reactor thermal power	16,300 kw
Active core volume	14.45 ft^3
Semi-homogeneous element	
Fueled graphite fraction	29.9 vol%
Moderator fraction	59.1 vol%
Metal fraction	3 vol%
Void	15 vol%
Fuel radius	0.4375-in.
Can thickness	0.025-in.
Shell thickness	0.375-in.
Length	33-in.
Number of elements	253
Homogeneous element	
Fueled graphite fraction	78.9 vol%
Metal fraction	6.1 Vol%
Void fraction	15 vol%
Fuel radius	0.734-in.
Can thickness	0.025-in.
Length	33-in.
Number of elements	356

The temperatures, power, and energy releases for a 2% step change in reactivity in the semi-homogeneous and canned element, respectively are shown below:

SEMI-HOMOGENEOUS ELEMENT CHARACTERISTICS

	Time	Nominal Average Temperatures			Power	Excursion Energy
	Millisec	Fuel °F	Can °F	Shell °F	Mw	Mw-Sec
Steady State	0	2010-2090	1820-1840	1660	16.3	-
Zircaloy 2 Melts	79	5130	3300	1790	132,000	10,400
Hastelloy X Melts	70	3175	2350	1716	50,000	3,520
Monel Melts	71	3285	2400	1721	55,000	3,920
"A" Nickel Melts	74	3715	2600	1742	77,000	5,680
Platinum Melts	79	5095	3224	1808	130,000	10,400
Graphite Sublimes	83	6600	3950	1875	204,000	16,900

CANNED ELEMENT CHARACTERISTICS

	Time	Nominal Average Temperatures		Power	Excursion Energy
	Millisec	Fuel $^{\circ}F$	Can $^{\circ}F$	Mw	Mw-Sec
Steady State	0	1875	1600	16.3	-
Zircaloy 2 Melts	79	3575	3300	132,000	10,400
Graphite Sublimes	90	6600	6325	432,000	38,800

A summary of the results obtained from the study are:

1) The GCRE-II prompt temperature coefficient is on the order $-4 \times 10^{-6}/^{\circ}F$.

2) The reactivity, $\Delta k/k$, tied up in the can material of the semi-homogeneous element is 0.15 % for Zircaloy-2, 5.4 % for Hastelloy-X, 5.3 % for Monel, 5.8 % for "A" Nickel and 7.3 % for Platinum.

3) Graphite sublimation and subsequent core disassembly, which occur in less than 100 millisec in both elements, are the shut-down mechanisms for a 2% step increase in reactivity. The boiling points of the can materials are not reached before disassembly.

4) Because of the high core heat capacity, excursions can be limited short of can material meltdown with about the following worths of reactivity in the semi-homogeneous element: $1.14 with Zircaloy 2, $1.18 with Hastelloy X, $1,19 with Monel, $1.22 with "A" Nickel, and $1.26 with Platinum. $1.54 can be added with Zircaloy 2 in the homogeneous element. These calculations assume a 400 msec scram delay time.

5) The worths of reactivity which may be added in the case of the semi-homogeneous element to obtain a given temperature in the can material in a fixed time interval, increases with increasing thermal conductivity of the can material. This is caused by the decreasing thermal resistances between the fueled and unfueled portions of the element.

6) The high heat capacity of the core provides an excellent heat sink in case of temporary loss of coolant, or during transients.

7) Meltdown of the can material in the semi-homogeneous element should not significantly increase an excursion since the can material is retained within the fuel element. Can meltdown will, however, release fission products.

8) Fission product retention during a major excursion will primarily depend on the integrity of the coated fuel particles.

9) The chemical reactions of core materials with water and air in case of an excursion should be investigated because a considerable amount (10^{10} joules) of potential chemical energy is available.

10) More advanced ceramic moderating materials warrant investigation since such materials may make possible softer spectrums, thereby giving longer neutron lifetimes, and thus tending to make excursions self-limiting.

Accomplishments - June:

1. ML-1 Improvements: Previous studies showed that optimizing the ML-1 for minimum weight results in reducing system weight by about 1400 lb compared to the reference design with a net plant output of 330 kw. Without altering plant operating conditions, this saving in weight can be converted into 22 kw of increased plant electrical output. Since this is a somewhat marginal gain in net output; it is of more interest to determine the changes required to obtain a substantial increase in plant capacity. Accordingly, studies were made of the effect of turbine inlet temperature and turbomachinery efficiencies on net electrical output, since these parameters significantly affect plant efficiency without greatly affecting the optimized operating conditions. The results showed that for each one percentage point increase in turbine efficiency the net plant output can be increased 11.0 kw, and for each one percentage point increase in compressor efficiencies, the net plant output can be increased 7.5 kw, without increasing the reference plant design weight. Also, for each 50°F increase in turbine inlet temperature, the net plant output can be increased 21.0 kw for a fixed plant weight. Therefore, the ML-1 capacity can be increased from a reference value of 330 to 500 kw if the compressor efficiency is increased from 83 to 86%, the turbine efficiency is increased from 86 to 89%, the turbine inlet temperature is increased from 1200 to 1400°F, and the pressure increased to 375 psia.

2. Helium Closed-Cycle Gas Turbine System: The advantages and feasibility of a helium closed-cycle gas turbine nuclear power plant are being evaluated. Such a system would serve as an advanced ML-1; i.e., it would satisfy all requirements for the ML-1, provide longer fuel element lifetimes (because of the inert gas coolant), reduce the plant weight, or, alternately, substantially increase the plant output without increase in weight. Cycle calculations were made using the PECAN (IBM-704) code. Heat exchangers are being designed so that accurate weight calculations can be used to normalize weight scaling relationships. Plant operating conditions will then be determined for the weight-optimized system. Feasibility will hinge on the state of helium turbomachinery technology. Accordingly, inquiries are being sent to manufacturers involved in this technology to establish the degree of advancement.

3. Dual Cycle - Helium/Air: Feasibility studies continued on a dual cycle power plant employing a helium primary system and an open cycle gas turbine plant. Generalized curves were found for the reactor to permit extrapolation of its overall characteristics throughout a wide range of independent variables. Preliminary weight scaling relationships were developed for power conversion equipment, and will be refined when information is received from vendors.

Anticipated Accomplishments - July:

Feasibility studies will continue for a dual cycle power plant employing a helium primary system and an open cycle gas turbine secondary.

Work will continue on the design and feasibility of the closed cycle helium gas turbine system. Cycle and weight optimization calculations will be completed, and this advanced system will be compared with the reference ML-1 system.

Accumulation of performance and design data from vendors of gas turbine equipment will continue.

C. MATERIALS DEVELOPMENT (Task 49-300)

Narrative Summary - January through May:

The materials program during the period was aimed primarily at developing a fueled graphite material capable of fission product retention at surface temperatures from 1750 to 1850°F. Studies were initiated to achieve three objectives: to develop a fueled graphite material; to develop a canning metal for fission product retention and/or as a carburization barrier; and to develop a corrosion-resistant coating for graphite.

Five areas were studied to achieve these objectives: compatibility of material, graphite coatings, graphite joining, coated fuel particles, and mechanical and physical properties.

1. Compatibility Studies: Studies were conducted on the solid compatibility of graphite with zirconium, Zircaloy 2, and nickel-based alloys; and on the compatibility of Hastelloy X with graphite coated with molybdedum, niobium carbide, and zirconium carbide.

Graphite coated with niobium carbide and with molybdenum was placed in contact with samples of Hastelloy X. The Hastelloy X samples were examined after 1000 hr exposure at 1750°F and 300 psi contact pressure. One sample of Hastelloy X was discarded after discovering that the corrosive atmosphere (99.5 vol% N_2 + 0.5 vol% O_2) had come in contact with the niobium carbide coating and the graphite encapsulated with the Hastelloy X. Metallographic and carbon analyses of the Hastelloy X encapsulated with the molybdenum coated graphite indicated no carbon diffusion. Mechanical tests showed a decrease in strength and about 70% loss in ductility. Additional test samples (molybdenum- , niobium carbide- , and zirconium carbide-coated graphite samples in contact with Hastelloy X will be exposed for 3000 hr at 1750°F. These samples have passed 2500 hr exposure.

Test samples of zirconium and Zircaloy 2 in contact with graphite were examined after 1000 hr exposure at 1750°F. Metallographic and carbon analyses showed negligible carburization for zirconium and Zircaloy 2. Test samples of zirconium and Zircaloy 2 were examined after 1500 hr exposure at 1850°F. The average carburization penetration for the zirconium after this exposure was 0.0015-in. For the Zircaloy 2, the average carburization penetration was 0.0003-in. (Figure 1)

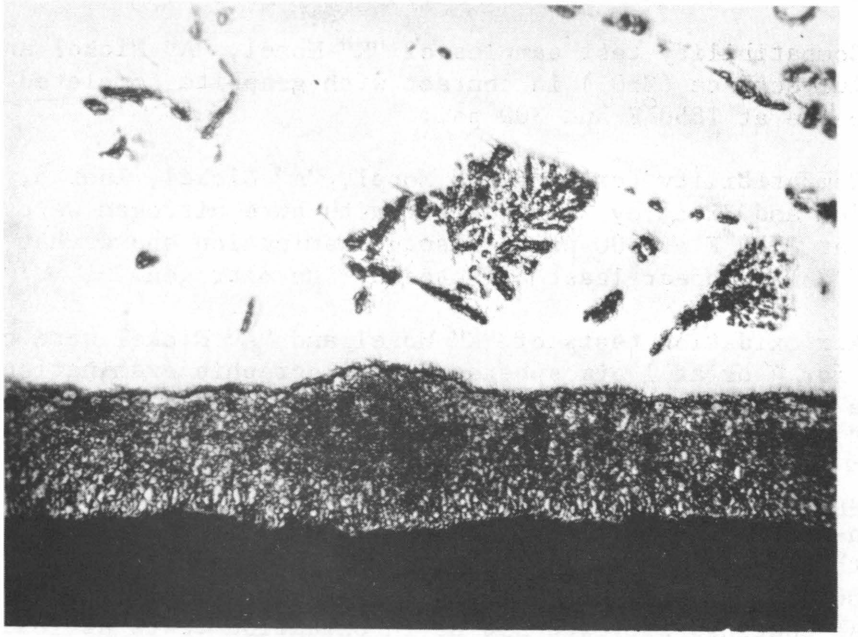


FIGURE 1. ZIRCONIUM TEST COUPON AT 600x. NOTE CARBURIZATION ZONE. AVERAGE PENETRATION 0.0015 in.

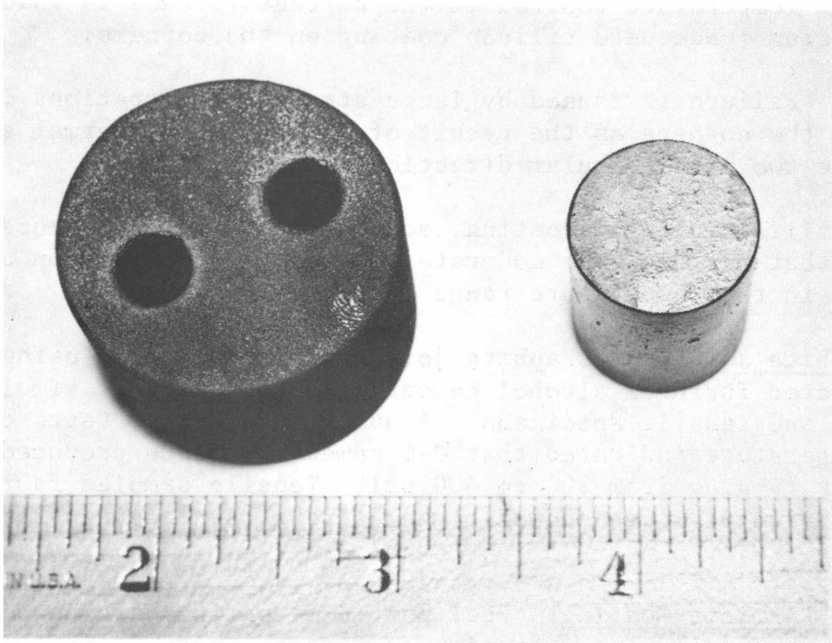


FIGURE 2. SILICON-SILICON CARBIDE COATED GRAPHITE SAMPLES. AFTER 300-HR OXIDATION TEST AT 832°F. LARGE SAMPLE MANUFACTURED BY 3M, SMALL BY AEROJET.

Compatibility test samples of "K" Monel, "A" Nickel and oxidized zirconium surface (ZrO_2) in contact with graphite completed 1000 of 1500 hr exposure at 1850°F and 300 psi.

Compatibility tests of "K" Monel, "A" Nickel, Inor 8, Hastelloy X, zirconium and Zircaloy 2 in contact with pure nitrogen were conducted for 100 hr at 1750°F at 300 psi. Visual examination shows that "A" Nickel and "K" Monel appear least affected by the nitrogen.

Air oxidation tests of "K" Monel and "A" Nickel were conducted at 1850°F for 4 hr at 1 atmosphere. Metallographic examination showed an average oxidation penetration of 0.001-in. for "A" Nickel and 0.007-in. for "K" Monel.

2. Graphite Coatings: The previous semiannual report stated that Aerojet silicon-silicon carbide coatings had about 80% probability of no leaks. Since then, development has made it possible to achieve leak tight coatings 100% of the time as determined by a hot oil bath test. Some samples of these coatings survived 350 hr in oxidation tests at 1832°F in air at 1 atmosphere pressure, although some samples failed at less than 300 hr. Representative samples produced at Aerojet and at 3M, tested for 300 hr without failure, are shown in Figure 2. All graphite coated by Aerojet with the present coating technique failed in the same way: the right circular cylinders always fail at the bottom corner (as defined by the position of the sample in the coating application furnace). Thus it appears that failure is not inherent in the method of coating, but occurs for one (or both) of the following reasons:

1) Temperature control in the current furnace is inadequate, producing inadequate silicon coating on the corners.

2) Failure is caused by large stress concentrations in the coating at the corners as the result of differential thermal expansion in the two perpendicular directions.

Silicon-silicon carbide coating, according to the literature, is the only coating that has had even moderate success as an oxidation barrier on graphite in the temperature range of interest.

3. Graphite Joining: Graphite joints were fabricated using C-6 cements and selected furfuryl alcohol cement mixes on parts of simulated fuel elements and tensile specimens. A number of tensile tests conducted at room temperature indicated that C-6 cemented joints produced tensile strengths ranging from 300 to 400 psi. Tensile samples fabricated from furfuryl alcohol mixes showed higher strengths, ranging from 1000 to 1700 psi.

4. Fuel Particle Coating: Fuel particle coatings are being investigated as a means of achieving retention of fission products in the fuel element. Five metals and their carbides were selected for experimental evaluation as coatings (10 to 20 microns thick) on uranium oxide (UO_2) and uranium carbide (UC) particles about 100 to 150 microns diameter. The program includes applying the coating to UO_2 and UC, incorporating the coated fuel in graphite, and evaluating any chemical reactions that occur between the coatings and the fuel and/or the graphite.

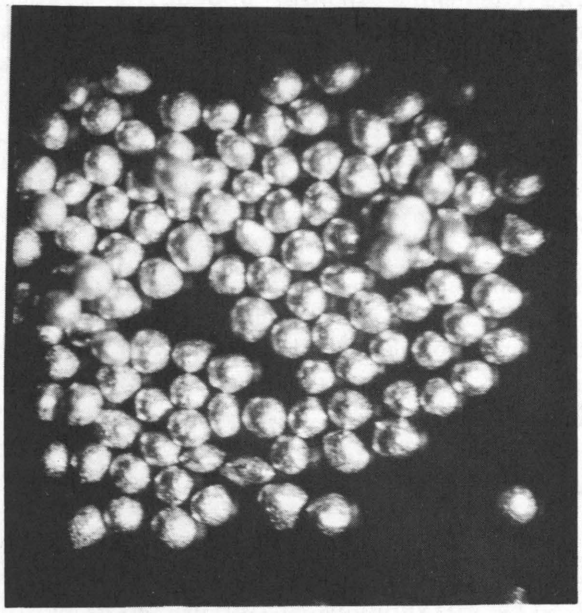


FIGURE 3. 100μ DIA. UO_2 COATED WITH 8μ MOLYBDENYM METAL AT 80x.

Samples of UO_2 coated with molybdenum, supplied commercially by NUMEC, were examined and found to have good uniform coatings (Figure 3). According to the vendor, samples tested by acid leach tests revealed no leaks. A purchase order was let to the vendor to procure spherical uranium carbide particles coated with molybdenum, niobium and vanadium. Uranium carbide particles coated with metal carbides will be evaluated in the future.

5. Mechanical and Physical Properties: The mechanical and physical properties of graphite, Zircaloy 2, "A" Nickel and "K" Monel were surveyed and compiled.

6. Graphite: Work on structural graphite consisted of literature search and personal inquiries to vendors and to the technical personnel of other concerns engaged in work with nuclear power and high temperature materials. Results to date indicate that the graphite best suited for use as a canning material should be fine grained and should be processed to 4712°F during manufacture. It should be re-impregnated with a carbonaceous material, either gas or liquid, during manufacture to reduce, or eliminate, gas leakage through the material.

The results of tests performed by General Atomics and National Carbon Co. show that the two best materials are impregnated graphite pipe produced by Hawker-Siddeley and impregnated research grades of graphite produced by National Carbon Co.

The Hawker-Siddeley material is a relatively porous graphite that was treated with a carbonaceous liquid (such as furfuryl alcohol) then heat treated to carbonize the impregnetant, producing a stronger, more oxidation-resistant graphite. Impregnated tubes have held a vacuum of better than 10 microns for several hours at 2732°F. This represents a reduction in permeability of 10^4 over the original material.

National Carbon's approach to the problem is liquid impregnation to densify and form a disconnected pore structure. This material is still in the developmental stage.

7. Zircaloy 2: Specimens 3-in. long by 1-in.-OD were thermally cycled 100 times from 850 to 1850°F to determine the effects of thermal cycling on Zircaloy 2 tubing and to verify information reported earlier. Examination showed that the samples grew 3.4 to 3.8% in length and acquired a wrinkled surface (Figure 4).

Accomplishments - June:

1. Compatibility Studies: Studies of the compatibility of solid graphite with zirconium, Zircaloy 2, nickel-based alloys, and of the compatibility of graphite coated with molybdenum, niobium carbide and zirconium carbide with Hastelloy X continued.

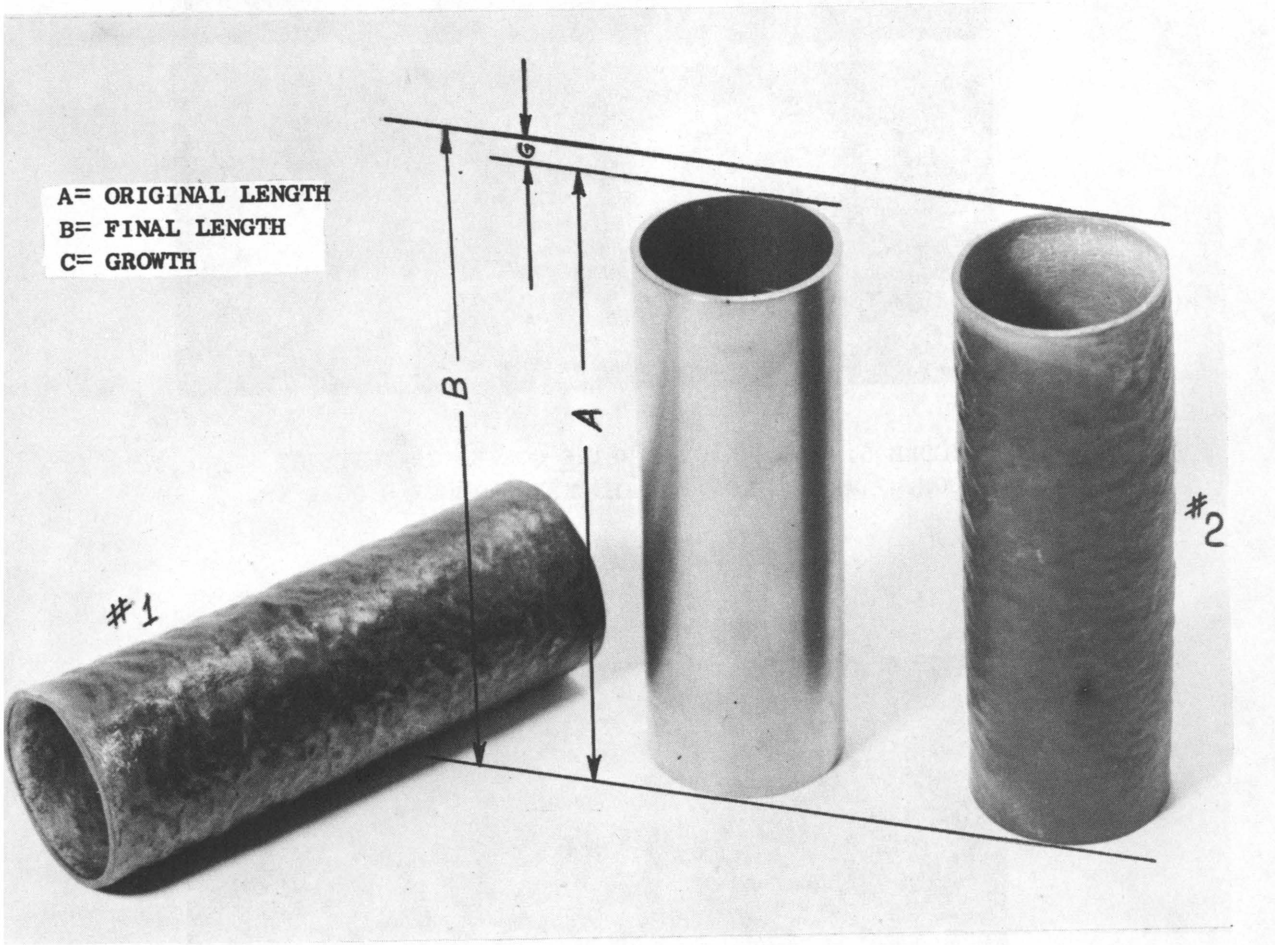
Compatibility tests of graphite coated with molbydenum, niobium carbide, and zirconium carbide in contact with Hastelloy X were terminated after completing 3000 hr exposure at 1750°F at 300 psi. Visual examination showed that all graphite samples retained a good, adherent coating. Metallographic examinations of the niobium carbide and zirconium carbide coatings showed them to be somewhat porous yet uniform in thickness (Figures 5 through 8). The average thickness of the niobium carbide coatings measured 0.005-in. and the average thickness of the zirconium carbide coatings measured 0.0014-in. Metallographic examinations, carbon analyses, and tensile tests were conducted on the Hastelloy X samples in contact with each of the coated graphites. Neither metallography nor carbon analyses revealed any diffusion of carbon into any of the Hastelloy X samples. Mechanical tests showed a decrease in strength and about 90% loss in elongation and ductility.

Tests of the compatibility of graphite with "A" Nickel, "K" Monel, zirconium and Zircaloy 2 were terminated after completing 1500 hr exposure at 1850°F in 300 psi. The metal samples are being examined. Mechanical tests of the zirconium and Zircaloy 2 samples showed about 20% loss in strength without noticeable change in elongation and ductility.

2. Graphite Coatings: Outgassing and silicon-silicon carbide coating of graphite samples continue. The results are encouraging. Several samples withstood 400 hr exposure in air at 1832°F without failure during oxidation tests.

3. Graphite Joining: Graphite joints were fabricated with furfuryl resin binders, graphite flours, C-6 and C-15 cements and tensile tested.

ZIRCALOY 2 TUBING



AFTER 100 THERMAL CYCLES BETWEEN 850 TO 1850°F.
3.4 TO 3.8% GROWTH IN LENGTH.

FIGURE 4

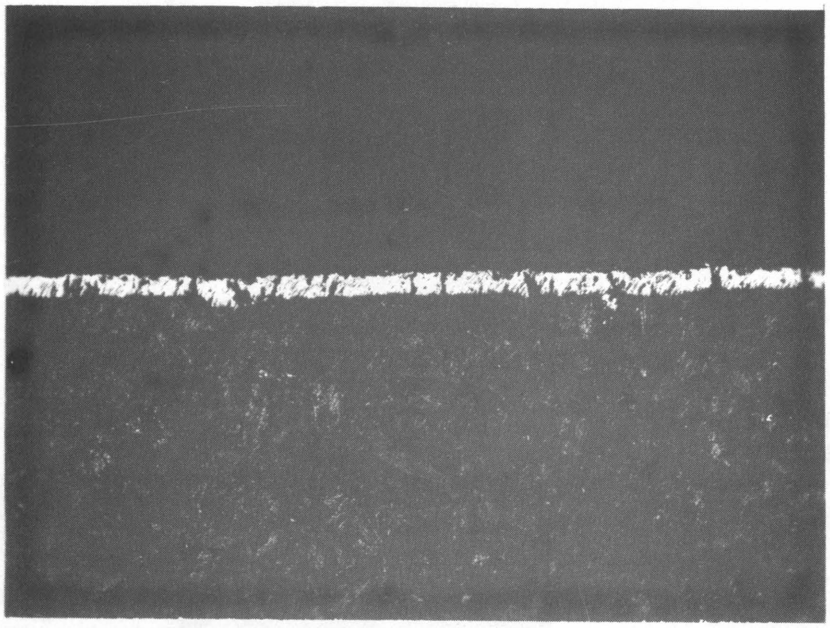


FIGURE 5. ZIRCONIUM CARBIDE-COATED GRAPHITE AT 100x. AVERAGE COATING THICKNESS ABOUT 0.0014 in.

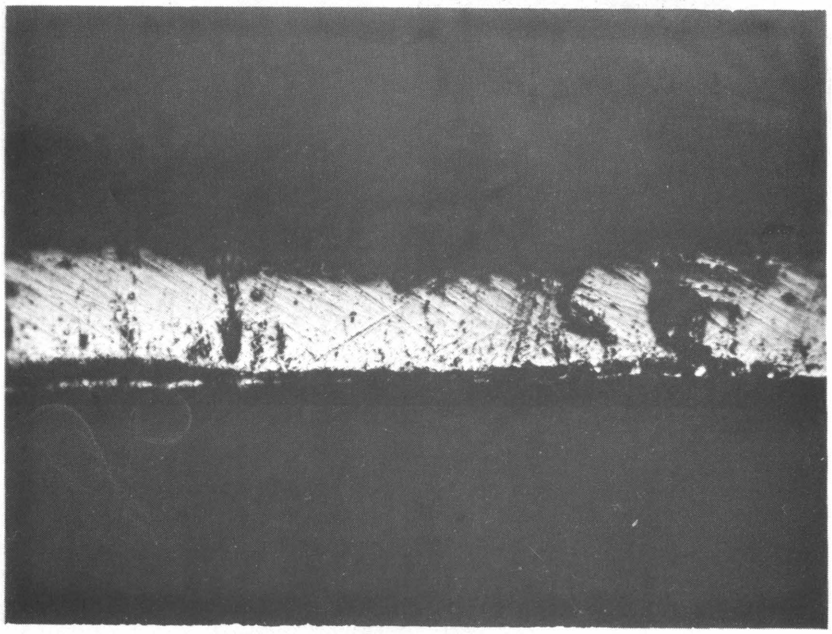


FIGURE 6. ZIRCONIUM CARBIDE-COATED GRAPHITE AT 500x. NOTE THE VOIDS INDICATING POROSITY.

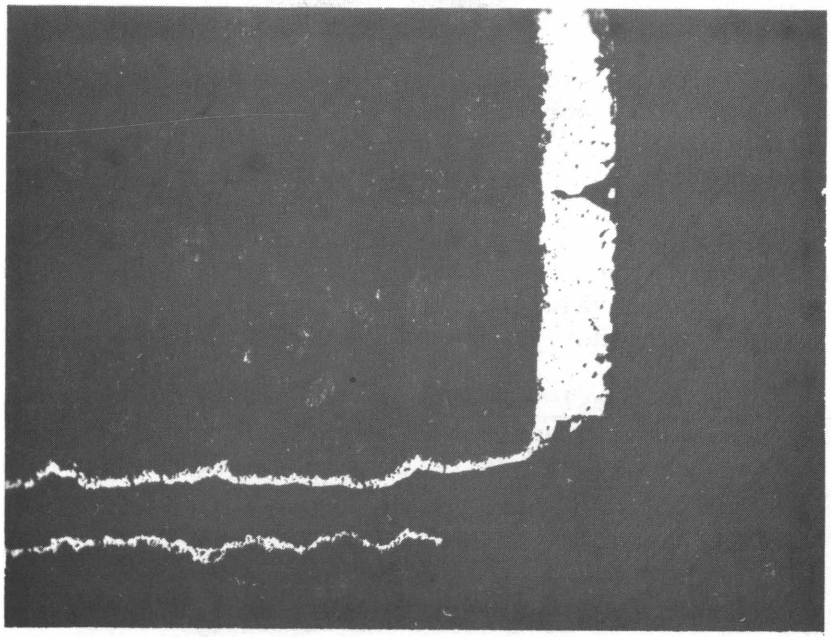


FIGURE 7. NIOBIUM CARBIDE-COATED GRAPHITE AT 100x. THE THICKNESS OF THE COATING IS FROM 0.0002 TO 0.006 in.

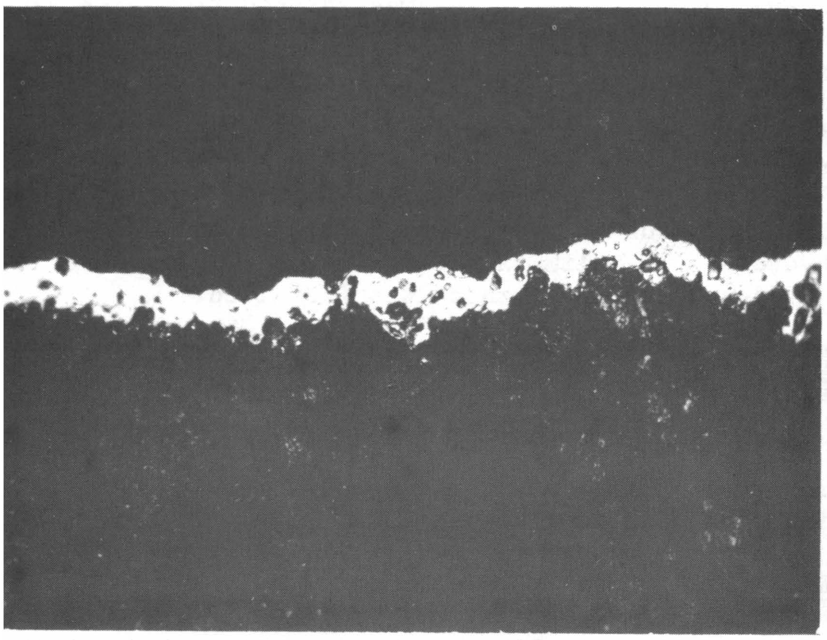


FIGURE 8. NIOBUIM CARBIDE-COATED GRAPHITE AT 500x. THICKNESS OF COATING IS 0.0002 in.

A combination of furfuryl alcohol with C-6 achieved about 2000 psi, although tensile strengths were inconsistent.

4. Coated Fuel Particles: A state of the art survey was completed on particle coatings.

No additional coated fuel particles will be purchased until the quantities on hand are evaluated, and further investigation is made into the processes used at other laboratories.

5. Mechanical and Physical Properties: A literature survey and experimental tests continue on graphites. Results of preliminary tests indicate that Grade H molded graphite (from Speer Carbon Co.) is as strong as conventional graphites.

Mechanical tests of Zircaloy 2 tubing after thermal cycles from 850 to 1850°F for 100 cycles showed about 25% increase in strength with 99% loss in elongation and ductility.

6. Capability and Test Equipment: An optical pyrometer (capable of indicating temperatures to 7592°F) was received and used.

A "Brew" high temperature (4532°F) furnace heater was ordered.

Four "Hevi-Duty" tube furnaces were ordered. These are capable of operation at 2200°F.

A 100 kva motor generator set was secured from USAF surplus by IDO and installed at Aerojet. An induction furnace fixture was designed and fabricated. It was demonstrated that the furnace has a temperature of 4352°F for a piece 4-in.-dia by 12-in-long in a vacuum or in a controlled atmosphere, using a graphite susceptor crucible with zirconia bubbles for insulation.

The induction furnace was used for sintering $BeO-UO_2$ fuel pellets (ML-1) in hydrogen, in helium and in vacuum during process development before the Harper sintering furnace was installed.

Graphite pieces (about 30-in.-long by 1½-in. dia) were de-gassed at 3632°F and less than 1 micron pressure for use in fuel element mechanical development tests.

The furnace is being used to develop a liquid metal interlayer "self-healing" graphite fuel element.

Anticipated Accomplishments - July:

Results from compatibility tests of samples of "A" Nickel, "K" Monel, zirconium and Zircaloy 2 in contact with graphite exposed for 1500 hr at 1850°F at 300 psi will be reported.

Graphite joints will be fabricated with a combination of furfuryl alcohol and C-15 cement, and tested.

Outgassing and silicon-silicon carbide coating of high density graphite samples will be continued in an effort to make reproducible oxidation-resistant coatings on graphite.

The processes of coating uranium carbide with metallic carbides will be further investigated at other laboratories.

D. FABRICATION AND STRUCTURES DEVELOPMENT (Task 49-400)

The thermal cycling loop described in the previous semiannual report (IDO-28549) was assembled and checked out. No further work was undertaken.

III. THE ML-1

A. SUMMARY

1. Major Events:

a. January through May: Activation measurements were made in the Lid Tank Facility in January. The results were the basis for changing the shield design by replacing some of the structural steel with aluminum, and incorporating a polystyrene neutron shield.

Re-analysis of stresses in the tube sheet indicated high stresses in certain regions. Moderator water passages were incorporated in the tube sheet.

Design of most of the reactor package (including pressure vessel, shield, auxiliary tank and control blades) was completed and fabrication initiated. Fabrication is progressing satisfactorily.

An alloy (80% silver/15% indium/5% cadmium) was selected for the ML-1 control blades on the basis of ductility tests, corrosion tests and neutronic calculations.

A critical experiment was performed at BMI on the ML-1 configuration with pin-type fuel elements. The criticality predictions were confirmed, but the fuel flux depression in the inner seven pins was found to be less than calculated. Consequently the fuel loadings were modified to equalize surface temperatures.

The designs were completed on the Stratos and Clark turbine-compressor sets, and appear to be satisfactory. Contracts were negotiated for fabricating the T-C sets.

The design of the alternator was completed and fabrication initiated. The 50-hp starting motor will be attached on the end of the alternator.

The recuperator design selected is a four pass, shell and tube heat exchanger. The design was completed and core tests were made to determine heat transfer and pressure drop characteristics. A contract was negotiated for fabricating the recuperator.

The design of the pre-cooler was changed to incorporate the moderator and oil coolers, and the number of fans was increased from six to eight. The pre-cooler design selected is a straight finned tube, and the design of the heat exchanger was confirmed by core tests. A contract was negotiated for fabricating the pre-cooler.

Construction work started on the ML-1 facility at NRTS.

Design and fabrication continued on schedule for the ML-1 controls and instrumentation, and the ML-1 auxiliaries.

b. June: Fabrication progressed satisfactorily on the reactor package.

Heat transfer and pressure drop core tests were completed on the recuperator. The pressure drop on the tube side was higher than anticipated, apparently because the external finning operation constricts the tube.

Budget limitations made it necessary to discontinue planning for life tests of the heat exchanger.

2. Problem Areas: The requirement of a 15-ton maximum package weight for the reactor and power conversion skids continues to be a problem. The nominal reactor package weight is 29,900 lb. Weight estimates are being confirmed by the actual weights of components.

The problem of removing shutdown heat is under continuing investigation.

3. Schedules: The achievement of the final scheduled milestones still appears attainable, although some intermediate milestons have slipped. The pacing items are the reactor tube bundle, fabrication of tungsten for control blade shields, the turbine-compressor sets, and the fuel elements.

B. REACTOR ENGINEERING

1. Control Blade Actuators (Task 58-1XX)

Summary - January through May:

Fabrication of the control rod drive shaft and dashpot assembly was started and completed during the period. It was discovered during assembly and testing that the dashpot housing was difficult to center over the shaft, and that the dashpot housing galled on the shaft. A centering ring added to the housing remedied this difficulty and eased assembly.

The static seals were tested to find a satisfactory seal that would not be subject to radiation damage. This investigation is continuing. Rubber "O" rings are being used throughout except near the radial shield where radiation dosage is high. The information available leads to the conclusion that silver-plated stainless steel "O" rings best meet the requirements of the ML-1 control system. Other metallic seals are too dependent on high surface finish and precise control of groove depth. A mechanical face seal (made by Sealol Corp.) was found to be preferable to rubber "O" rings for the dynamic seals in the system from the standpoint of radiation as well as sealing efficiency.

The double universal joints at the ends of the control rod drive shaft were both tested and found to be suitable. One is a special Oldham coupling-type design and the other an Apex double universal joint.

Tests of the prototype drive shaft housing and dashpot assembly revealed that the dashpot chamber pressure is no more than 20 psi. It was difficult to establish proper working clearances between the dashpot vanes and housing. The best vane material tested to date is bronze. The optimum clearance between vanes and housing is 0.001-in. The housing is AISI Series 300 stainless steel. The vanes were grooved to increase turbulence and pressure loss between them and the housing to obtain more damping. However, the effect of the grooves proved negligible. Pressure has little effect on dashpot operation but damping is directly related to the viscosity, and thus the temperature, of the water.

No damage resulted to the system when the dashpot and control blades were scrammed dry.

The design of the actuators was nearly completed during the period. Fabrication of the prototype actuator reached 50% completion.

Accomplishments - June:

Static seal testing was continued on a silver-plated stainless steel "O" ring. This seal proved less sensitive to surface finish and precision of groove depth than other types of metallic seals. A study of the resistance of asbestos-filled gaskets to radiation damage revealed that the material would be satisfactory in the actuator region, but of doubtful value at the flange near the inner radial shield. A Stainless steel asbestos-filled gasket (Spirotallic) sealed well under all test conditions. However, at this time the silver-plated stainless steel "O" ring seals seem to be the most suitable for use in the ML-1 control blade system.

Tests were continued with a dashpot using chromium-plated 17-PH stainless steel vanes in an effort to eliminate galling of blades against the dashpot housing. No improvement was noted over the performance of the bronze blades. Burnishing MoS_2 ("Molycote") into the dashpot housing and vance surfaces effected an improvement. Investigations in the area will continue.

A prototype shim-scram actuator was assembled and tests show that modifications are unnecessary. The regulating actuator is being assembled.

The 8-in.-dia bellows that joins the dashpot to the actuator housing was ordered, and delivery is expected in July. A fixture was designed for holding and for use in handling the bellows during welding and when the flange is being bolted to the actuator housing. The jig will also serve as a seal at the dashpot to permit leak testing the reactor moderator system with all control blade shaft housing mounted on the reactor.

The 17-PH stainless steel for the Apex double universal joint was procured by Aerojet and transmitted to the vendor for fabrication, with delivery promised in August, or earlier. The complete system will be tested, however, with one of these universal joints ordered for evaluation tests.

A jig was designed to permit placing the actuator on its mounting plate and sliding it into place, properly indexed to mate with the tang on the end of the drive shaft.

Electrical control equipment for automatically cycling the actuators was received.

A time study showed that a skilled mechanic can replace an actuator in the field in about three minutes.

Specifications were written for shock and vibration tests of the control blade system.

Drawings for the control blade system are complete.

Anticipated Accomplishments - July:

Silver-plated stainless steel "O" rings will be received and will be tested on the aluminum/steel joint at the actuator housing.

Dashpot vanes will be surface treated to eliminate galling, and tested. Automatic cyclic endurance tests will be performed on the prototype shim-scram and regulating actuators.

The equipment for the pressure vessel control blade test will be received and installed.

The 8-in.-dia bellows will be received.

The jig for holding and handling the bellows will be built.

Fabrication will be completed on the dashpot and drive shaft housing assemblies.

Fabrication of actuators will reach 80% completion.

2. Reactor Shielding (Task 58-200)

a. Mechanical

Summary - January through May:

The material for the outer shell of the inner radial shield was established during January as aluminum instead of stainless steel. In addition, lead was successfully bonded to stainless steel and tungsten for use in the ML-1 reflectors, and fabrication was initiated on a test reflector can.

Bid packages were released to obtain tungsten for the blade mount shield. Aerojet, Downey, was authorized to begin fabricating the ML-1 shield baffle. A baffle weld test program was successfully completed at Aerojet, Downey. Stainless steel forgings were received for use in fabricating the baffle can.

Detailing of the ML-1 shield components was completed during April and May. Aerojet, Downey, was authorized in April to fabricate the ML-1 radial and end shield assemblies.

A purchase order covering tungsten for the blade mount shield was let to a vendor. Bids were requested for fabricating the ML-1 reflector and blade mount shields.

An additional thermal stress test was initiated on the reflector in May to obtain test data to back up the results of a previous test.

Accomplishments - June:

The radial and end shields are being fabricated. Part of the lead was received, and the remaining material was ordered.

The baffle assembly is being fabricated and is about two weeks ahead of schedule.

The reflector and blade mount shields are being fabricated. All parts were ordered from one vendor.

The tungsten inserts for the baffle were sent to Aerojet, Downey. Two tungsten inserts for the reflectors were received and a third is in transit. The tungsten for the blade mount shield is being expedited and will be ultrasonically inspected.

A test can is being fabricated for the thermal stress test on the reflector.

All radial and end shield drawings were released to Aerojet, Downey.

Anticipated Accomplishments - July:

Fabrication will continue on the radial and end shields.

Fabrication will continue on the baffle assembly.

Fabrication will continue on the reflector and blade mount shield.

Tungsten for the inserts will be received at Aerojet, San Ramon, and sent to the vendor.

The thermal stress test will be completed on the reflector.

b. Nuclear

Summary - January through May:

1) Lid Tank Experiment: Data from a series of experiments performed at the ORNL Lid Tank Facility was used to establish a reference shield design by December 1959. (In these experiments the proposed shield was mocked up in slab geometry.) Stainless steel and aluminum foils were used in additional activation measurements at the Lid Tank Facility in January. These activation measurements included both gross counting and gamma spectral counting of foils located on the mock-ups of the radial and end duct shields. The results of the activation analysis were refined to determine the thickness of lead required for the gas duct and end shielding. To shield against horizontal penetration in the direction of the cab, 3.75-in. of lead will be used. The radial shield design was changed as a result of data from the Lid Tank Experiments to replace with aluminum the outer stainless steel canning of the inner lead shield. This change will reduce the contribution of the stainless steel canning of the inner lead shield to the shutdown dose rate.

Data from these experiments also were used to refine calculations of the shutdown dose rate 25-ft from the reactor centerline in the direction of the cab. Additional calculations determined the shutdown levels at the back side of the shield as well as in the axial directions above and below the reactor. These calculations show that the radiation levels established as design criteria for the case of a year of full power operation will be met with the power conversion skid in place. (These criteria include 15 mr/hr 24 hr after shutdown 25-ft from the reactor centerline in the direction of the cab; 100 times this level in the axial direction; and 10 times this level in all other directions.) These calculations may be in error by a factor of ± 2.

The dose rate due to neutrons streaming through the gas duct during reactor operation was calculated for a location 500-ft horizontally from the core centerline. These calculations were based on extrapolation of data obtained in traverses of the end duct mock-up during the Lid Tank Experiments. The resultant level at 500-ft is above the 5 mr/hr established as a design objective. If this situation is confirmed by ML-1 operational measurements, the dose rate could be reduced by the use of expedient shielding.

Further Lid Tank measurements are proposed to obtain more refined data on duct streaming during operations. Previous measurements were limited by the physical location of the equipment inside the duct. Slight modifications will permit measurements outside the tube, thus greatly reducing the extent to which the measurements are dependent on analytical techniques. Drawings of these modifications were completed.

2) Photoneutron Experiment: An experiment was proposed to determine the magnitude of the photoneutron intensity from the Be(γ,n) reaction in the ML-1 core. Five cans of BeO will be inserted in the GCRE-I core immediately after shutdown and the photoneutron intensity measured with

a long counter placed near the radial shield. The cans were fabricated and filled with BeO, and the long counter is available. The photoneutron experiment is scheduled to be completed during July.

The magnitude of the photoneutron dose date at 25-ft from the reactor centerline 24 hr after shutdown with the moderator and shield water drained was calculated with the SNG code to confirm the results of earlier calculations. The calculations showed a dose rate of 1.7 mrem/hr through the shield, including 20-in. of polystyrene. (Previous hand calculations showed a level of 1.0 mrem/hr.) The photoneutron experiment will eliminate the uncertainty associated with the values for photoneutron source strength used in these calculations.

3) Radiation Damage Tests: Capsules containing borated and non-borated samples of polystyrene were subjected in the MTR to an exposure equivalent of one year full power operation in the ML-1. The non-borated material was highly discolored but appeared to be structurally sound. As a result of this test, the polystyrene shield was re-located 3-in. further from the center of the core to ensure reduced radiation damage.

Samples of the stainless steel gas duct, spray coated with boron carbide, will be irradiated in the GCRE-I reactor to evaluate the effectiveness of the bond between boron carbide and stainless steel. Further radiation damage tests of polystyrene will be performed in the GCRE-I reactor where the neutron flux distribution is more similar to that in the ML-1 than in the MTR. These tests are scheduled to start 1 August.

4) Neutron Flux Distribution Codes: Several codes are available for use in calculating neutron flux, in addition to the SNG code.

1) SNG Neutron Transport Code: Used to calculate a 16-energy group neutron flux distribution through the ML-1 shield.

2) GRACE-I Code: A multi-group, multi-region, gamma ray attenuation code designed for computing gamma ray heating and dose rates in infinite or semi-infinite slab shields. This code is being used to calculate the operational levels measured in the Lid Tank Experiment.

3) FADE-I Code: Written and checked at Aerojet, San Ramon, this code is designed to calculate activities and fluxes from raw data for any power level, radiation and decay time desired from physical and nuclear data for any number of foils counted any number of times. This code will greatly reduce the time required to analyze experimental data from future Lid Tank and GCRE-I shielding measurements.

4) ELSA-I Code: Written and checked at Aerojet, San Ramon, this code is used to calculate dose rates from line sources with varying shield and source distributions. The code will be useful in many calculations involving handling fuel elements, removing control rod shafts, and so on.

Accomplishments - June:

1) Lid Tank Experiment: Drawings of the components needed for the Lid Tank Experiment were completed. Aerojet, San Ramon, is preparing to build the parts. The planned measurements are scheduled to be completed in September.

2) Radiation Damage Tests: Irradiations of polystyrene and spray-coated stainless steel in the GCRE-I are scheduled to start about 1 August. Preparations are being made for these tests.

3) Foil Irradiation: Irradiation of stainless steel foils in the GCRE-I is scheduled to start 1 August to confirm the build-up of long-lived isotopes.

Anticipated Accomplishments - July:

1) Lid Tank Experiments: Fabrication will be in process for those parts needed to complete modification of the end duct assembly.

2) Photoneutron Experiment: The photoneutron source strength measurements will be completed, and the results will be applied to the ML-1 shield.

3) Radiation Damage Tests: Preparations for the insertion of capsules of polystyrene and spray-coated stainless steel in the GCRE-I reactor will be complete.

4) Thermal Resistance Measurement: Measurements to assess the thermal resistance of bonded lead-tungsten and lead-stainless steel will be in process.

3. Reactor Auxiliaries (Task 58-300)

Summary - January through May:

a. Shield Tank: Conceptual design of the shield tank was completed, and assembly drawings were approved for construction. The drawings were released to Aerojet, Downey, for fabrication. Fabrication of the shield tank was 25% complete by the end of the period.

The power conversion skid to reactor skid interface connections for the gas system were approved.

b. Moderator and Shield System: Design concepts and calculations were completed for the heat transfer and pumping equipment.

The layout assembly drawings were 50% completed for the moderator and shield system. Specifications and bid packages for system components were released for bid.

Vendors were selected for the shield water heat exchanger, the main moderator pump, the standby pump, the shield water pump, and for the moderator demineralizer. Purchase orders for this equipment were either released or in process at the end of the period.

A piping and instrumentation diagram was approved.

The requirements for process and analysis instrumentation were defined and approved.

A partial model of the moderator pumping system was fabricated to aid in laying out drawings.

c. Afterheat Removal: The problems of removing afterheat were studied. It was concluded that two afterheat removal systems are required for the ML-1. One system will be needed when transporting hot cores. A second system is planned for operations at NRTS to assess the magnitude of the problem of afterheat removal in case of accidental loss of coolant. These systems are being investigated, and will be reported on soon.

d. Special Tests: A test was conducted to define operational problems associated with the 10% boric acid solution in the shield tank during make-up, steady state operation, and reactor shutdown.

A flow model of the tube sheet passages was fabricated and tested to determine reactor flow resistances and to aid in sizing core passages.

Accomplishments - June:

The urgency of design work limited the effort devoted to afterheat removal. (Additional personnel were assigned before the end of the period.) Investigation was continued on removal of afterheat during transportation.

Bellows section drawings were 75% completed.

A purchase order was issued for the moderator water de-mineralizer.

A partial flow model of the moderator passage is being fabricated.

Anticipated Accomplishments - July:

Shield water and moderator water system assembly drawings will be 75% complete.

Investigation of afterheat removal problems will continue.

Solenoid valves, hand valves and flanges will be ordered.

Bid packages will be released for the expansion joints.

The sources and types of blanket heaters will be investigated.

Drawings of the interface for the moderator system between the reactor and the power conversion skids will be completed and approved.

Tests will be conducted with the flow model of the reactor core.

4. Pressure Vessel (Task 58-400)

Summary - January through May:

The major components for the pressure vessel are being fabricated at Aerojet, Downey. Vendors will perform helium mass spectrometer leak checks and strain gage tests on the assembled pressure vessel.

A contract was awarded for fabricating the test unit for the upper flange joint test, and the test unit fabricated. The first test of the upper flange joint failed because of plastic deformation of the seal ring. An AISI Type 347 stainless steel seal ring was replaced by one made of AISI Type 410 stainless. After the new seal ring was completed, testing proved the integrity of the seal design. The tests included helium leak, hydrostatic and elevated temperature tests. The ability to make, break and re-make the joint was demonstrated.

Tests were performed to evaluate the 10-in. Grayloc seal (AISI 304L stainless steel) with an AISI Type 4130 stainless steel assembly. The first test failed due to 0.019-in. ovality of the hub after the weld operation. The vendor subsequently achieved an ovality of 0.005-in. and tests were successful. Helium leak tests were performed at 350 psi pressure and 3000 ft-lb bending moment.

A preliminary helium leak test was successfully completed on a 10-in. stainless steel assembly before the vendor determined that cold rolling the lead-in lip edges of the seal improved performance. The seal ring was returned to the vendor to have the lip edges cold-rolled.

The tube expander, tube trimming fixture, automatic welding fixture, tubes and tube sheet forgings for the tube-to-tube sheet joints were available at Aerojet, Downey, in February. The more important design parameters for this joint were established by tests performed at Aerojet, Downey. The program to develop a tube-to-tube sheet joint and the necessary fabrication methods and techniques were carried out during the period.

Re-analysis of stresses in the tube sheet indicated that stresses at the junction of the tube sheet and the plenum exceeds the yield strength of the material. Modifications to the design brought the stresses within the yield strength of the material, in some cases by eliminating or reducing stress concentrations, and in others by adding material to provide adequate strength. These modifications were kept within the dimensional limits of the existing rough forgings.

Increased values for the temperature profiles in the ML-1 tube sheets resulted from the use of more accurate methods of calculating the contributions of conductive and nuclear heating to tube sheet temperatures. Stress calculations based on the higher temperatures indicated unsafe operating stress levels. Coolant passages were then incorporated in the tube sheet midway between faces, thus reducing the temperatures to obtain satisfactory stress levels.

The design for mounting reflectors and control blades to the plenum was revised by substituting a circumferential groove for the multiple slot arrangement. The hooked ends of the components, in the current reference design, will be held in the circumferential groove by cap screws. Azimuthal positioning is achieved by slotting only for the six control blade mounts.

The pressure vessel plenums are being fabricated.

Detailed fabrication and assembly procedures, and a schedule were completed in preliminary form for the ML-1 reactor. These procedures identify all tools, fixtures, reactor detail parts and assemblies, and provide instructions for the proper assembly sequence. The preliminary draft, and revisions, were used to coordinate assembly and fabrication fixtures with fabrication of reactor parts.

Gas ducts, expansion joints, seal bellows, and insulation designs were completed. Bids were let for the upper and lower moderator water seals. Bellows are being fabricated for the duct-to-reactor tank seals. A contract was awarded for fabricating the lower moderator water seals with delivery scheduled for late July. Drawings were completed for the boron carbide-coated gas duct, for the gas duct insulation, and for the tube sheet insulation. Bellows for the gas duct, the 90^{o} elbows, the 10-in. pipe, and the upper moderator seal were received.

The ML-1 pressure vessel was revised by providing dowels and keys for carrying to the primary support structure the torque loads transmitted to the pressure tube bundle. Drawings were completed for the upper and lower cap sub-assemblies of the pressure vessel and the split support ring. Three major assembly drawings are in process.

Pressure vessel instrumentation will be limited to strain gages.

Fabrication of the assembly cage is about to begin.

Accomplishments - June:

Strain gage locations in the tube bundle were determined but the drawing was not completed.

Tube sheet insulation drawings were released for fabrication.

A die was completed for use in dimpling the insulation sheets, and was tested on sample configurations. Fabrication of the insulation assembly for the 90^{o} elbow was started. All insulation drawings were released.

The upper plenum insulation was slightly modified before release to facilitate remote handling for the reactor cap. The effect of the modified insulation on the temperature of the plenum wall was calculated.

Additional tests are being planned for the stainless steel Grayloc seal for the gas ducts. Drawings and specifications for the upper flange joint were received from the vendor and are being incorporated into existing drawings. A specification control drawing will be made of the seal ring.

Drawings were released for those gas duct sub-assemblies to be coated with boron carbide. Two elbows are being coated by a vendor. The pipe and three remaining elbows will be shipped to Aerojet, Downey, for assembly and coating. Five drawings of the gas duct assemblies and parts are being held until connections are selected. Except for the final assembly drawing, all other gas duct drawings were released. A detail drawing of the upper gas duct support, inside the reactor tank, is being drawn. However, the external end supports for the gas duct (for use in transportation and fuel element change) have yet to be designed. Weld neck flanges for the gas ducts are to arrive at Aerojet, San Ramon, no later than 12 July. Drawings of the Grayloc connections that may be used in the gas duct were received. Layout of the gas duct was changed in accordance with a request from Aerojet, Azusa.

A revised preliminary reactor package assembly procedure was completed. A tooling list was completed based on the assembly procedure. All major assembly tooling was released for fabrication and is about 50% fabricated. About 75% of the design work is completed for the minor tooling. The assembly drawing of the reactor core is being checked.

Anticipated Accomplishments - July:

The drawings of the pressure vessel strain gage instrumentation and the specifications for strain gages, leads, connections and waterproofing will be completed.

Bids will be requested for the tube sheet insulation and a contract awarded. Fabrication will be started.

Plenum and gas duct insulation will be in fabrication.

A remotely operated disconnect clamp for testing the connections for the upper gas duct will be ordered. The specification control drawings of the upper flange joint seal ring will be completed and released. Additional upper flange joint seal rings will be ordered. Additional tests may be performed on 10-in. Grayloc connections.

The gas duct subassemblies will be completed and sent to a vendor for coating. The gas duct connections, for the interface between the reactor and power conversion skids, will be completed and released. The external gas duct supports will be designed. Connections will be ordered. Possible methods of eliminating exhaust gas duct connections inside the reactor tank will be explored.

The final reactor package assembly procedure and schedule will be completed. All tooling drawings will be completed and released for fabrication. The assembly drawing for the reactor primary assembly will be completed and the assembly drawing will be started for the reactor package.

5. Control Blades (Task 51-850)

Summary - January through May:

The design of the blade mount was finalized and contracts let for fabricating gears, shaft spline, investment castings for the supporting structure, and ball bearings of 17-4H stainless steel. A spline was developed for insertion of the driven gear in the blade mount and properly indexed without binding.

Physical tests were performed on alloys of silver, indium and cadmium that seemed to have high nuclear control worth. Alloys with 60 to 75 wt% silver were found to be too brittle. The alloy selected has 80% silver, 15% indium and 5% cadmium: its reactivity control worth is 3 to 5% less than the other alloys tested, but it is ductile and has been previously used as a control material. This silver alloy was ordered for the reactor shim-scram blades. AISI Type 202 stainless steel was selected for the regulating blades.

Accomplishments - June:

The reference silver alloy blade material was received.

The support structure castings for the blade mount were welded. Shrinkage of the structure during welding was not excessive.

Half of the ball bearings for the blade mounts were received and the vendor promised to deliver the rest in July.

All of the blade mount gears and splines were delivered. The center to center distance for each set of gears was measured with an accuracy of 0.0002-in. so that bearing holes can be jig bored within this limit to minimize backlash.

The jig for holding the support structure castings during welding was modified to improve the results obtained from test welds.

A jig was fabricated to locate the attachment holes of the blade mount in relation to the bearing holes.

Anticipated Accomplishments - July:

The blades and blade mounts will be fabricated and assembled, and tests will be initiated.

6. Special Studies (Task 51-810)

Summary - January through May:

A special study was initiated for a device to locate a defective fuel element in the ML-1 core. Such a device would be used to detect which of the 61 elements had a defective (leaky) pin so the element could be replaced to minimize contamination. (Studies showed that a single defective fuel pin in the ML-1 might leak enough fission products to contaminate the power conversion equipment over a period of time.)

The device is a plate holding 61 disks of silver screen or activated charcoal. It can be inserted in the top plenum of the reactor directly above the fuel elements. If the reactor is operated at low power with direct cycle air cooling and reverse flow, the fission products (primarily the iodines) leaking from a defective fuel pin will be caught on the screen or charcoal located above the particular element. When the device is removed and the screens counted, high activity would reveal the location of the defective element.

A small in-pile loop was designed and built to demonstrate the feasibility of the device. The loop was designed as a reduced scale model of the ML-1 core. Permission to operate the loop in the AGN-201 was granted by the Reactor Safeguards Committee.

Accomplishments - June:

Tests were run during June, operating the defective pin test loop in the AGN-201 reactor. Experiments showed that Hastelloy X-clad pellets (0.241-in. OD) absorbed sufficient neutrons so that the final worth of the in-pile loop loaded with 10 pellets of dense highly enriched UO_2 (10.58 grams U-235) was negative about 0.1% $\Delta k/k$.

Two ambient air temperature runs were made with the in-pile loop in the reactor, the latter operating at 5 w for four hours. The first run operated with two channels in parallel, one containing the leaky fuel pin, the other a blank. This run showed that the silver screen, located only 3-in. downstream from the leaky fuel pin (at 45% of the neutron flux at the pin) became so activated by neutron absorption (forming Ag-110, $T_{\frac{1}{2}}$ = 270 days) that it was impossible to show if any fission products indeed were caught and held by the silver. The fission products were caught outside the reactor on activated carbon (Type BPL, 4 x 10 mesh, Pittsburg Coke and Chemical Co.) held in a column made of 11 Polyvials, each holding about 5.7 grams of carbon. Analysis of the activity held on this carbon one hour after reactor shutdown showed that the Polyvial of carbon caught about 40% of the gross fission products entering the column. In comparison, the other ten Polyvials caught only 7.6% of the fission products entering each in sequence. Incidentally, about 18% of the gross fission products passed through the activated carbon and were vented out the stack. This first run had 0.142 scfm of air flowing in each channel, giving velocities of 11.2 ft/sec past the leaky fuel pin, and 46.3 ft/min into the carbon. The carbon temperature averaged 77°F.

The second run used three channels in parallel, one containing the leak fuel pin, a second containing iodine crystals, and the third a blank. Again the run showed that the silver screen became too activated to show if fission products were held by the screen. The silver screen was located 15-in. downstream from the leaky fuel pin (5.5% of the neutron flux at the pin) comparable to ML-1 conditions. The data from the channel containing iodine crystals showed that the silver screen held 45% of the activated iodine (I-128; $T\frac{1}{2}$ = 25 min). It is concluded that the fission product iodines, I-130 through I-135, have too low a yield to be detected this way. This run also had activated carbon held in 11 mm glass tubes in the reactor downstream of the silver screens in addition to the carbon in Polyvials outside the reactor. The activated carbon caught the gross fission products with about the same efficiency shown in the first run; but the carbon inside the reactor showed little activity from neutron absorption, thus making carbon the candidate for the detector instead of silver. To check the ability of the carbon to retain fission products when washed with water (as would be the case when using it in the ML-1 where installation and removal must take place through a 12-ft deep pool of water) every other vial of carbon in the original column was arranged into a new column and 500 ml of de-mineralized water was re-circulated through it ten times. The carbon retained the activity without loss. In the second run, the air flow in each channel was 0.148 scfm, giving velocities of 11.7 ft/sec past the leaky fuel pin, 266 ft/min into the carbon in the glass tubes, and 48.3 ft/min into the carbon in the vials. The average temperature of the carbon was 75°F.

Anticipated Accomplishments - July:

More runs will be made with the in-pile loop to explore the effects of small leaks in the fuel pins, the temperature function of carbon absorption of fission products, and the retention of fission products when the carbon is pre- and post-treated with quantities of water.

7. Critical Assembly Support (Task 51-860)

Summary - January through May:

The experiments conducted by BMI on the GCRE and the ML-1-IA critical assemblies in the past were reviewed early in the report period. Experimental data required by various ML-1 design groups were examined to establish desired experimental accuracies and the sequence for the experiments. An experimental program was established after discussion with the critical assembly group at BMI to provide most of the information required by the design group. As new experimental data were generated, the program was reviewed and revised.

The highly enriched UO_2 powder for the ML-1-IB critical assembly was received from the vendor in January 1960. Fabrication of fuel pellets began in February after development of fabrication techniques.

Four different types of fuel pellets were fabricated (nomenclature and approximate compositions are tabulated below). The fuel, in all cases, was contained in a Hastelloy X tube with Epon seals at both ends. Except for Type III (sintered), the pellets were used green, unsintered.

NOMENCLATURE AND COMPOSITION OF FUEL PELLETS

MATERIAL	TYPE I PELLET	TYPE II PELLET	TYPE II POWDER	TYPE III PELLET	TYPE IV PELLET
U-235 (gm/pin)	58.9	20.2	19.6	75.0	26.6
Al_2O_3 (wt%)	--	32.5	37.5	--	16.3
P V A* (wt%)	1	1.75	--	--	1.9
Steratex (wt%)	1	0.5	--	--	1.9
Graphite (wt%)	--	2.5	--	--	4.0
Teflon (wt%)	0.6	0.7	--	--	0.9

*P V A - polyvinyl alcohol

The following materials and test equipment were procured and shipped to BMI for the test program:

1) Copper-cadmium alloy foils to simulate burnable poisons.

2) Cobalt alloy foils to determine reactivity worth of these foils for use as ML-1 reactivity shimming materials.

3) Test control blades to simulate the ML-1 shim-scram and regulating blades for evaluation in the critical assembly.

The first fuel shipment (62 elements) reached BMI 6 April. These used Type I fuel in the seven central pins and Type II fuel in the 12 outer pins. Powdered fuel was used in the 12 outer pins of 49 of these elements. The other elements used pressed pellets in 19 fuel pins.

Fuel for two sets of modified elements was fabricated to obtain data on pin-to-pin power ratios with different pin-to-pin fuel loadings. Each set consisted of a cluster of seven modified fuel elements. The first modified elements were made with Type III fuel for the seven inner pins and Type IV fuel in the 12 outer pins. The second set of modified elements were made with Type III fuel for the inner pins, but using Type II (pellet) fuel for the outer pins.

Split fuel pins and specimen capsules were fabricated for use as relative power detectors in obtaining pin-to-pin power ratio data to the desired accuracy. The fission product activity of the specimen capsules after irradiation was taken as a measure of the pin-to-pin fission rate. The required number of split pins and specimens capsules were fabricated and shipped to BMI during the report period.

The core mock-up went critical on 12 April with 48 fuel elements and with control blades worth 1% Δ k/k inserted.

The calculations used to predict reactivity of the 61-element critical assembly with a 39 kg loading were refined early in the report period. Fast neutron constants weighted with ML-1 neutron spectra were used in these improvements. This refinement predicted criticality at 45+ fuel elements, and compares favorably with the 48 elements in the experiment.

Preliminary data from BMI on the intracell studies of the first and second modified elements were reduced. The power ratio data is summarized in Table 1 on the following page. The effect of these data on fuel element design is discussed under IB Analysis, Task 21-1XX in Section IV, Fuel Element Development.

Accomplishments - June:

The experimental critical assembly program was reviewed and the schedule revised. The revised schedule cancels most of the work on the unpoisoned core, but increases the time allowed for intracell studies.

The intracell flux and power data taken from the "18-pin" fuel elements (this is the designation given to a 19-pin element with an unloaded central pin) were reduced and transmitted to the reactor physics group for analysis. Further consideration of data on the measured activity worth of the silver-cadmium test blade was deferred in order to maintain closer liaison with the BMI critical assembly group. The high reactivity worth of this test blade indicates that the reference ML-1 control blades provide the requisite amount of reactivity control.

Eight Type II powdered fuel specimen capsules were fabricated and shipped to BMI.

The Haynes 25 (cobalt alloy) foils were received and shipped to BMI. Various thicknesses of these foils will be wrapped around each of the seven central fuel elements to determine reactivity worth as a function of foil thickness.

A pair of reference ML-1 regulating control blades was shipped to BMI for testing. A pair of 70 wt% silver/30 wt% cadmium test blades was shipped to BMI for evaluation of the maximum worth of the shim-scram control blades. Detailed control blade studies, however, will be made using the reference ML-1 shim-scram blades. These blades are made from a silver/indium/cadmium alloy instead of the silver/cadmium alloy used

TABLE 1

REDUCED POWER RATIO DATA

(From BMI intracell studies on modified elements)

Parameters	Central Position (FE #1)			Peripheral Position (FE #49)		
	Total	Epicad	Thermal	Total	Epicad	Thermal
I Mod #1						
P_3/P_2	0.915	0.501	*	1.066	0.532	1.401
P_3/P_1	1.067	0.545	*	1.289	0.555	1.882
P_2/P_1	1.166	1.088	*	1.209	1.042	1.344
II Mod #2						
P_3/P_2	0.732	0.414	1.025	0.774	0.412	1.016
P_3/P_1	0.867	0.441	1.358	0.958	0.448	1.388
P_2/P_1	1.186	1.065	1.325	1.238	1.086	1.365
III Mod #1'						
P_3/P_2	0.948	0.528	1.376	1.086	0.543	1.470

*An error was discovered in the experimental data which causes unduly low thermal power ratios at this point. A rerun of this experiment is being considered.

Nomenclature:

1. P_3 = outer ring power per pin
2. P_2 = middle ring power per pin
3. P_1 = central pin power per pin
4. Mod #1: 75 $\frac{\text{grams}}{\text{inner pin}}$; 26.6 $\frac{\text{grams}}{\text{outer pin}}$
5. Mod #2: 75 " ; 20.2 "
6. Mod #1': 18 pin model of Mod #1

in the first test blades.

Anticipated Accomplishments - July:

The experimental program will be reviewed to determine if additional test fuel elements should be produced. The high reactivity worth of the shim-scram blades may require a change in the schedule. It is possible that the flooded core experiments may be completed early, in view of the possibilities extended by the high reactivity worth control blades.

The experimental procedure for the detailed evaluation of the control blades will be re-examined to provide more precise specification of the desired information.

The intracell flux and power data on the first core loading and the various reactivity worth data will be reduced and transmitted to the reactor physics group for analysis.

8. Systems Analysis (Task 51-870)

Summary - January through May:

Several possible variations in the ML-1 power control system were considered during January and February to determine the optimum control technique or combinations of control techniques. The combination of methods selected maintains a constant amount of gas in the system and divides operations into three regions of the ambient air temperature range: below $0^{o}F$, from 0 to $100^{o}F$ and above $100^{o}F$ (Figure 9).

1) Above $100^{o}F$: Turbine inlet temperature will be held constant at $1200^{o}F$; compressor inlet temperature will increase with increased ambient air temperature.

2) 100 to $0^{o}F$: Turbine inlet temperature will be decreased with decreased ambient air temperature in such a manner that maximum power remains constant; compressor inlet temperature will decrease with decreased ambient air temperature.

3) Below $0^{o}F$: Turbine inlet temperature and compressor inlet temperature will be held constant at the values established for $0^{o}F$. The air flow will be reduced by reducing the number and speed of the fans to maintain a constant compressor inlet temperature. Maximum power will remain constant.

For loads less than the maximum at all ambient air temperatures the bypass valve will automatically open the amount required to regulate frequency. The turbine inlet temperature set-point will be manually set and automatically controlled. The compressor inlet temperature will be manually controlled only.

Almost continuous effort was given to the problem of starting power requirement. It was determined that the Clark Brothers t-c set set will

ML-1 REFERENCE CONTROL METHOD

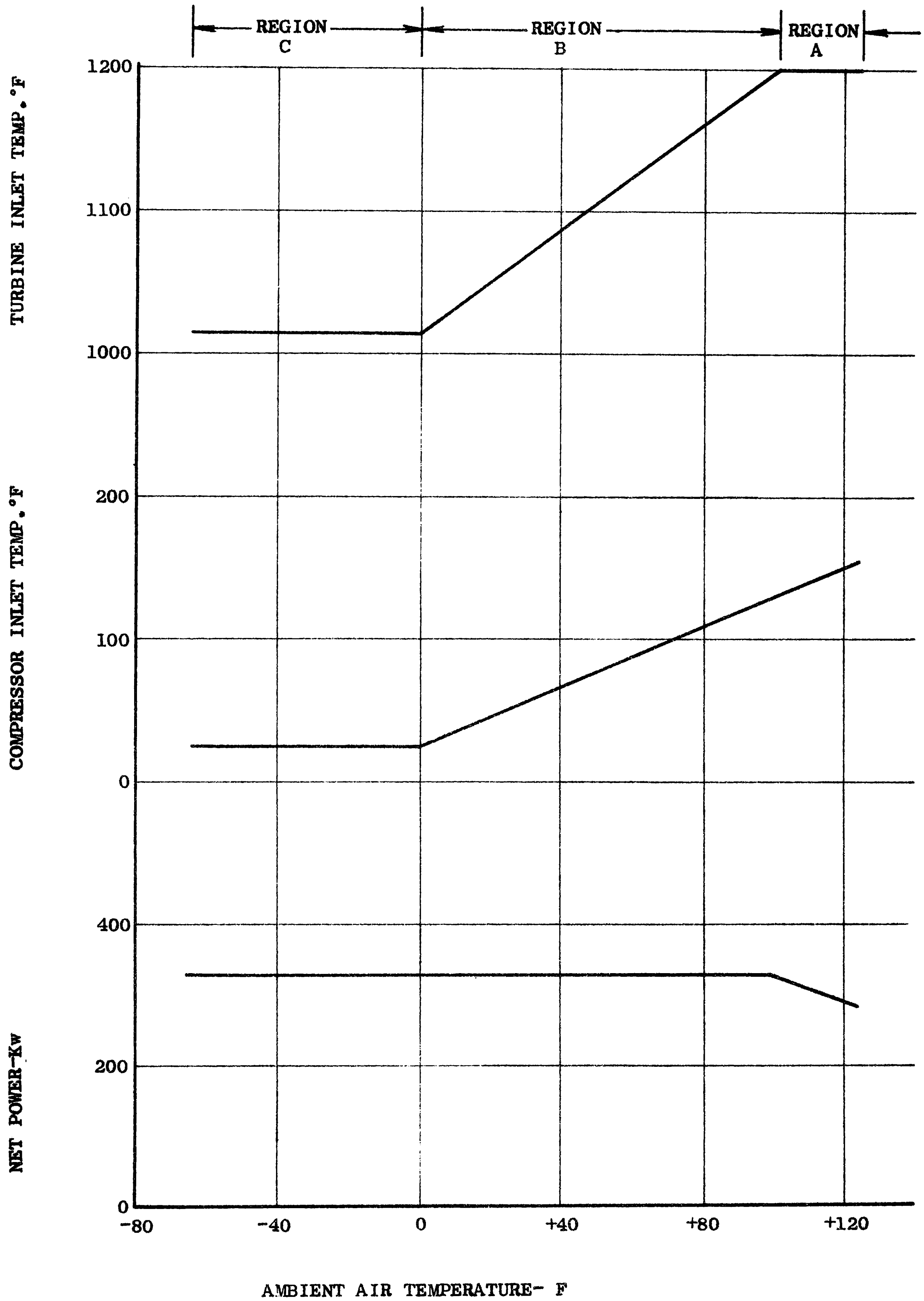


FIGURE 9

start at about 850°F turbine inlet temperature at 50% of t-c set shaft speed. The starting requirements of the Stratos t-c set are expected to be completed soon.

A table in influence coefficients was prepared during February, March and April. These coefficients are partial derivatives of dependent variables with respect to independent variables. As an example, the net power output will decrease 0.41 kw for each 100 ft^2 decrease in pre-cooler air side flow area. These coefficients are intended to aid design and operating personnel in evaluating the effect on performance of small changes in hardware characteristics. (Table 2 is typical of the influence coefficients tables.)

The characteristics from the Clark final design report t-c set were used to re-evaluate the system state points (Table 3 shows typical ML-1 performance data for 100°F ambient temperature). The characteristics from the Stratos final design report are being used to determine the state-points associated with the Stratos t-c set under all conditions of load and ambient air temperature.

The data generated at the GTTF were examined in detail to ensure that the ML-1 will receive maximum benefit from these tests. A preliminary check of the mathematical method used for the ML-1 was obtained from an analysis of the closed cycle tests at GTTF. A scheme was devised for analyzing test data. As additional data is obtained, a more comprehensive check will be made. This effort extended throughout the period and is expected to continue.

Refinement of the CHOP (IBM-704) program for closed-cycle gas turbine power plants continued throughout the report period.

The effect of pressure dependance of Cp on plant output, investigated in April, showed that the initial assumption of Cp being a function of temperature caused an error of 10-15 kw in the calculated net plant output. This small effect is being included in all current power calculations.

The output expected when operating at 50 cycles was also calculated during April. Operating at 50 cycles will reduce the t-c set speed, the air side flow rate for the pre-cooler, and the auxiliary power requirements. After considering all effects, it is predicted that the maximum power will be about 305 kw with the Clark t-c set. Fifty cycle operations will also require more gas in the system than 60 cycle, using 315 psia as the limit of reactor inlet pressures.

The effects of possible changes in the reactor core on system performance were considered during May. The results will be reported by Task 21-300.

Accomplishments - June:

Work began on an estimate of the heat loss through power plant piping and through the shells of the heat exchangers and rotating machinery.

Until these calculations were begun, it was assumed that the piping was isothermal. Preliminary results indicate the ambient air will increase about 3°F in temperature as it passes over the power conversion skid on its way to the pre-cooler. In turn, the maximum net output of the plant will decrease by about 7.5 kw.

Startup of the Stratos 670 t-c set was determined to be different than that of the Clark t-c set, and a full speed starting motor will be required. The turbine inlet temperature for startup will be higher than that required by the Clark machine.

Steady-state state-points are being determined for the full spectra of ambient air temperatures and load. Initial results indicate that the Stratos t-c set will deliver about 70 kw less at maximum than the Clark machine. This effort will be continued.

Analysis of GTTF test data continued.

Preliminary results were received from the heat exchanger core tests. A cursory examination indicates a slight power decrement will result from the increase in pressure drop on the recuperator tube side.

Anticipated Accomplishments - July:

The energy balance calculations for the power plant will be completed.

The calculations for the startup problem will be completed.

The steady-state state-points for both the Clark and Stratos t-c sets will be re-evaluated, including consideration of the heat exchanger core test data.

9. Operational Planning (Task 51-880)

Summary - January through May:

For the final Hazards Summary Report, the radiological hazards were calculated for a postulated major excursion of the ML-1 reactor. Radiation exposures and ground contamination were calculated as a function of distance from the reactor site, based on an excursion energy release of 300 Mw-sec and an extensive operating history. The hazards considerations include the possible toxicity problem of BeO.

Work on an ML-1 facility manual started on a limited basis. A layout was completed showing the floor plan of the auxiliary control building with the placement of all facility office furnishings; and a floor plan of the test building, showing the initial operating location of the power plant and all applicable auxiliaries.

The ML-1 test program and test procedures were started. A rough draft was completed of the schedule for the ML-1 critical experiment, including a draft of the initial criticality procedures.

TYPICAL ML-I INFLUENCE COEFFICIENTS

SYSTEM PARAMETERS	REFERENCE VALUES	
System Mass	52.5	LBS.
Bypass Flow		%
Turbine Inlet Temperature	1200	°F
Ambient Air Temperature	100	°F
Auxiliary Power	70	KW

SYSTEM PARAMETERS	UNIT CHANGE	+10 KW AUXILIARY POWER	-100 RPM TC SPEED	-10 °F TURBINE INLET TEMPERATURE	-1 °F AMBIENT AIR TEMPERATURE	+1% BYPASS FLOW	-1 LB SYSTEM MASS	-1% COMPRESSOR ISENTROPIC EFFICIENCY	-1% TURBINE ISENTROPIC EFFICIENCY	-1% RECUPERATOR EFFECTIVENESS	-1.0 RECUPERATOR NTU	-1% PRECOOLER EFFECTIVENESS	-1.0 PRECOOLER NTU
System Output Power	KW	-10	-0.85	[illegible]	+2.52	-17.33	-6.46	-15.2	-19.37	-0.77	-2.79	-9.35	-30.35
Reactor Power To Gas	KWT	0	-15.9	-33.9	+5.41	-31.3	-53.3	-1.74	-16.92	+37.3	+135.8	-21.37	-68.0
Compressor Flow Rate	LBS/HR	0	-341	-172	+37.2	+326.8	-1726.3	+104.5	+88.4	+57.0	+209.5	-154.8	-488.0
Turbine Flow Rate	LBS/HR	0	-337	-170	+36.8	-604.6	-1709.1	+103.5	+87.5	+56.4	+207.5	-153.3	-483.5
Compressor Pressure Ratio	N.D.	0	-0.012	-0.005	+0.0045	-0.022	+0.02	-0.0012	0	-0.0025	-0.0094	-0.0172	-0.0536
Turbine Pressure Ratio	N.D.	0	-0.0025	-0.0045	+0.0038	-0.018	+0.02	-0.0006	0	-0.0019	-0.0047	-0.0144	-0.0439
Compressor Isentropic Eff.	%	0	+0.05	0	-0.01	0	0	-1.0	0	0	0	+0.055	0
Turbine Isentropic Eff.	%	0	0	0	0	0	0	0	-1.0	0	0	0	0
Cycle Efficiency	%	-0.3	+0.05	-0.25	+0.06	-0.4	0	-0.47	-0.56	-0.19	-0.47	-0.22	-0.49
Recuperator Effectiveness	%	0	-0.025	0	0	0	0	0	0	-1.0	-3.76	0	0
Recuperator NTU	N.D.	0	[illegible]	[illegible]	-0.0008	+0.007	+0.02	0	0	+0.0006	-1.0	+0.0033	+0.0098
Precooler Effectiveness	%	0	-0.05	0	+0.01	-0.1	0	-0.06	-0.06	-0.06	-0.47	-1.0	-3.42
Precooler NTU	N.D.	0	-0.0038	+0.0045	-0.0005	-0.008	+0.06	-0.0024	-0.0024	-0.0006	-0.0047	+0.0044	-1.0
Compressor Inlet Pressure	PSIA	0	+0.187	-0.298	-0.184	+0.380	-2.48	+0.195	+0.142	+0.192	+0.700	+0.700	+2.282
Compressor Inlet Temperature	°F	0	-0.326	-0.325	-1.035	-0.016	-1.22	+0.275	+0.132	+0.536	+1.952	+4.09	+13.02
Reactor Inlet Pressure	PSIA	0	-0.902	-1.418	+0.029	-1.579	-5.96	+0.384	+0.329	+0.217	+0.802	-0.140	-0.429
Reactor Inlet Temperature	°F	0	+0.714	-6.415	-0.594	+1.663	-0.28	+0.719	+2.795	-5.01	-18.23	+2.32	+7.41
Turbine Inlet Pressure	PSIA	0	-0.816	-1.307	+0.017	-1.4	-5.60	+0.361	+0.296	+0.238	+0.872	-0.093	-0.278

TABLE 2

TYPICAL ML-1 PERFORMANCE DATA

100 °F AMBIENT TEMP.

CLARK TURBINE-COMPRESSOR SET

MASS 51,976 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	131.8	123.4	131.9	121.8	131.9	120.1	131.5	118.5	131.6	116.6			1
	OUT 2	332.5	291.8	340.1	298.5	348.3	305.4	355.4	311.8	366.5	320.0		.2	2
RECUPERATOR (HP)	IN 3	332.5	291.5	340.1	298.2	348.3	305.1	355.4	311.6	366.5	319.8	5.8		3
	OUT 4	823.1	286.5	815.2	293.0	807.1	299.7	799.7	306.0	791.1	314.0		.6	4
REACTOR	IN 5	823.1	285.9	815.2	292.4	807.1	299.1	799.7	305.4	791.1	313.4	24.0		5
	OUT 6	1200.0	265.0	1200.0	270.7	1200.0	276.7	1200.0	282.3	1200.0	289.4		.7	6
TURBINE	IN 7	1200.0	264.4	1200.0	270.1	1200.0	276.1	1200.0	281.6	1200.0	288.7			7
	OUT 8	945.9	126.6	935.0	125.0	923.7	123.3	913.4	121.8	900.8	120.0		.1	8
RECUPERATOR (LP)	IN 9	945.9	126.5	935.0	125.0	923.7	123.3	913.4	121.7	900.8	119.9	1.2		9
	OUT 10	462.1	125.6	466.4	124.0	471.0	122.2	474.9	120.6	481.5	118.7		.1	10
PRECOOLER	IN 11	438.4	125.5	447.0	123.9	457.1	122.1	466.6	120.5	479.2	118.6	1.8		11
	OUT 12	131.8	123.6	131.9	122.0	131.9	120.3	131.5	118.7	131.6	116.8		.2	12
												32.8	1.9	34.7
NET POWER	KW	0		92		184		276		368				
REACTOR POWER	KW	2370		2493		2624		2747		2904				
COMPRESSOR FLOW	LB/HR	98490		96959		95471		93409		91715				
TURBINE FLOW	LB/HR	79481		81930		84492		86870		89880				
CONTROL BYPASS	LB/HR	18092		14112		10062		5622		917				
COMPR EFF (ISEN)	%	82		83		83		84		84				
RECUP EFFECTIVENESS	%	80		80		80		80		80				
TURBINE EFF (ISEN)	%	87		87		87		87		87				
PRECOOLER EFFECTIVENESS	%	91		[illegible]		91		91		92				

TABLE 3

Methods were investigated for calibrating control blades, for calibrating the nuclear power and for flux mapping. By the end of May, the initial draft of the test program and test schedule for operating the ML-1 at NRTS was about 80% complete.

The neutron detector positions in the shield tank were established, based on flux levels predicted for the ML-1 and assuming a neutron source of 3 x 10^7 neutrons/cm^2-sec., to support the instrumentation program.

An outline of the organization needed for the proposed operations of the ML-1 was nearly completed. The outline includes formal job descriptions for each engineer and operator.

The size of the start-up neutron source for the ML-1 was reviewed and procurement initiated. Procurement of special test fuel elements for power calibration and flux mapping was initiated.

Accomplishments - June:

The organization of the proposed ML-1 operations crew for NRTS was completed, including formal job descriptions of each engineer and operator.

An initial draft was published of the test program and test schedule for operation of the ML-1 at NRTS.

Operating manuals were outlined for the ML-1 power plant.

Work on the ML-1 hazards report achieved 90% completion.

A start-up neutron source and special test fuel elements are being procured for the ML-1.

Procurement was initiated for counting equipment for the criticality experiments.

Anticipated Accomplishments - July:

Work on the ML-1 hazards report will continue and an initial draft will be completed.

Work will begin on writing operating manuals for the ML-1.

Work will begin on a detailed test program and on the procedures.

10. Critical Assembly Research (Task 51-890)

Summary - January through May:

This task was essentially inactive until 6 April when the first shipment of fuel elements was received. The fuel elements were X-rayed immediately, but no significant number of pellets showed evidence of damage. The copper/cadmium burnable poison foils were cut, weighed and installed to simulate the reference ML-1 burnable poisons.

First criticality was attained 12 April with a loading of 48 fuel elements (31.1 kg of U-235) and about 1% worth of reactivity inserted in the core. The predicted loading for k_{eff} = 1.031 (2.1% to overcome the burnable poison) was 29 kg for a 61 element core and more for a 48 element core. These figures compare favorably with experimental results. Additional reactivity poison in the form of steel shim stock, (0.028-in.-thick) was wrapped around each of the fuel elements. Power level and control blade calibrations were completed in preparation for the initial studies of intracell flux and power distribution.

Intracell flux and power distributions were determined for the first and second modified clusters of fuel elements. These fuel elements, and some of the experimental results, are described under Task 51-860, Critical Assembly Support. Flux and power detectors were placed in and around the central fuel element of a cluster of seven modified elements. These measurements were taken with both bare and cadmium-covered detectors to separate the epicadmium flux and power from subcadmium values.

The modified clusters were investigated at both the central and a peripheral position of the critical assembly core to evaluate the effects of the flux skewing across the peripheral elements.

Accomplishments - June:

The intracell flux and power measurements were completed on the "18-pin" fuel elements (these are the 19-pin elements used with an unfueled central pin). The measurements were made at two different positions of the critical assembly core, the central and a peripheral position.

The critical assembly control blades were calibrated to prepare for the series of reactivity worth measurements. The temperature coefficient of the moderator was determined with the moderator temperature near ambient.

The reactivity worth of the shim-scram blade near its maximum worth position was measured. The measurement was made using a pair of test shim-scram blades made of a 70% Ag/30% Cd alloy.

The reactivity worth of foils of Haynes 25 (cobalt-based) alloy is being measured. In these measurements, various thicknesses of cobalt alloy foils are wrapped around each of the seven central fuel elements.

Anticipated Accomplishments - July:

Measurements of reactivity worth will be completed on the cobalt alloy foils, the copper-cadmium burnable poison foils, the steel shim stock foils, the peripheral fuel elements, and the modified fuel elements. The reactivity worth of the reference ML-1 regulating blades (AISI Type 202 stainless steel) will be measured near maximum worth position.

The flux and power distributions over the whole core will be determined, both radially and axially.

The distribution of intracell flux and power in the fuel elements for the first core loading will be determined. These intracell measurements will be taken in elements containing both Type II fuel pellets and Type II fuel powder.

11. ML-1 First Core Fabrication (Task 53-8XX)

Summary - January through May:

Procurement was initiated in late Fabruary for such long lead items as UO_2 pellets, UO_2 powder, and alloy stock for pin tubing. Bids were prepared in May for inert components except poison foil and shims. An additional 1600 lb of low-cobalt Hastelloy X ingots, ordered because of the long lead time required, made possible expeditious replacement of material ruptured by the vendor during forging. The initial delivery in April of UO_2 pellets from a vendor was acceptable: the rejection rate was about 1%. (This delivery was delayed by re-processing to eliminate excessive fluorine before pelletizing.)

Developmental fabrication of BeO-UO_2 fuel pellets for the IB-2L core was successful. Uniformity of product and consistent production rate are the most serious problems to be solved.

The first nonfueled ML-1 element was assembled for use in mechanical and structural evaluation as well as a check of assembly design.

Accomplishments - June:

Bids were awarded on all inert parts except poison foils and shims. The latter items are being re-designed. A section of the spider casting was increased in size to improve high temperature stability.

The fuel development facility was committed to fabricate BeO-UO_2 pellets for the IB-2L core.

Anticipated Accomplishments - July:

About 75% of the parts needed for pin assembly will be delivered. Initial lots of pin tubing will be received and inspected.

Fuel development facilities will continue to fabricate pellets for the IB-2L core.

C. POWER CONVERSION EQUIPMENT

1. Turbine-Compressor Set

Summary - January through May:

(This task includes the procurement of axial compressor t-c set from the Clark Brothers Company and a centrifugal compressor t-c set from the Stratos Division of Fairchild Engine & Airplane Corporation.)

The preliminary report on the Clark axial t-c set design was evaluated during January.

A decision was made in February to locate a lubrication oil pump on the gearbox portion of the t-c set housing. In addition, the responsibilty for re-designing the compressor outlet piping was assigned to the t-c set vendors to permit more latitude in locating the diffusers.

The t-c set final specification and the preliminary specification drawing were completed during March and forwarded to both t-c set vendors for review. The t-c set final design reports were received from both vendors and the evaluations of the designs were initiated. Letter contracts for t-c set fabrication were given to Stratos and Clark during April. The letter contracts authorized limited fabrication before negotiating the fabrication contract.

Technical evaluation of Stratos t-c set final design was completed and the evaluation task reports were forwarded to ERDL, Fort Belvoir. Initially, the t-c design was not acceptable due to undesirable surge characteristics during the starting transient. This condition was corrected by re-designing the second-stage compressor diffuser. The t-c design, therefore, is acceptable to Aerojet and appears to meet the requirements of Specification AGC-60015, MLS-55. A few areas pertaining to design and performance received the required additional documentation and clarification.

Stratos completed an addendum to its design report, including additional technical data on lubrication system requirements and labyrinth seal flow rate requirements during the starting transient and steady state operation.

Detail drawings of the long-lead-time items were completed and procurement initiated.

The t-c set fabrication contracts were negotiated with both Stratos and Clark during May. The Stratos and Clark t-c sets are scheduled to be delivered to Azusa by 19 December 1960 and 1 January 1961 respectively.

Stratos placed a purchase order for the t-c housing castings. The housing is to be fabricated and tested by 1 October.

Stratos placed a purchase order for the gear reduction assembly. The gearbox is to be fabricated 1 September.

The technical evaluation of the final design of the Clark t-c set was completed. With the exception of a few design areas (subsequently cleared up) the t-c set design was acceptable to Aerojet and appears to meet the requirements of Specification AGC-60015, MLS-55.

The Clark preliminary layout of the compressor discharge elbow was reviewed and approved by Aerojet. However, Clark was requested to review other types of expansion bellows in order to reduce the overall length.

The Clark auxiliary gear-drive layout drawing was reviewed and suggested modifications were forwarded to Clark.

Accomplishments - June:

a. Stratos T-C Set: All design changes required to assure proper installation of the unit on the power conversion skid were completed.

The vendor reviewed the final Aerojet design for the t-c set lubrication system and agreed that the system would meet the requirements.

The detail casting drawings were completed for the t-c housing assembly, and the pattern equipment was fabricated.

The turbine nozzle ring assembly was redesigned, and Stratos is completing a detailed stress analysis of the new nozzle design.

The shaft forging, and guide-vane and diffuser castings were received and finish machining started.

Turbine wheel forgings and compressor wheel castings were received and finish machining initiated.

The thrust and journal bearings were received from the vendor.

It is now determined to be unnecessary to calibrate separately the two compressor stages. Test results on the TCS-560 demonstrated that the compressor efficiencies are satisfactory and design revisions on the ML-1 compressor will further improve the efficiency.

The gearbox preliminary design report was received from Stratos and forwarded to ERDL Fort Belvoir, Virginia.

The gearbox structural supports for the bearings and gears were re-designed. The new support structure weighs less and provides more regidity.

b. Clark T-C Set: The compressor discharge elbow and auxiliary gear-drive layout drawings were completed.

A purchase order was placed for fabricating the turbine and compressor blades. The blades will be fabricated by a cold-forming process developed by General Motors and Kelsey-Hayes.

Clark is reviewing the final Aerojet design for the t-c set lubrication system and gave tentative approval.

About 65% of the drawings required for fabrication were released. All of the detail drawings for long-lead-time items have been released. The t-c set installation drawing is about 50% complete.

The gearbox housing was redesigned to include the mounting structure for the auxiliary drive. Design details were completed for an assembly fixture to align the auxiliary drive output shaft and the lubrication pump shaft.

Task reports were forwarded to ERDL, describing the Aerojet technical evaluation of the t-c set.

Anticipated Accomplishments - July:

a. Stratos T-C Set: All detail drawings required for fabrication will be released.

The vendor's final design report for the gearbox will be received.

b. Clark T-C Set: The remaining detail drawings required for fabrication will be released.

Flow tests will be completed of a full-scale model of the compressor discharge volute. Since the discharge volute is the most critical aerodynamic section with respect to compressor efficiency, aerodynamic model tests are the most practical solution for proper design of the diffuser.

The vendor's preliminary design report for the gearbox will be received.

2. Alternator (Task 56-18X)

Summary - January through May:

The final alternator specification was completed in February. The preliminary heat transfer analysis for the alternator and the preliminary stress analysis of the housing were also completed. Aluminum was selected as the alternator case material on the basis of the results.

The alternator preliminary design analysis report was completed and forwarded to IDO. The alternator electrical design was completed.

The design criteria were established for the ML-1 starting motor in April. An analysis indicated the maximum expected starting torque curve would have peak torque of 30 lb.-ft. at 42% rated speed and a peak housepower value of 50 h.p. at 50% rated speed. The minimum expected starting torque curve had a peak torque value of 18 lb.-ft. at 45% rated speed and a peak horsepower value of 30 hp at 50% rated speed. The requirements of the maximum expected starting torque curve dictated the selection of a two-speed starting motor design.

A conceptual design of the starting motor was completed. The design was based on the assumption that all starts will be made with 60-cycle power supplied to the motor. This design indicated that the starting motor would extend 5.5-in. beyond the alternator, producing an overall alternator starting motor assembly length of approximately 38-in.

The alternator layout drawing was completed, incorporating the latest mounting provisions for the starting motor.

The alternator design was re-analyzed to provide minimum losses. The analysis indicated that modifying the field circuit would increase the alternator efficiency by 1% at 25% load and 0.5% at full load. In addition, the modification would reduce by 2.3 kw the heat rejection into the lubrication oil. Modifying the field circuit will make a minor change in the configuration of the alternator drive end housing. The new configuration appears to be compatible with the gearbox designs.

The losses in the present alternator design are summarized below. The losses are for operation at 60 cycles and 0.8 power factor with a standard 167°F winding temperature and a 165°F lubricating oil temperature.

	Alternator Load - Percent					
Alternator Losses	0	25	50	75	100	125
Variable Losses (kw)	0	1.73	4.28	7.69	12.10	17.88
Fixed Losses (kw)	12.63	12.63	12.63	12.63	12.63	12.63
Total Losses (kw)	12.63	14.36	16.91	20.32	24.73	30.51
Output (kw)	0	100	200	300	400	500
Input (kw)	12.63	114.36	216.91	320.32	424.73	530.51
Efficiency %	0	87.5	92.1	93.6	94.3	94.3

An analysis of the effects of 50-cycle operation on the power conversion skid electrical equipment resulted in the following recommendations:

1) The present volts-per-cycle design criterion for the alternator should not be changed.

2) "Boost" transformers should be used where there is a requirement for operation at 2400/4160 volts and 50 cycles.

3) All starts should be made with 60-cycle power to minimize the size of the starting motor.

4) The specifications for all accessory electrical equipment should specify volts-per-cycle design for minimum weight.

The preliminary design of the starting motor was initiated in May. Design calculations were made for two configurations: an axial air-gap motor and a radial air-gap motor.

The preliminary design of the static-exciter and voltage regulator was initiated. The design of the current transformers was completed.

The stress and thermal analyses of the alternator and starting motor were initiated.

The alternator detail fabrication drawings were completed except for the drawing of the drive end housing.

Accomplishments - June:

The electrical design of the starting motor was completed. A radial air-gap design was selected as the best configuration for the ML-1 starting motor requirements. The starting motor is 20-in.-diameter and 7-in. long overall. The motor extends 3-in. beyond the alternator. Detail drawings of the starting motor are 50% complete.

The electrical design of the voltage regulator was completed except for temperature compensation. The voltage regulator detail drawings are 50% complete.

The fabrication of the alternator stator and rotor assemblies was initiated.

The thermal analysis of the starting motor and alternator was completed, based on estimated air flow over the casing. The results show that the internal hot spot temperature will be 275°F. While this is higher than the 250°F design point, it is well within the thermal limits of the machine. An analysis is being made to establish that the available flow of cooling air is adequate for this design.

The alternator bearing seals were changed from a rubbing ring type to a standard labyrinth to ensure a seal life commensurate with the requirements of the ML-1.

Anticipated Accomplishments - July:

The detail drawings of the starting motor and voltage regulator will be completed.

The alternator housing drawing will be completed.

Fabrication of the starting motor and voltage regulator will be initiated. Fabrication of the alternator parts will continue.

The analysis of the alternator cooling air flow requirements will be completed. The design of the alternator shroud and fin assembly will be completed.

3. Lubrication System (Task 56-12X)

Summary - January through May:

The conceptual design study of the lubrication system was conducted under Contract DA-44-192-ENG-8, and the design of a prototype lubrication system then assigned to Contract AT(10-1)-880.

The main objective of the studies was the basic design of a lubrication system to lubricate the t-c set, the reduction gearbox and the alternator. A secondary objective was to prevent the entrance of oil into the process gas system.

A literature search was conducted to evaluate oil leak-tight seals and sealing methods which would operate satisfactorily for 10,000 hr without maintenance. Commercial seals studied included a cursory investigation of the lip-type seal, a more thorough investigation of face-type rubbing seals (such as "Sealol") and shaft rubbing-types ("Cartriseal", for example). These types were rejected on the basis of service life and because it was quite possible that many of these seals would not meet the leakage requirement without selective fit and installation.

It was decided that only a labyrinth-type seal without rubbing contact would meet the life requirements. Because this type is not leak-proof, the system was designed to be pressurized to prevent the entry of oil into the working gas, but to permit the entry of working gas into the oil system. The system bleeds nitrogen (from the second stage of a centrifugal compressor or from intermediate stages of an axial compressor) into the cavity between the two labyrinths separating the oil from the working gas. The nitrogen then flows two ways at high pressure: either into the working gas or into the oil system. The flow into the oil system under the consequent pressure differential is sufficient to prevent oil from flowing into the working gas.

After selecting the basic lubrication system a reference system was established. This system was then improved by rearranging, combining or eliminating components. The final configurations resulting from this study are shown schematically in Figure 10 (Clark T-C Set), and Figure 11 (Stratos T-C Set).

The function of the lubrication and clean-up system is to supply lubricating oil to the t-c set, including the gearbox and alternator; supply regulated nitrogen to the t-c seal system; and to purify the nitrogen bleed gas.

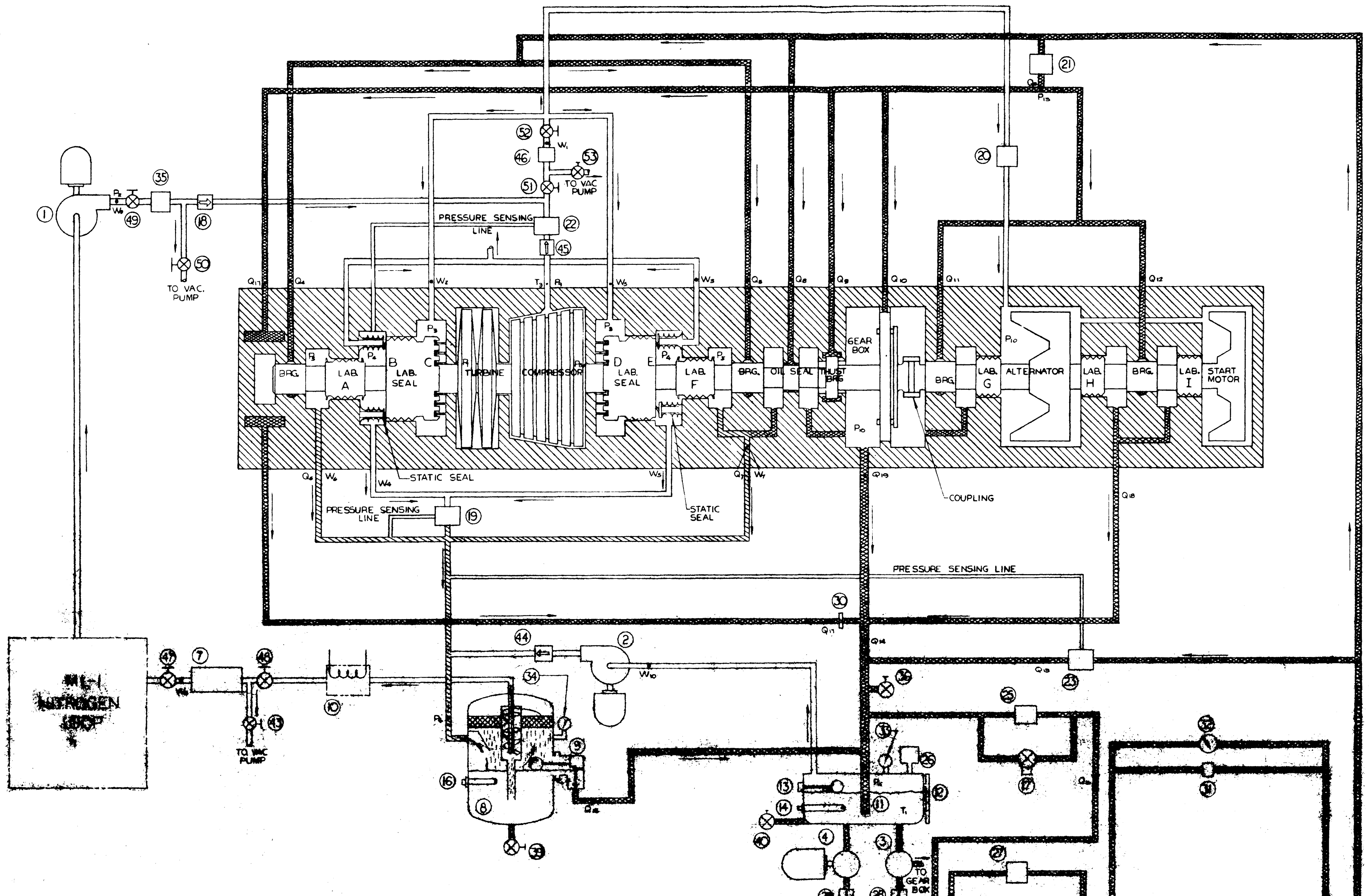
Oil is supplied to the system by a 45 gpm gear-type pump driven by the gearbox at 1800 rpm. A 45 gpm auxiliary pump (motor-driven) provides lubrication during start-and-stop operation to prevent bearing damage. The oil discharged from the pump is cooled by an air-cooled oil cooler (integrated within the pre-cooler) to reduce the temperature from 180°F to 150°F. The cooler is capable of handling 290,700 Btu/hr at an ambient temperature of 100°F. The heat rejection rates for the Clark and Stratos lubrication systems are tabulated on Table 4.

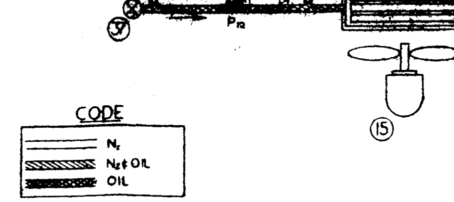
TABLE 4

Calculated Heat Rejection
to the ML-1
Lubrication System

<table>
<tr><th rowspan="3">Source</th><th colspan="4">Heat Rejection, HP</th></tr>
<tr><th colspan="2">5/6 Speed</th><th colspan="2">Full Speed</th></tr>
<tr><th>Clark</th><th>Stratos</th><th>Clark</th><th>Stratos</th></tr>
<tr><td><u>Turbine-Compressor</u></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Journal Bearing</td><td rowspan="2">31.4</td><td rowspan="2">28.5</td><td>10.0</td><td>5.6</td></tr>
<tr><td>Thrust Bearing</td><td>26.0</td><td>28.4</td></tr>
<tr><td>Oil Seal</td><td>4.5</td><td>4.5</td><td>6.0</td><td>6.0</td></tr>
<tr><td>Case Cooling</td><td>17.8</td><td></td><td>17.8</td><td></td></tr>
<tr><td>Nitrogen Seal Leakage</td><td>0.7</td><td>3.4</td><td>0.7</td><td>3.4</td></tr>
<tr><td><u>Gear Box</u></td><td>19.4</td><td>28.5</td><td>26.0</td><td>34.0</td></tr>
<tr><td><u>Alternator</u></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Journal Bearings</td><td>2.0</td><td>2.0</td><td>2.7</td><td>2.7</td></tr>
<tr><td>Field Coil</td><td>8.9</td><td>8.9</td><td>8.9</td><td>8.9</td></tr>
<tr><td><u>Oil Pump Loss</u></td><td>1.0</td><td>1.6</td><td>1.2</td><td>2.0</td></tr>
<tr><td><u>Oil System Pressure Drop</u></td><td>4.1</td><td>6.6</td><td>4.9</td><td>8.0</td></tr>
<tr><td><u>Total Heat Rejection</u></td><td>89.8</td><td>84.0</td><td>104.2</td><td>99.0</td></tr>
</table>

THE ML-1 LUBRICATION SYSTEM WITH THE CLARK T-C SET.



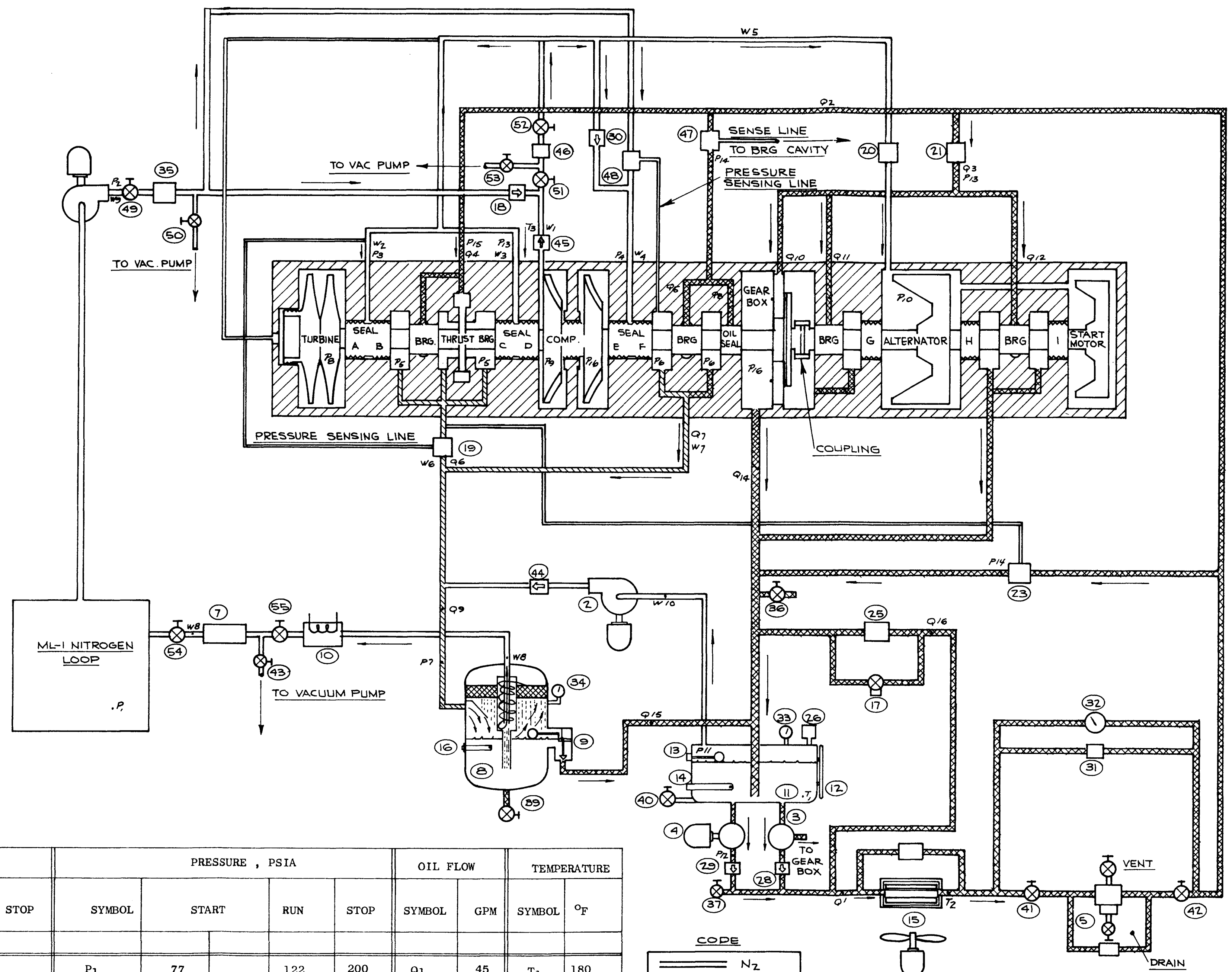


NITROGEN FLOW-LBS/SEC				PRESSURE-PSIA				OIL FLOW		TEMPERATURE	
SYMBOL	START	RUN	STOP	SYMBOL	START	RUN	STOP	SYMBOL	GPM	SYMBOL	°F
W_1	[illegible]	[illegible]	—	P_1	77	122	200	Q_1	45	T_1	180
W_2	[illegible]	0.0664	[illegible]	P_2	94	—	217	Q_2	3½	T_2	150
W_3	[illegible]	[illegible]	0.0675	P_3	88	131	209	Q_3	33	T_3	210
W_4	[illegible]	[illegible]	0.0418	P_4	83	128	206	Q_4	2		
W_5	[illegible]	[illegible]	[illegible]	P_5	82	127	205	Q_5	2		
W_6	0.0104	0.0104	0.0154	P_6	82	127	205	Q_6	2		
W_7	[illegible]	0.0104	0.0154	P_7	77	126	200	Q_7	2½		
W_8	[illegible]	0.0936	0.1104	P_8	77	122	200	Q_8	1½		
W_9	[illegible]	—	0.1750	P_9	77	162	200	Q_9	17		
				P_{10}	20	20	20	Q_{10}	8		
				P_{11}	20	20	20	Q_{11}	2		
				P_{12}	142	187	265	Q_{12}	1		
				P_{13}	50	50	50	Q_{13}	6½		
								Q_{14}	34		
								Q_{15}	4½		
								Q_{16}	0		
								Q_{17}	5		
								Q_{18}	1		
								Q_{19}	28		

55	
54	
53	MANUAL SHUT-OFF VALVE
52	MANUAL SHUT-OFF VALVE
51	MANUAL SHUT-OFF VALVE
50	MANUAL SHUT-OFF VALVE
49	MANUAL SHUT-OFF VALVE
48	MANUAL SHUT-OFF-VALVE
47	MANUAL SHUT-OFF VALVE
46	NITROGEN FILTER
45	CHECK VALVE (NITROGEN)
44	CHECK VALVE (NITROGEN)
43	MANUAL SHUT-OFF VALVE
42	MANUAL SHUT-OFF VALVE
41	MANUAL SHUT-OFF VALVE
40	MANUAL OIL DRAIN VALVE
39	MANUAL OIL DRAIN VALVE
38	
37	MANUAL OIL DRAIN VALVE
36	MANUAL OIL FILL VALVE
35	NITROGEN FILTER
34	SEPARATOR PRESSURE GAGE
33	SUMP PRESSURE GAGE
32	DIFFERENTIAL PRESSURE GAGE
31	DIFFERENTIAL PRESSURE SWITCH
30	ORIFICE
29	CHECK VALVE (OIL)
28	CHECK VALVE (OIL)
27	THERMOSTATIC BY-PASS VALVE
26	SUMP RELIEF VALVE
25	RELIEF VALVE - SAFETY
24	
23	DIFFERENTIAL PRESSURE RELIEF
22	DIFFERENTIAL PRESSURE REGULATOR
21	PRESSURE REGULATOR
20	PRESSURE REGULATOR
19	DIFFERENTIAL PRESSURE REGULATOR
18	NITROGEN CHECK VALVE
17	BY-PASS SOLENOID VALVE
16	IMMERSION HEATER
15	OIL COOLER
14	IMMERSION HEATER
13	REMOTE LEVEL INDICATOR AND ALARM
12	LEVEL INDICATOR (VISUAL)
11	OIL SUMP

10	REFRIGERATION COOLER
9	FLOAT CONTROL
8	SEPARATOR
7	NITROGEN FILTER
6	
5	FILTER WITH BY-PASS VALVE
4	AUXILIARY OIL PUMP/MOTOR
3	MAIN OIL PUMP
2	SUMP COMPRESSOR/MOTOR
1	SEAL COMPRESSOR/MOTOR
ITEM	COMPONENT

FIGURE 10



NITROGEN FLOW LBS/SEC				PRESSURE, PSIA				OIL FLOW		TEMPERATURE	
SYMBOL	START	RUN	STOP	SYMBOL	START	RUN	STOP	SYMBOL	GPM	SYMBOL	°F
W_1		0.168		P_1	77	122	200	Q_1	45	T_1	180
W_2	0.0431	0.0850	0.0558	P_2	99		222	Q_2	13½	T_2	150
W_3	0.0389	0.0365	0.0501	P_3	92	264	215	Q_3	20	T_3	325
W_4	0.0342	0.0471	0.0445	P_4	92	147	215	Q_4	10		
W_5				P_5	85	244	208	Q_5	2		
W_6	0.0339	0.0770	0.0419	P_6	82	127	205	Q_6	10		
W_7	0.0156	0.0225	0.0197	P_7	82	127	205	Q_7	2½		
W_8	0.0495	0.0995	0.0616	P_8	77	239	200	Q_8	1½		
W_9	0.1162		0.1504	P_9	77	264	200	Q_9	12½		
W_{10}	(3 TO 4 S C F M)			P_{10}	20	20	20	Q_{10}	17		
				P_{11}	20	20	20	Q_{11}	2		
				P_{12}	145	304	268	Q_{12}	1		
				P_{13}	50	50	50	Q_{13}	11½		
				P_{14}	112	157	235	Q_{14}	21		
				P_{15}	115	274	238	Q_{15}	12½		
				P_{16}	77	122	200	Q_{16}			

ITEM	COMPONENT
1	SEAL COMPRESSOR/MOTOR
2	SUMP COMPRESSOR/MOTOR
3	MAIN OIL PUMP
4	AUXILIARY OIL PUMP/MOTOR
5	FILTER WITH BYPASS VALVE
6	
7	NITROGEN FILTER (MOLECULAR SIEVE)
8	SEPARATOR
9	FLOAT CONTROL
10	REFRIGERATION COOLER
11	OIL SUMP
12	LEVEL INDICATOR (VISUAL)
13	REMOTE LEVER INDICATOR AND ALARM
14	IMMERSION HEATER
15	OIL COOLER
16	IMMERSION HEATER
17	BY-PASS SOLENOID VALVE
18	CHECK VALVE (NITROGEN)
19	DIFFERENTIAL PRESSURE REGULATOR
20	PRESSURE REGULATOR (NITROGEN)
21	PRESSURE REGULATOR (OIL)
22	
23	DIFFERENTIAL PRESSURE RELIEF VALVE
24	
25	RELIEF VALVE - SAFETY
26	SUMP RELIEF VALVE
27	THERMOSTATIC BY-PASS VALVE

28	CHECK VALVE - (OIL)
29	CHECK VALVE - (OIL)
30	CHECK VALVE - (NITROGEN)
31	DIFFERENTIAL PRESSURE SWITCH
32	DIFFERENTIAL PRESSURE GAGE
33	SUMP PRESSURE GAGE
34	SEPARATOR PRESSURE GAGE
35	NITROGEN FILTER
36	MANUAL OIL FILL VALVE
37	MANUAL OIL DRAIN VALVE
38	
39	MANUAL OIL DRAIN VALVE
40	MANUAL OIL DRAIN VALVE
41	MANUAL SHUT-OFF VALVE
42	MANUAL SHUT-OFF VALVE
43	MANUAL SHUT-OFF VALVE
44	CHECK VALVE (NITROGEN)
45	CHECK VALVE (NITROGEN)
46	NITROGEN FILTER
47	DIFFERENTIAL PRESSURE REGULATOR
48	DIFFERENTIAL PRESSURE REGULATOR
49	MANUAL SHUT-OFF VALVE
50	MANUAL SHUT-OFF VALVE
51	MANUAL SHUT-OFF VALVE
52	MANUAL SHUT-OFF VALVE
53	MANUAL SHUT-OFF VALVE
54	MANUAL SHUT-OFF VALVE
55	MANUAL SHUT-OFF VALVE

Figure 11

An oil filter provides 25 micron filtration for lubricating oil. The filter element will require replacement approximately every 30 days, depending on the rate of contamination. A differential pressure switch indicates when a filter change is required. The oil pressure to the t-c bearings is regulated at 30 psi above the bearing drain cavity pressure. An oil shaft seal isolating the gearbox and alternator from the t-c maintains the gearbox and alternator case pressures at 20 psia. The oil flow requirements for the Clark and Stratos lubrication systems are shown in Table 5.

Oil from the gearbox and alternator is returned by gravity to a sump. The sump has an oil capacity of 50 gallons and a gas volume equivalent to 20 gallons to provide for expansion. The sump contains a 5 kw immersion heater to heat the oil during low temperature starting. The oil level is shown by a level indicator.

The entry of bearing lubricating oil into the gas cycle is prevented by labyrinth seals adjacent to each bearing on the t-c shaft. The seals are supplied with regulated nitrogen from the compressor through external connections. The differential pressure across the single stage seals in the Stratos t-c set is maintained at 20 psi during running conditions. The Clark t-c set has two stages of labyrinth seals with a vented cavity between each stage. The total differential pressure across the seals is regulated at 4 psi. As the two-stage seal offers a more restrictive path for oil back diffusion, the pressure drop in the Clark unit is lower.

Nitrogen is supplied to the labyrinth seals by a motor driven auxiliary compressor during startup and shutdown when main compressor gas is not available. This provides the barrier nitrogen gas for proper seal operation and also the necessary cooling during shutdown operation. The auxiliary compressor has a capacity of approximately 30 cfm and is capable of boosting the inlet pressure approximately 25 psi. The compressor capacity exceeds the normal seal requirement to provide additional flow if seal clearances increase with wear. Gas for the auxiliary compressor is bleed gas from the main compressor inlet. When the system compressor develops sufficient pressure, the auxiliary compressor will automatically shut off.

The seal flow rates for the Clark and Stratos seal systems are shown on the respective system schematics.

The nitrogen flow across the labyrinth seal system mixes with the lubricating oil in the bearing cavities. The mixed flow is then delivered to a "clean-up" system consisting of a mechanical separator and an absorption filter. The separator mechanically separates the oil from the nitrogen and returns the oil to the sump. The nitrogen is filtered to reduce the oil content to acceptable limits, before it is returned to the system. This filter will require servicing every 30 days.

The 3 cfm nitrogen compressor (motor-driven) returns the nitrogen from the oil to the separator. This is necessary because nitrogen is continuously carried in solution by the oil as it is returned from the

TABLE 5

ML-1 Turbine-Compressor Set

Lubrication Requirements

Location	Flow Rate - Gal/Min	
	Clark T-C Set	Stratos T-C Set
Turbine-Compressor		
Journal Bearings	4	2
Thrust Bearing	19	10
Case Cooling	5	None
Shaft Seal	1.5	1.5
Gear Box	8	17
Alternator	2.6	2.6
Total Flow	40.1	33.1

separator to the sump. Nitrogen is also supplied to the alternator case and flows across the alternator seals to the sump. The nitrogen flow maintains a constant 20 psia pressure to prevent the entrance of oil into the alternator rotor cavity. The amount of nitrogen transferred from the separator to the sump is dependent upon the change in pressure level and the flow rate of oil. The solubility of nitrogen in oil is proportional to the pressure and is determined by the Bunsen Solubility Coefficient which was found to be approximately +0.076 for lubricating oil at 180°F. The Bunsen Coefficient (α) is defined as the volume of gas at 0°C and 14.7 psia pressure dissolved in a unit volume of the liquid with a partial gas pressure of 14.7 psia. The solubility of a gas in a liquid is expressed by the following equation*:

$$\frac{\text{Volume of gas at N T P}}{\text{Volume of liquid}} = \frac{\alpha P}{14.7}$$

Where:

N T P = Normal Temperature Pressure (0°C, 14.7 psia)

α = Bunsen Solubility Coefficient

P = System Pressure, psia

From the above relation, the amount of nitrogen released in the sump after being transferred from the separator is 0.025 lb/min and 0.072 lb/min for the Clark and Stratos lubrication systems, respectively.

The lubricating oil tentatively selected is Chevron OC Turbine Oil No. 11, a product of the Standard Oil Company of California. This oil conforms to Military Specification MIL-L-17672A and is a 100% paraffinic base oil with very low carbon-forming tendencies. The oil contains special inhibitors to improve oxidation stability, retard corrosion and reduce foaming. The lubricating oil has the following properties:

Viscosity, SSU	223 (at 100°F) 47.5 (at 210°F)
Viscosity Index	93
Pour Point, °F	-5
Flash Point, CCC, °F	435
Carbon Residue, %	0.01
Vapor Pressure, psia	0.05 (at 435°F)

The oil manufacturer rates the oil life at 10 years in a mild radiation environment. However, further evaluation will be required to determine its suitability for this application. The flash point is

* R. R. Baldwin and S. G. Daniel, "The Solubility of Gases in Lubricating Oils and Fuels", J. Petroleum Inst. v. 39, No. 351 (1953)

higher than the maximum operating temperature, eliminating fire hazard if there is an oil leak.

Most of the components for the lubrication system were selected and procurement initiated. Procurement specifications were completed for non-standard components except for the nitrogen filter, the seal compressor and the sump-equalizing compressor.

Quotations for a nitrogen/oil separator were requested from about 30 vendors. In the meantime, several separators were ordered for evaluation. However, commercial separators filter on the basis of oil-particle size rather than on the amount of oil in the gas, thus such separators can only be evaluated in a test program simulating ML-1 operating conditions.

Two proposals submitted by vendors appear to meet the requirements for a sump-equalizing compressor. (Not all of the vendors have replied.) One unit was ordered for evaluation.

One rotary-vane compressor was ordered for evaluation as a seal compressor.

The leakage rate past the shaft seal will be determined during evaluation of the compressor. If the leakage proves excessive, the compressors will be installed in a container to prevent external leakage.

A preliminary design installation drawing of the sump and associated equipment was completed in May. The preliminary layout of lubrication system components was begun, and will be continued as additional components are selected.

Accomplishments - June:

Procurement specifications were completed for the compressor and nitrogen filter, and are being released. Specifications are now complete for all non-standard components for the lubrication system.

Several commercial nitrogen/oil separators, purchased from different manufacturers, were received. Tests to determine the relative effectiveness of each separator when subjected to varying rates of oil and nitrogen flow will be conducted as soon as the test installation is complete.

One compressor, for use as a sump-equalizing compressor, was received. Development tests will be conducted when the appropriate test installation is completed. It is believed that leakage past the shaft seal will be the major problem, making it necessary to "can" the unit. The canned motor-compressor units used in refrigeration and air-condition were reviewed and can be readily adapted to nitrogen service. A motor-compressor unit of this type was ordered and delivery is expected within 30 days. Tests will be conducted on this unit.

The rotary-vane compressor will be delivered in July. Tests will be conducted on this unit to determine its suitability as a seal compressor, and that the compressor vanes can withstand the high pressures anticipated during shutdown of the ML-1 system. The survey of compressor manufacturers is continuing in view of the possibility that this compressor may not be satisfactory.

Reciprocating compressors also are being considered for use as a seal compressor because most 60 cycle ac rotary compressors cannot provide more than 10 psi boost. (A minimum of 20 psi is required.) A second source for the seal compressor cannot be selected before further design evaluation. However, several commercially available reciprocating compressors appear to meet the requirements.

Procurement of lubrication system components continues. Purchase orders were initiated to procure the oil filter, oil pump, auxiliary pump/motor unit, oil differential regulator.

Anticipated Accomplishments - July:

Separator tests will be initiated.

Compressor tests will be initiated.

Arrangement of components on the power conversion skid will continue.

The review of commercially available compressors will be completed.

4. Recuperator (Task 56-100)

Summary - January through May:

The design of the recuperator was established during January. The design is a four-pass, shell and tube, mixed cross-flow and counter-flow exchanger. This design is a hot-shell exchanger which establishes the inlet and outlet headers in their proper relation to the reactor and to the power-conversion skid, thus reducing header piping problems.

Detailed layouts were initiated to incorporate the revisions required by the change to a hot-shell design. Over-all recuperator dimensions, including insulation, were frozen at 81-in. long by 49-in. OD.

Agreement was reached during February on the location of the flanges for the high pressure inlet headers and low pressure inlet nozzle. Calculations, based on clearance and tube length from the layout drawings, showed the recuperator effectiveness to be 80.35% with a total $\Delta p/p$ equal to 2.6% under steady state conditions. Materials for tube brazing and finning were ordered.

Stress analysis studies were conducted during March by both Aerojet and the recuperator manufacturer, the Griscom-Russell Company, to revise

6-point mounting support system. The recuperator shell was increased from 1/4-in. thickness to 3/8-in. and a Number 20 flange size was selected for the turbine discharge-recuperator inlet flange.

The vendor's preliminary design report on the recuperator was reviewed during March.

A meeting was held with representatives of the Griscom-Russell Company during April to review the requirements and status of the design, testing and procurement of the heat exchanger. The following problems were resolved during the meeting:

1) The vendor agreed to the selection of a four-point recuperator support used in the six-point support system for the t-c set, alternator and recuperator.

2) The operating and transportation shock loads specified in the recuperator procurement specification were revised to meet the load requirements for the other power-conversion equipment.

3) A reference flange design was selected for the recuperator. The reference flange consists of a "Flexitallic" gasket using bolted flanges, each flange specially designed for its loading requirement.

A letter of intent was forwarded to this vendor authorizing procurement of materials for three recuperators and limited fabrication. Further fabrication will not be authorized until the final design of the recuperator is approved and the core tests are completed.

The results of the tension and compression tests on the recuperator tube sheet weld samples were satisfactory. The results showed a tension yield point range of 35,800 psi to 36,300 psi and a compression yield point range of 34,800 psi to 36,600 psi.

The recuperator specification control drawing was revised to include the detail mounting structure arrangement.

The recuperator fabrication contract was negotiated during May with the vendor.

The recuperator specification control drawing was completed and the specification revised to incorporate more rigorous quality control requirements. A meeting was held with the vendor to coordinate the revised recuperator specification and the specification control drawing.

The tube fin material and brazing alloy were received by Griscom-Russell. Fabrication of the finned tubes will be initiated when the core tests are complete.

Aerojet completed the review of all of the Griscom-Russell designed recuperator flanges during June. Final agreement was reached on flange thickness, facing details, bolt hole dimensions and stress levels.

A revision was issued to clarify certain provisions of the recuperator specification (AGC 60021).

The tubing for the recuperator was received by the vendor. All tubing shop drawings were completed and released to the fabrication shops, and it is estimated 80% of all recuperator drawings were completed.

Final recuperator specification control drawing was completed and released.

Fabrication of the finned tubes was not initiated in June due to the requirement for further testing of the core sections.

Anticipated Accomplishments - July:

Fabrication of the recuperator shell, structure supports, and flanges will be started.

Fabrication of the finned tubes will be initated.

5. Pre-cooler (Task 56-110)

Summary - January through May:

A reference design for the combination pre-cooler/moderator cooler was established in January. The design incorporates two passes on the tube side of the moderator cooler, and uses eight fans instead of six to permit operating the moderator cooler independently of pre-cooler conditions. Using two passes on the tube side reduces the size of the moderator cooler. The original pre-cooler design provided three inlet and three outlet nozzles to reduce the size of the manifold and to permit maximum heat exchanger lattice size. The reference pre-cooler design was agreed on during a conference between the vendor and Aerojet. The reference design uses one inlet and one outlet nozzle. Both manifolds were re-designed and the vendor accepted responsibility for designing the piping to connect the pre-cooler inlet and the recuperator.

A straight tube pre-cooler was selected as the reference design in February. This design allows space for the pre-cooler discharge/compressor inlet line.

It was decided in March to incorporate the lubrication cooler into the pre-cooler to conserve space on the skid. The size of both the pre-cooler and moderator heat exchanger was changed to provide room for the oil cooler. The lubrication oil cooler and moderator cooler in the present design are cooled by one pair of fans.

Burst tests were conducted on samples of aluminum tube of the type selected for the pre-cooler. The average burst pressure (2400 psig at ambient temperature) satisfies the operational pressure requirements. The tube material was changed from 3S to 100-0 aluminum to facilitate extrusion.

The vendor completed the preliminary layout drawings and the support structural drawings for the pre-cooler.

The requirements and the status of heat exchanger design, testing and procurement was reviewed with the vendor at a meeting in April. The following points were decided at the meeting:

1) The shock, operating and transportation loads specified in the pre-cooler procurement specifications were revised to agree with the load requirements for the other power conversion equipment.

2) Tentative locations were established for inlet and discharge connections for the pre-cooler, moderator cooler, and lubrication oil cooler. Agreement was reached on the method of attaching the pre-cooler structure to the power conversion skid structure: The pre-cooler structure will be bolted to T-pads on the skid frame at 15 points. The support system for the pre-cooler tube and header assembly will be designed so that the spring constant of the assembly will not impose loads on the pre-cooler at operating temperatures. The loads imposed by the pre-cooler on the recuperator are not critical in the cold condition.

3) The pre-cooler fan support system was modified so that all loads will be introduced to the trusses at panel points on the skid.

The vendor was given a "letter of intent" authorizing procurement of materials for three pre-coolers and limited fabrication. Authorization will not be given to complete fabrication until the final design of the pre-cooler is approved and the core tests are completed.

The pre-cooler fabrication contract was negotiated during May with the vendor. The pre-cooler specification control drawing was completed and more rigorous quality control requirements were included in the revised specification. All tube-to-tube sheet connections will be welded to minimize external leakage, and the welds leak-checked with a mass spectrometer.

The vendor agreed to modify the design of the pre-cooler structure to include the tension tie-rods and transverse tubular lower chord members that previously were part of the skid structure. The result of this design change is that the entire top area of the skid is unobstructed when the pre-cooler is removed.

Results from the pre-cooler tests show that the pressure drop on the shell side is higher than predicted. Performance calculations based on these results show that total power for the fan motor must be increased about five horsepower to obtain adequate flow of cooling air. Additional calculations were initiated to verify the need for the design air flow in view of the fact that the measured heat transfer area per running foot of tube was larger than calculated.

Performance calculations for the moderator and lubrication oil cooler, based on results of the core test, show that the capacity of the lubrication oil cooler is about 10% oversize.

Specimens of the weld connecting the 1100-0 aluminum tubes to the 2219 aluminum tube sheets were completed. Inspection showed excessive porosity in the welds. Representatives of the vendor of the material are assisting Griscom-Russell in solving this problem.

Accomplishments - June:

The design of the tension tie rods, and transverse and longitudinal tubular members (now incorporated in the lower chord of the pre-cooler structure) was submitted to Aerojet in June for review. (This design facilitates assembly of the pre-cooler onto the skid frame, and provides better access to the other components before the pre-cooler is assembled.)

The design, partially based on the results of the core tests, relocates the mounting pads between the pre-cooler and skid frame. The change was made possible by relocating the tubing joining the pre-cooler, moderator and oil cooler, thus eliminating the need to increase the power of the fan motors. The vendor was advised that the original mounting point locations must be preserved, and is re-designing the structure. The new design will be submitted early next month. The specification control drawing will be changed to reflect the final design.

Review of the pre-cooler flanges designed by the vendor was completed, and agreement reached on thickness of flange, facing details, dimensions of bolt holes, and stress levels.

The design drawings are about 75% complete for the pre-cooler, lubrication oil cooler, and moderator water cooler.

A 1/8 scale model of the pre-cooler was designed and fabrication initiated. The model will be used to determine the distribution of cooling air for the fans and to obtain qualitative information on the effects of power conversion components on the air flow. This information will provide the basis for locating and designing such components as the control centers for the motor and generator.

The material for the tubing and fins was ordered by the vendor (Griscom-Russell) and fabrication has begun.

Anticipated Accomplishments - July:

The test model (1/8 scale) will be completed.

The specification control drawing for the pre-cooler will be released. (The drawing was not released in June because of the change in size of the fan plenums.)

6. Materials Evaluation (Task 51-620)

Summary - January through May:

Samples of the recuperator tube-to-tube sheet welds were made, using materials and techniques that will be used in fabrication of the heat exchanger. Analyses of photomicrographs and physical tests run at the expected maximum operating temperature (1000°F) proved the welds sound and more than adequate for the ML-1 system.

Hydraulic rupture tests, conducted on the pre-cooler tubing (Series 1100 aluminum) to determine the effect of pre-cooler-type finning, showed that internal fins increase tube strength about 65%, and the combination of internal and external fins increase strength about 115%. (The strength of the fins provides an additional safety factor in the present tube design.)

Three test furnaces were procured from AEC surplus for use in elevated temperature corrosion tests in reference atmosphere at system pressure.

Accomplishments - June:

A partial shipment of the alloys to be used in the Stratos t-c set was received. Samples are being machined and tests will begin in July. Corrosion coupons and physical test bars will be exposed to three different gas atmospheres at 300 psi and 1300°F: 100% nitrogen; 99.5 vol% nitrogen + 0.5 vol% oxygen; and air. Corrosion coupons will be examined at 1000, 2500, 5000, 7500 and 10,000 hr. The test coupons will be used to narrow the field of interest. For example, if significant corrosion attack occurs early in the program, some of the test bars will be exposed for that length of time to determine the effect of corrosion on physical properties.

A section of pre-cooler tube was thermal cycled between 100 and 500°F 340 times to determine the effect of thermal cycles on the mechanically-attached external fins. Each cycle consisted of 100 sec heat up followed by 30 sec quench to simulate the worst conditions during ML-1 scrams. In 50,000 hr of operation (lifetime for such tubes), less than 340 such cycles are expected. The integrity of the external fin was not affected by these tests.

Anticipated Accomplishments - July:

Test specimens of the turbine alloy will be prepared and gas corrosion compatibility tests initiated.

The pre-cooler tube-to-tube sheet weld specimen is scheduled to be delivered by the vendor. When it arrives, physical tests will be run at the maximum expected operation temperatures.

7. Heat Exchanger Core Tests (Task 51-630)

Summary - January through May:

Specifications were completed during January for the recuperator and pre-cooler test cores.

Fabrication of the test cores was authorized in February, and the test cores were completed in April.

The pre-cooler core tests, completed in May, verified the design parameters for both heat transfer and pressure drop on the tube side. The results from the shell side tests indicated that heat transfer performance was higher than predicted, although pressure drop also was higher. As discussed earlier, calculations were initiated to determine if larger motors are required for the cooling fans.

Unsatisfactory heat balance between heated air and condensed steam forced discontinuance of the recuperator core tests. Inspection showed the tube bundle pitch dimensions were incorrect. The test core was reworked to the proper dimensions and the core section ducts changed to improve facilities for instrumentation.

Accomplishments - June:

Analysis of results of the pre-cooler core tests was completed. (This analysis is discussed in Task 56-110, Pre-cooler.)

The recuperator core tests were completed. Preliminary results indicated a reduction in heat exchanger effectiveness of 0.9%, a tolerable reduction as far as effect on the reactor is concerned. The data further indicated that the pressure loss was greater than predicted on the high pressure (tube) side of the core section. An increase in $\Delta p/p$ of 0.93% was observed. The vendor said that the finning operating reduced the internal tube cross-section and caused ripples on the inside of the tube, thus bringing about an increase in $\Delta p/p$. The vendor was requested to develop methods of eliminating these conditions.

Anticipated Accomplishments - July:

The recuperator core tests will be evaluated.

The methods of eliminating excessive tube side pressure loss will be evaluated.

8. Operational Planning (Task 51-660)

(NOTE: Since this work is closely allied to work being done under Contract DA-44-192-ENG-8, progress on both tasks is reported.)

Summary - January through May:

The modification of "Study for GTTF-1A" (Testing ML-1 Power Conversion Skid No. 2) was completed during the period. The modification included plans to test the skid at the GTTF facility, using a by-pass control system from the conclusion of the 500 hr demonstration until the facility is modified to GTTF-1A. The conceptual design of the facility modification was completed, and drawings were prepared to illustrate the general layout and location of major items of equipment. A detailed test plan for operating the ML-1 power conversion skid was completed as part of the study. The test plan included test objectives, description of general procedures, and the results expected from the start-up/check out tests, performance evaluation, malfunction/safety tests, and endurance demonstration tests. The results of this study were published early in June as Report No. AN 186.

Plans for testing the two ML-1 power conversion skids at Aerojet, Azusa, were studied. An existing test facility within the plant was selected as the test site. A detailed specification was prepared for a heater with growth capacity and a wide range of operating conditions. Firm bids by six vendors were reviewed. Power Conversion Skid No. 1 is scheduled for initial tests by 1 February 1961 and for shipment to NRTS by 1 May 1961. Skid No. 2 is scheduled for initial tests by 31 May 1961 and tentatively scheduled to be shipped to Fort Belvoir by 1 November 1961. The following tests are typical of those to be conducted at Aerojet, Azusa:

TABLE 6: Typical Power Conversion Skid Tests

Type	Skid No. 1	Skid No. 2
Static pressure checks	X	X
Cold rotating test (5 hr)	X	X
Low speed hot rotating test (5 hr)	X	X
Rated speed checkout test (5 hr)	X	X
Acceptance test (10 hr)	X	X
Limited endurance demonstrations (80 hr)	X --ship to NRTS	0
Performance evaluation (250 hr)	0	X
Malfunction/Safety tests (100 hr)	0	X

Accomplishments - June:

A detailed specification was completed for the nitrogen heater required for tests at Aerojet, Azusa, and GTTF-1A. Authorization to proceed with design and fabrication of the heater is scheduled for release by 1 July.

The preliminary requirements for instrumentation and mechanical facilities was completed for the power conversion skid tests at Azusa and is being reviewed locally.

Anticipated Accomplishments - July:

Fabrication of the nitrogen heater will be authorized.

Planning will continue on the program for testing the power conversion skid at Aerojet, Azusa.

9. Component Development Tests (Task 59-4XX)

Summary - January through May:

Technical evaluation of the proposals for pre-cooler/recuperator tests was completed. A detailed test program was planned, based on the use of Allison Division (General Motors Corp.) facility.

A study was completed of the facility required for development and life tests of the alternator. It was concluded that the existing Aerojet, Azusa, test facility will best serve the needs of the program. The facility includes a 550-hp dc motor drive as the prime mover. Design and purchase was initiated for the miscellaneous small test equipment needed to adapt the alternator to this facility.

Accomplishments - June:

Minor revisions were made of the program planned for the pre-cooler/recuperator tests. However, planning for heat exchanger tests was discontinued until pending budget revisions are completed.

Design was continued on the test support structure and the modifications to the drive for the alternator/start motor test stand.

Evaluation tests were initiated to determine the effectiveness of several commercial oil/gas separators.

Anticipated Accomplishments - July:

The design of the test stand for the alternator will be completed. Material procurement and fabrication of the support structure will be initiated.

Evaluation tests will be continued on the lubrication system oil/gas separators.

Preparation of detailed procedures will be initiated for the alternator performance and development tests.

10. Static and Dynamic Analyses (Tasks 56-13X and 56-16X)

A preliminary study of gas lubricated bearings was submitted to IDO in April. Other material formerly reported here is now being reported under the appropriate individual tasks.

D. INSTRUMENTATION AND CONTROLS

1. Electrical Equipment Design (Task 57-1XX)

Summary - January through May:

The over-all electrical single line diagram, motor control center elementary diagram, and generator control center elementary diagram were revised. The power requirement tabulation was also brought up to date and still indicates that a 45 kw diesel will supply sufficient power for startup.

A table was compiled showing size and signal level of all power metering and control leads to be included in the cables between the power conversion skid and control cab. A portable cable continuity checker was purchased. Drawings were made of the plant grounding details and power conversion skid connector panels. The equipment for the d-c to a-c static inverter (to be used for emergency standby power) was purchased and received.

Specifications for the main generator circuit breaker were sent out to bid, and the vendor's plant was visited to investigate his ability to provide a reliable vacuum-type circuit breaker. The protective relays were purchased. Westinghouse is supplying the static type differential relay, General Electric is providing the reverse power relay and Allis Chalmers is supplying the static type overcurrent relays. The potential and current transformers for power metering and relaying were purchased from Westinghouse and were received. The power transformer specifications were sent out for quotation.

Specifications were written for the transfer contactor and surge protective system and sent out to bid. The surge protection system includes line and station type lighting arrestors as well as surge capacitors and inductors. Power branch circuit breakers were purchased to protect the auxiliary equipment branch circuits.

The electrical equipment was specified and locations selected on the gas storage skid, the gas drying skid, and the cable reel skid. The input connection boxes, magnetic starters, pushbutton switches, conduit, wire and conduit fittings were enumerated in detail and the mechanical details of the mountings shown on the drawing.

Accomplishments - June:

A summary of the power switchgear design was written describing the purpose and operation of each major power switchgear component. Work continued on the conduit layout and wire connection tables and diagrams, now 40% complete.

Tests were performed on the complete inverter breadboard using a series of automotive batteries connected in series to supply 150 volts of d-c input. These tests demonstrated the need to simplify the design and improve the reliability of the unit. Simplifying the driving and switching networks increases the weight of the filter circuit from about 30 pounds to 130 pounds, approximately.

The Size Zero motor starters were purchased from a vendor. The closing date for bids on the transfer contactor and the vacuum circuit breaker was extended two weeks to encourage additional bids.

Anticipated Accomplishments - July:

Work will continue on the conduit layout and wiring diagrams.

Work will start on the design of the static inverter package.

Purchase orders will be issued for the transfer contactor and power transformers.

The bid package for the vacuum circuit breaker will be sent to IDO for approval.

2. Neutron Monitoring and Control (Task 57-2XX)

Summary - January through May:

Orders were placed for the major components of the nuclear instrument subsystem, for the annunciators, and for the controls needed for the neutron-absorbing control blades. The specifications for these items were based on the preliminary design, and amended as firm information became available.

All schematic and block diagrams were made and main cable conductor requirements established.

The sensitivity required of the startup and power range flux monitoring detectors and associated amplifiers was determined, based on a high and low estimate of the full power neutron level at possible detector positions.

The preliminary design was completed and parts ordered for the auxiliary equipment box and cart for use in simulating the power conversion skid during the initial critical experiments.

A block diagram was prepared for the proposed blade control system. The functions were described, and the description approved, for the manual and automatic blade movement controls, the protective interlock circuitry, the startup by-pass circuits and the safety scram system.

The environmental conditions applying to electrical equipment on the power conversion and reactor skids were reviewed. It was recommended to use silicone and polyethylene insulants in those applications.

Criteria were established for the very low level pulse counting channels required for the critical experiments.

Accomplishments - June:

The instrumentation requirements were determined for the initial cold start of the reactor. Data sheets were prepared indicating the characteristics of the BF_3 neutron counters, the pulse pre-amplifiers, the linear amplifiers, the scalers, and the power supplies for all items.

The effects on instrument circuits of interference by relay switching in the clutch and blade driver motor circuits were reviewed. Contact arc suppressors were specified and ordered. A bundle shield, to provide double shielding, was specified for the nuclear cable to minimize interference from external, uncontrollable sources of radiation. Other circuits will be provided with a bare copper conductor added to the usual shielded, twisted pair (triad construction) to provide an easily-connectable low-impedance shielding circuit.

Anticipated Accomplishments - July:

The detailed design will be completed for the auxiliary equipment box and cart that will be used to simulate the power conversion skid during the initial critical experiments.

The blade control system relays will be laid out in drawers for mounting in one of the control cab racks. Interconnecting wiring diagrams will be made for these relays and the associated console and field mounted equipment.

A final drawing of the annunciator system will be received from the vendor, will be reviewed and approved.

3. Health Physics (Task 57-3XX)

Summary - January through May:

The final design of health physics instrumentation was about 50% completed during the period. Specifications were written for the remaining major pieces of hardware, including the components for the pre-cooler monitor, AES Specification No. 2929.64; the site health physics instrumentation, AGC Specification No. 60,053; and the remote area monitoring system, AES Specification No. 2929.31. The RAMS specification was amended to standardize connectors and to define cabling requirements.

Accomplishments - June:

The radioactivity detecting and sampling equipment were ordered for the pre-cooler monitor. This equipment includes the particulate collecting equipment (air pump, filter paper tape mechanism, shielded scintillation detector assembly); the associated high voltage power supply; a logarithmic counting rate meter and a recorder. Similar components, except for the filter paper mechanism, were ordered for the gaseous activity monitoring system. A cart was designed for housing the field mounted components, and the design sent to bid. Most of the site area monitor (SAM-I) drawings were received from the vendor and will be reviewed after the detector drawing is received.

The assembly drawing for the piping for the pre-cooler monitor is nearly complete. Detail drawings for this system are about 50% complete.

Requisitions were written for the specified safety equipment. This equipment includes the protective clothing, ultra-filters, air-packs, military specification portable Geiger-Mueller counters, alpha counters, slow neutron and fast neutron detectors.

The shielding required for the pre-cooler monitor was calculated, based on the latest isodose curves. The results show that about 4-ft of concrete shielding will be needed to reduce the background at the detector locations so that airborne activity can be sensed at the tolerance level.

Anticipated Accomplishments - July:

Final design of the pre-cooler monitor will be completed, and the cart for the field-mounted equipment will be ordered.

The health physics equipment will be ordered.

The vendor's drawings of the remote area monitoring equipment will be reviewed and approved.

4. Analysis Instrumentation (Task 51-740)

Summary - January through May:

The final design of the analysis instrumentation system was 80% completed during the period. The block diagram was revised and schematic diagrams were drawn.. Work was begun on the wiring diagrams, the cabling diagrams, and the rack and panel drawings. The installation of racks in the test building was drawn and approved.

A specification was written for the eight cables to connect the field equipment with readout instrumentation in the analysis building. The specification was approved.

Major components were ordered for the pressure, vibration and temperature measurement subsystems.

Requirements were established for analysis instrumentation for the t-c set lubricating oil system. A calibration system was incorporated in the design to remotely check the pressure transducers. A bottle of pressurized nitrogen (regulated to a low pressure and compared to a precision Bourdon gage) is connected to a pressure scanner switch. The pressure scanner switch routes the calibration gas to any of the analytical pressure transducers. The output of the pressure transducer is compared with the precision gage. The system permits calibration during operation and checks the validity of data taken during tests.

Accomplishments - June:

Design continued on the analysis instrumentation system. The rack assembly design was completed. The drawings needed for installing the nine-rack assembly were sent to NRTS for the Increment I contractor. Location and mounting design was initiated for the transducers and associated cabling on the power conversion skid.

The revised block diagram was approved and released. All rack wiring diagrams were released for fabrication. The gas analysis system specifications were sent out for bid. The cable bid was closed and the bid package approved by IDO. The panels are being installed in the racks. Drawings were completed for the pressure calibration panel and were approved. A second pressure scanner system was purchased for the pressure calibration system. Stainless steel tubing and solenoid valves were requisitioned for the calibration system.

Specifications were written for most of the thermocouple probes, and the probes requisitioned. Installation requirements were firmed for all analysis instrumentation to be located on the reactor skid. The specification was written for the flow computer.

Anticipated Accomplishments - July:

Fabrication of the rack assembly will be about 25% complete.

A layout will be drawn of the junction box to house analysis instrumentation equipment for the power conversion skid, and detailed design will be started.

Design will be initiated for the routing of cables from the analysis junction box to the transducers mounted on the reactor and power conversion skids.

Information on mounting temperature and pressure sensors will be collected.

The pitot static tube will be ordered for the compressor inlet.

5. Dynamic Analysis (Task 51-750)

Summary - January through May:

A study was completed of the kinetics of the control system for the ML-1 nuclear power plant. The two servo control loops (reactor outlet temperature and speed) were established and analyzed.

The reference control system is based on the concept of maintaining a constant inventory of working fluid in the system, and by-passing part of the flow to control the load. This is known as "by-pass control" or "the constant mass system". (For equilibrium considerations of the power plant control system over the ambient air temperature range, see Task 51-870, Systems Analysis.) The fast response feed and removal valves required by the "variable mass system" are not needed in the constant mass system, thus the latter system uses fewer valves and controllers. The constant mass principle assures greater reliability in the control system by its relative simplicity, and uses a slower speed regulating blade actuator (about 13 sec). The variable mass system has the single advantage of more uniform operating efficiency over the net output range from no load to full load, but a supplementary by-pass control is required to achieve satisfactory response rate of frequency regulation.

In the reference control system, the temperature of the reactor outlet gas, and therefore the reactor power level, is adjusted by changing the position of the regulating blade (Figure 12). The position of the blade is controlled by an error signal that represents the difference between the measured temperature of the reactor outlet gas and the set-point on the reactor outlet gas temperature controller. Figure 13 is a Nicol's* chart showing open and closed loop gain versus response phase angle.

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* In a Nicol's chart, two coordinate systems are used: linear coordinates are used for the lagging phase shift (in degrees) and the gain (in decibels) of the open-loop. Superimposed on this coordinate system is a set of curvilinear coordinates showing the closed-loop gain and phase shift. The stability criterion is that the frequency response curve passes to the right and below the points of -180° and 0 db. If the curve is too close to the intersection of these points, the system is underdamped and excessive ringing or overshooting can be expected. The curve should be approximately tangent to the +2 db closed-loop gain ellipse. The closed loop speed of response can be estimated by noting the frequency value that corresponds to the point of tangency of the closed-loop ellipse to the plotted response line.

Figure 13 shows that the temperature control loop has sufficient range of gain for stability and quick response. This servo loop is capable of controlling the reactor exit temperature (1200°F) to within ± 35°F for a 100% step change in plant power output. The temperature is stabilized within 40 sec. The corresponding reactor coolant flow rate change is 15% and is the result of closing or opening the by-pass control valve. The reactor outlet temperature response to a one degree step in set point temperature over the range of controller gain is shown in Figure 14. The curve $Kc = 2.5 \times 10^{-4}$ indicates sufficient loop sensitivity. The curve $Kc = 0.6 \times 10^{-4}$ indicates a critically damped loop.

Turbine speed is controlled by by-passing a portion of the coolant flow from the compressor discharge to the pre-cooler inlet (Figure 15). The turbine speed is sensed by a pulse-integrating tachometer. The desired speed value is manually set on the controller, making use of a position feedback loop to control speed. A Nicol's plot for the speed control loop is shown in Figure 16: Figure 17 shows a plot of the system response for a 100% step change in plant output power.

Dynamic analysis revealed that by-pass valve time constants up to 1.0 sec. can be used if supplemented by a lead network. Accordingly, the reference speed control system incorporates such a lead network. A valve with a time constant of 0.35 sec. is being procured. The kinetics study also shows that the constant mass design with a by-pass valve effectively regulates the turbine speed to design specifications. The polar moment of inertia of the proposed turbine shaft (1 ft-lb-sec^2) in combination with an 0.35-sec valve and the lead network can adequately limit the steady state turbine speed to within ± 0.33% of rated speed.

Several other dynamic studies were made of the plant. Various temperatures and pressures in the nitrogen loop after a scram are shown in Table 7,page 93. These results show it is unnecessary to run the pre-cooler fans after a scram to prevent excessive temperatures in the pre-cooler and compressor.

In addition, to the dynamic studies, the following problems were solved on the analog computer:

1) By-pass valve optimization problems were run with 0.1-, 0.2-, and 0.3-second time constants. A by-pass valve with a time constant equal to, or less than, 0.1-second is sufficiently fast without a lead network. However, valves with time constants greater than 0.1-second sustain oscillations in a number of system parameters unless a lead network is used. The frequency and amplitude of these oscillations are dependent on the time constants chosen.

2) Rapid set point changes of 100°F or more in reactor outlet temperatures will cause a power level scram. The neutron level will rise to about 150% above normal at full power under this condition.

3) An increasing load due to bearing failure (or other parasitic losses) apparently caused no harmful effects on any system component in the normal range of speed or temperature control. Neutron level did

TRANSFER FUNCTION BLOCK DIAGRAM FOR THE TEMPERATURE CONTROL SERVO LOOP

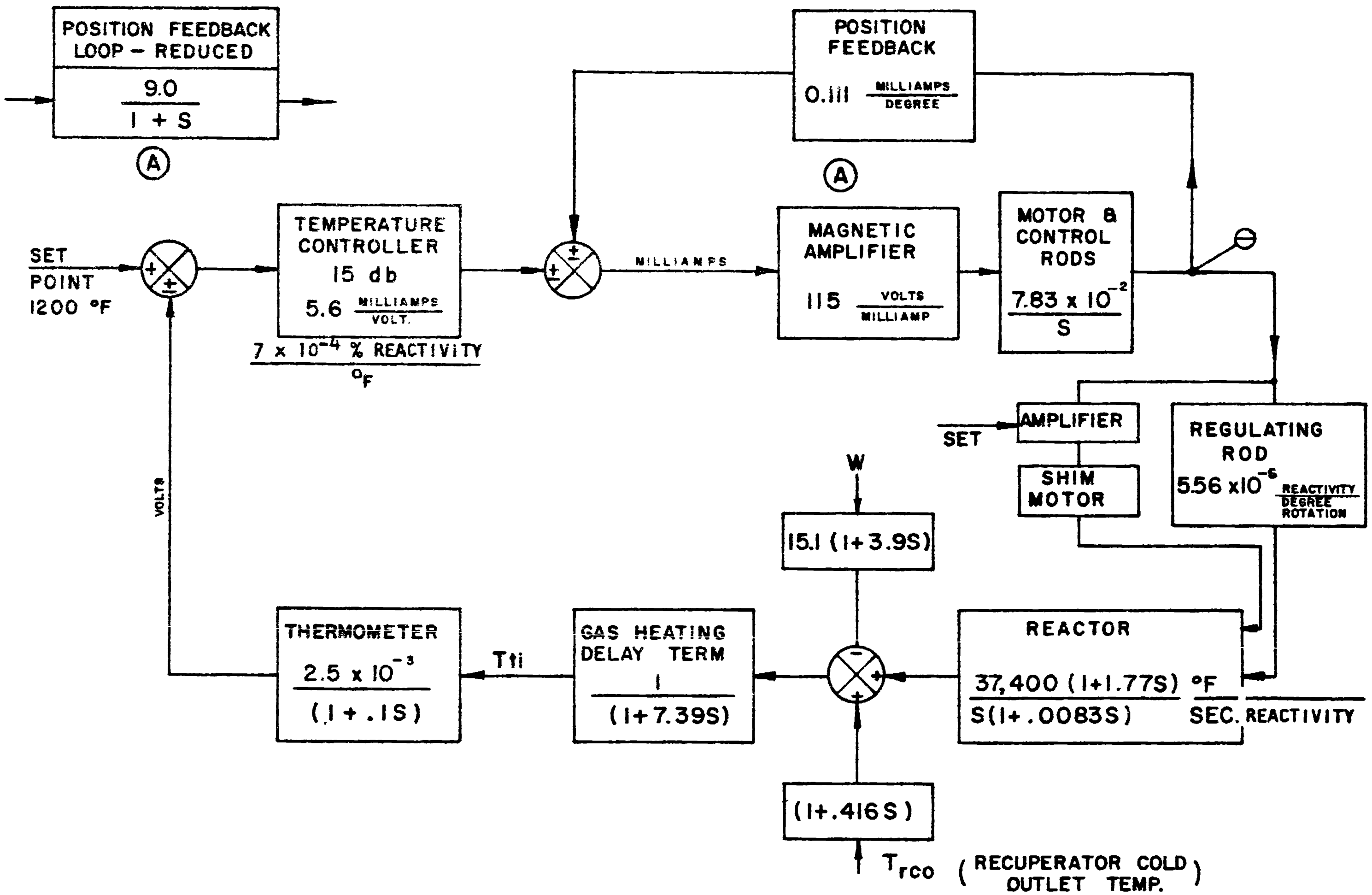


FIGURE 12

NICOL'S PLOT OF THE TEMPERATURE CONTROL SERVO LOOP

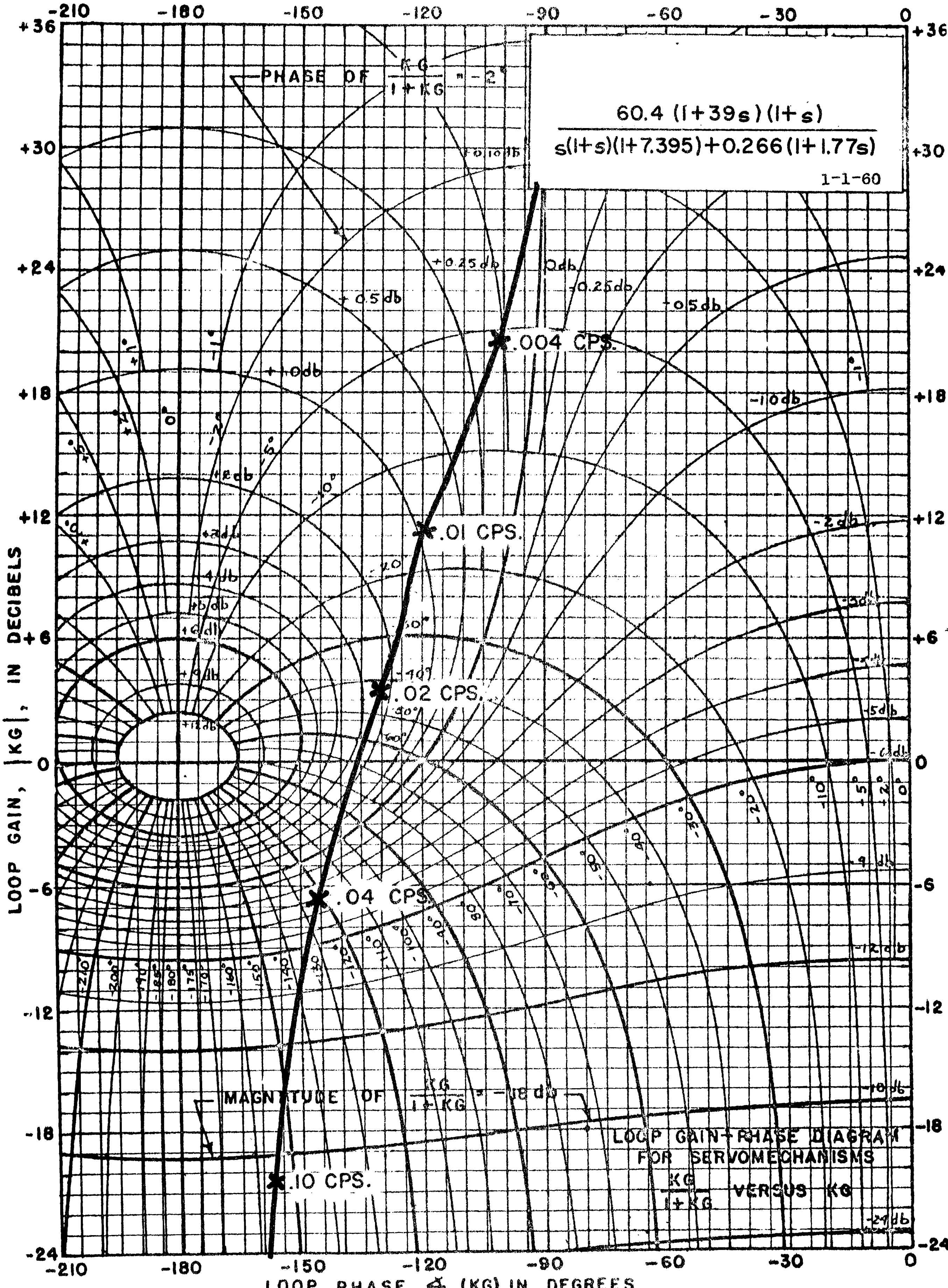


FIGURE 13

RESPONSE CURVES OF TEMPERATURE CONTROL SERVO LOOP
(FOR EXTREME RANGE OF GAIN)

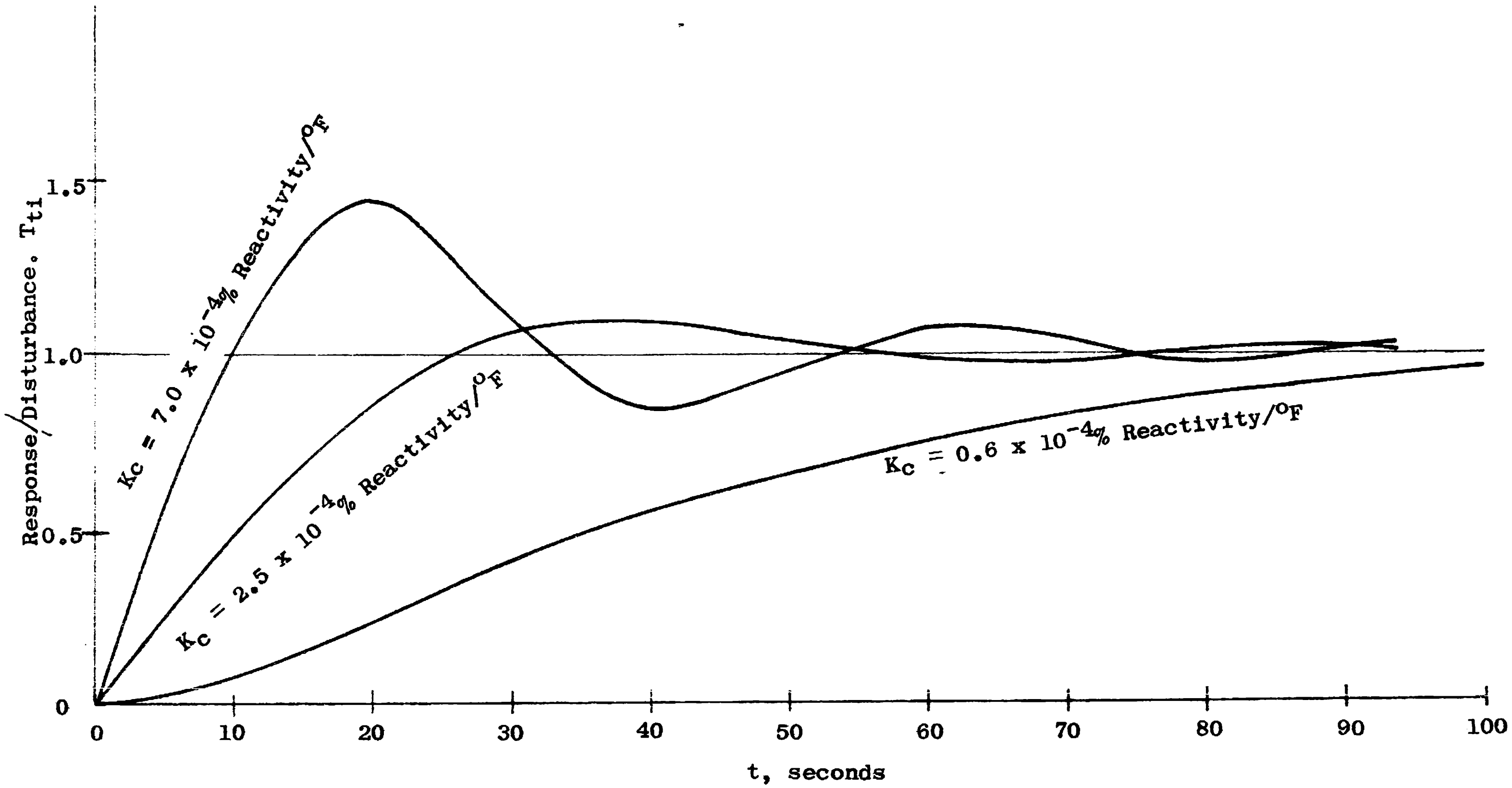


FIGURE 14

SPEED CONTROL SERVO LOOP
ML-1 SYSTEM

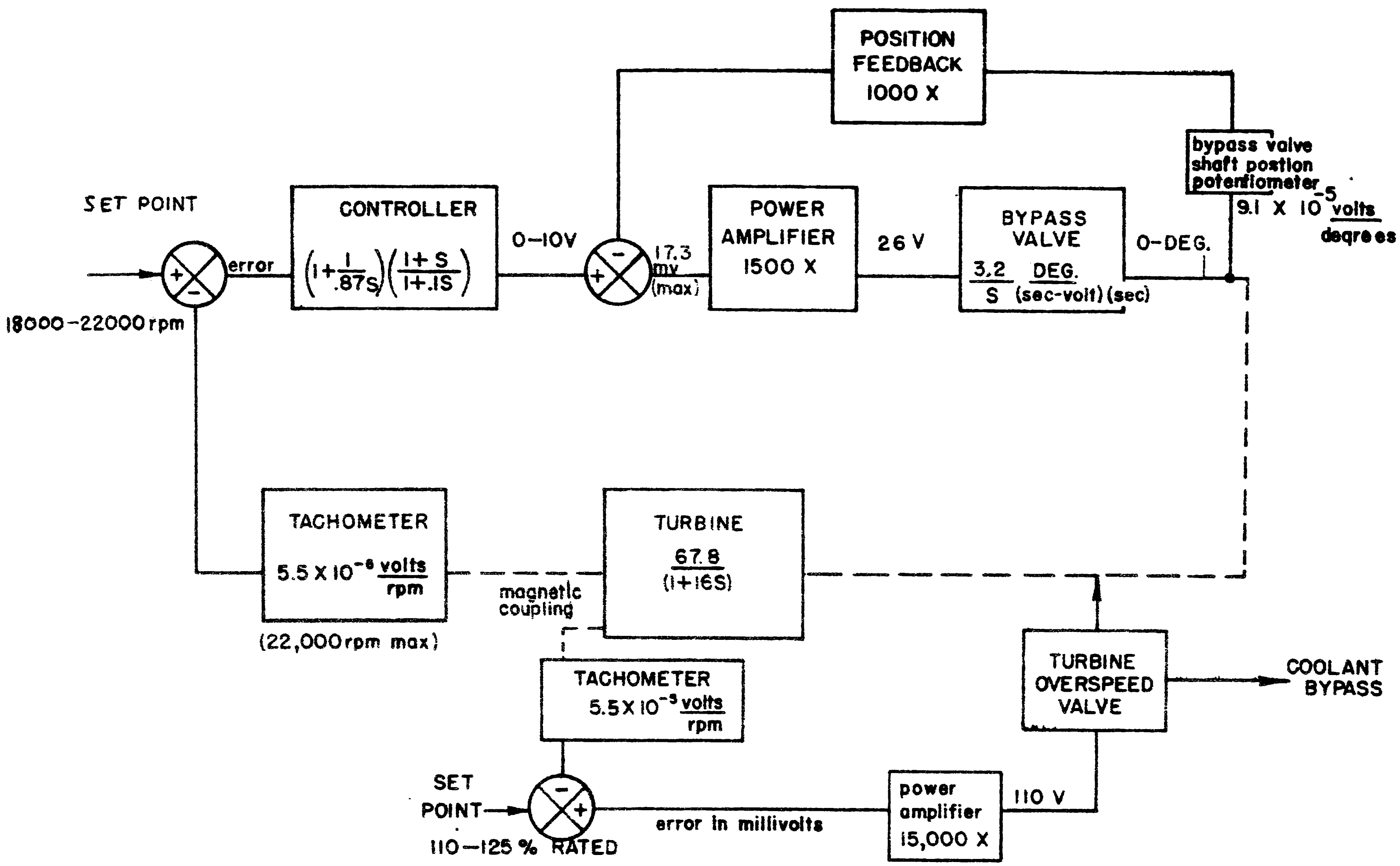


FIGURE 15

NICOL'S PLOT FOR THE SPEED CONTROL SERVO LOOP

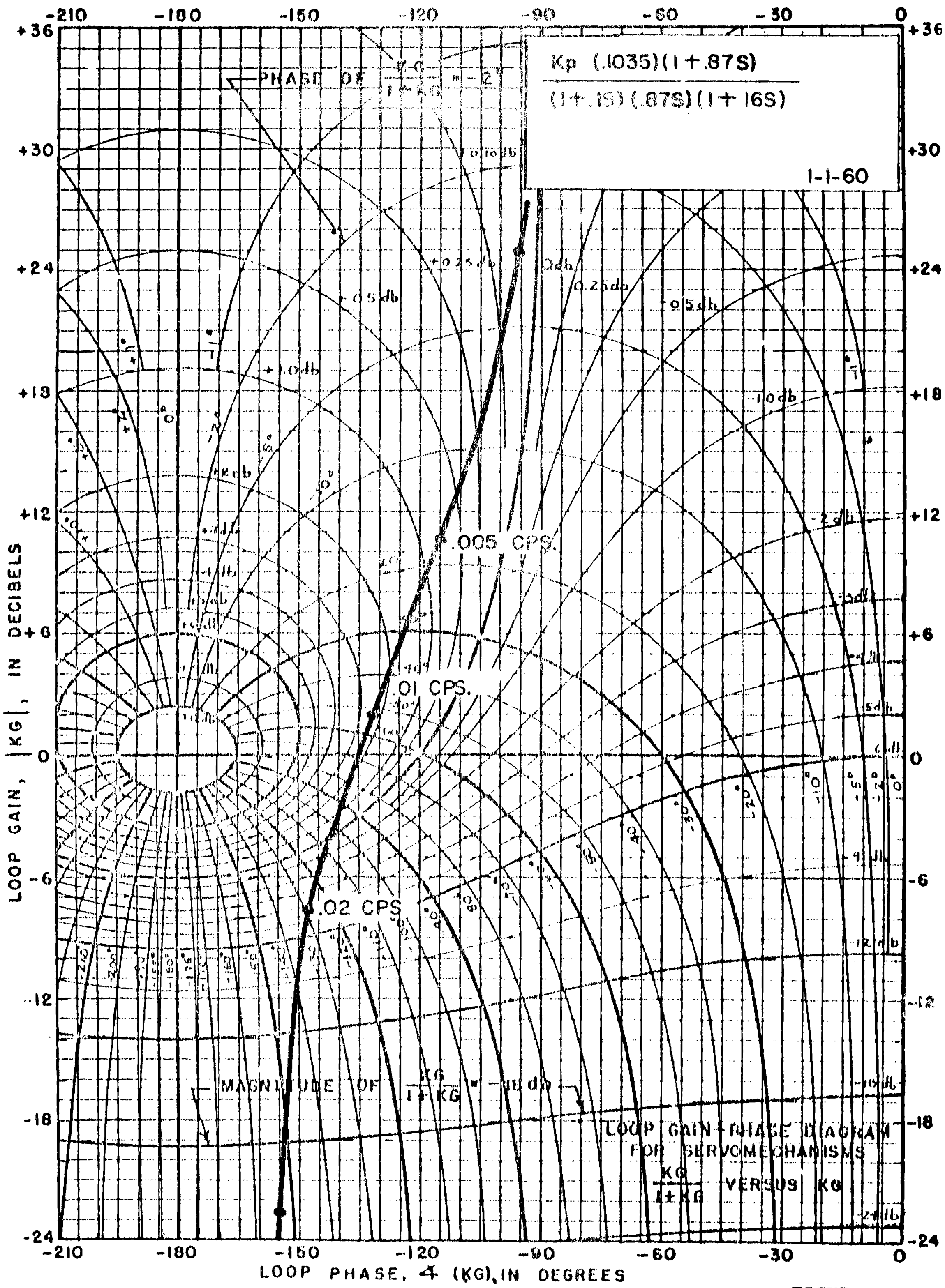
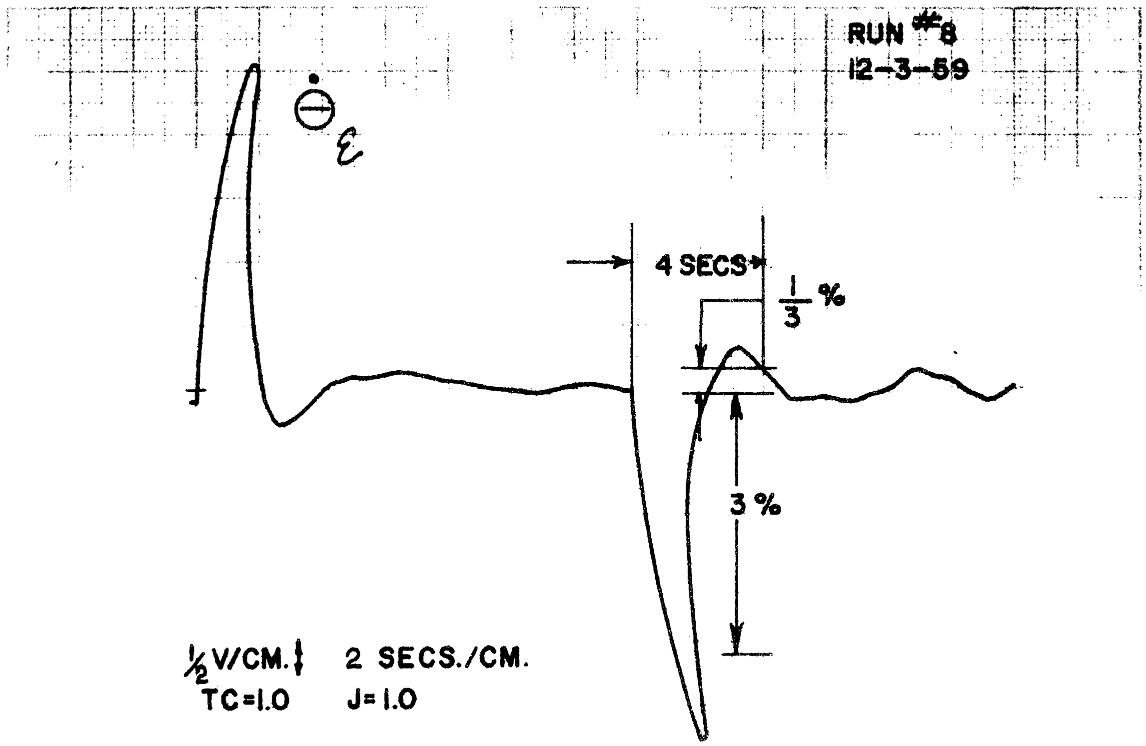
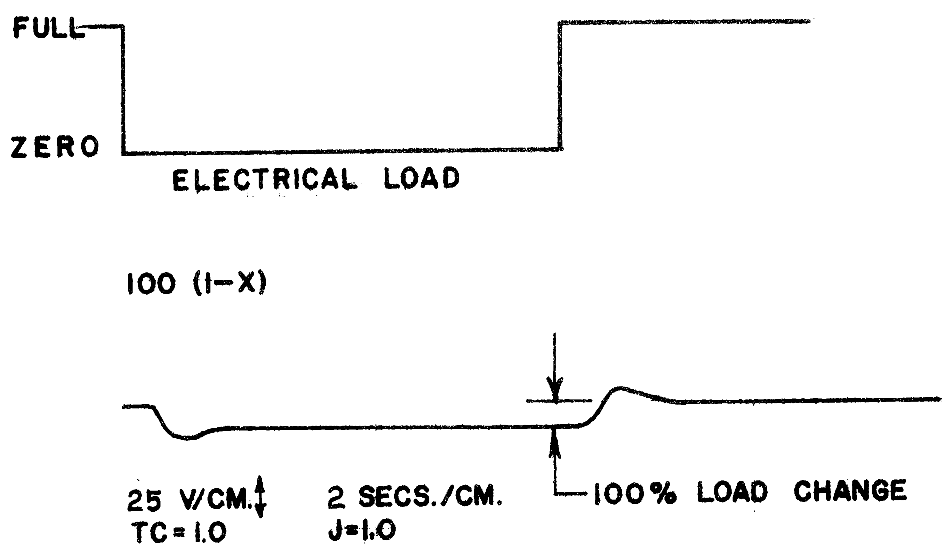


FIGURE 16

ML-1 TURBINE SPEED TRANSIENTS
(FOR J=1.0)



TURBINE SPEED ERROR



RELATIVE VALVE POSITION

FIGURE 17

Table 7. SUMMARY OF ANALOG RUNS
(Various Pre-cooler Air Weight Rates
During a Scram)

Pre-cooler Air Weight Rate, lb/hr	18,000	25,000	50,000	75,000	100,000
T_{pw} (1) Equilibrium Temp. after Scram °F	195	173	152	142	140
T_{pw} Max. Rate of Cooling °F/sec.	1.4	1.1	0.6	0.3	0.3
T_{wl} (2) Equilibrium Temp. after Scram °F	400 (3)	355 (3)	300 (3)	295 (3)	275 (3)
T_{rho} Initial Temp. at Full Power °F	465	438	430	430	430
T_{rho} Equilibrium Temp. after Scram °F	240 (4)	225 (4)	180 (4)	150 (4)	150 (4)
T_{to} Equilibrium Temp. after Scram °F	412	375	300	282	277
T_{to} Max. Cooling Rate after Scram °F/sec.	32	28	27	27	27

(1) Initial T_{pw} at full power = 125°F before scram

(2) Initial T_{wl} at full power = 850°F before scram

(3) Max. T_{wl} cooling rate = 20°/sec

(4) Max. T_{rho} cooling rate = 3°/sec

DEFINITIONS:

T_{pw} = Pre-cooler outlet wall temperature, °F

T_{wl} = Recuperator wall hot inlet, °F

T_{rho} = Recuperator outlet hot side (nitrogen) temperature, °F

T_{to} = Turbine outlet nitrogen temperature, °F not appear to rise within the accuracy of the analog (± 5%) for an increasing power demand, nor did any temperature become excessive.

Accomplishments - June:

Plans were written for the tests of the speed control loop at San Ramon and NRTS. Evaluation tests of calibration and frequencey response were defined in rough draft form.

A start-up schedule and starting transient curves were made for the ML-1 compressor inlet pressure, reactor outlet temperature, t-c set speed, and the relationship of KVA requirements to time during a typical start-up (Figures 18 through 22).

Anticipated Accomplishments - July:

Programming will be completed for the GTTF analog, and the transient temperature studies will be started.

6. Process Instrumentation (Task 57-6XX)

Summary - January through May:

Process instrumentation will indicate and remotely control the reactor, power conversion and auxiliary skids. The primary gas and moderator water systems parameters will be displayed on a graphic panel in the control cab. Gas admission and gas storage valves and piping will be displayed on a small graphic panel. Other necessary, but less important parameters, will be indicated by meters on a separate panel.

Most of the specifications for the process instruments were written during the report period and are either out for bid, or are being prepared for bid. Details of the graphic panels were prepared and are being released for bid.

Accomplishments - June:

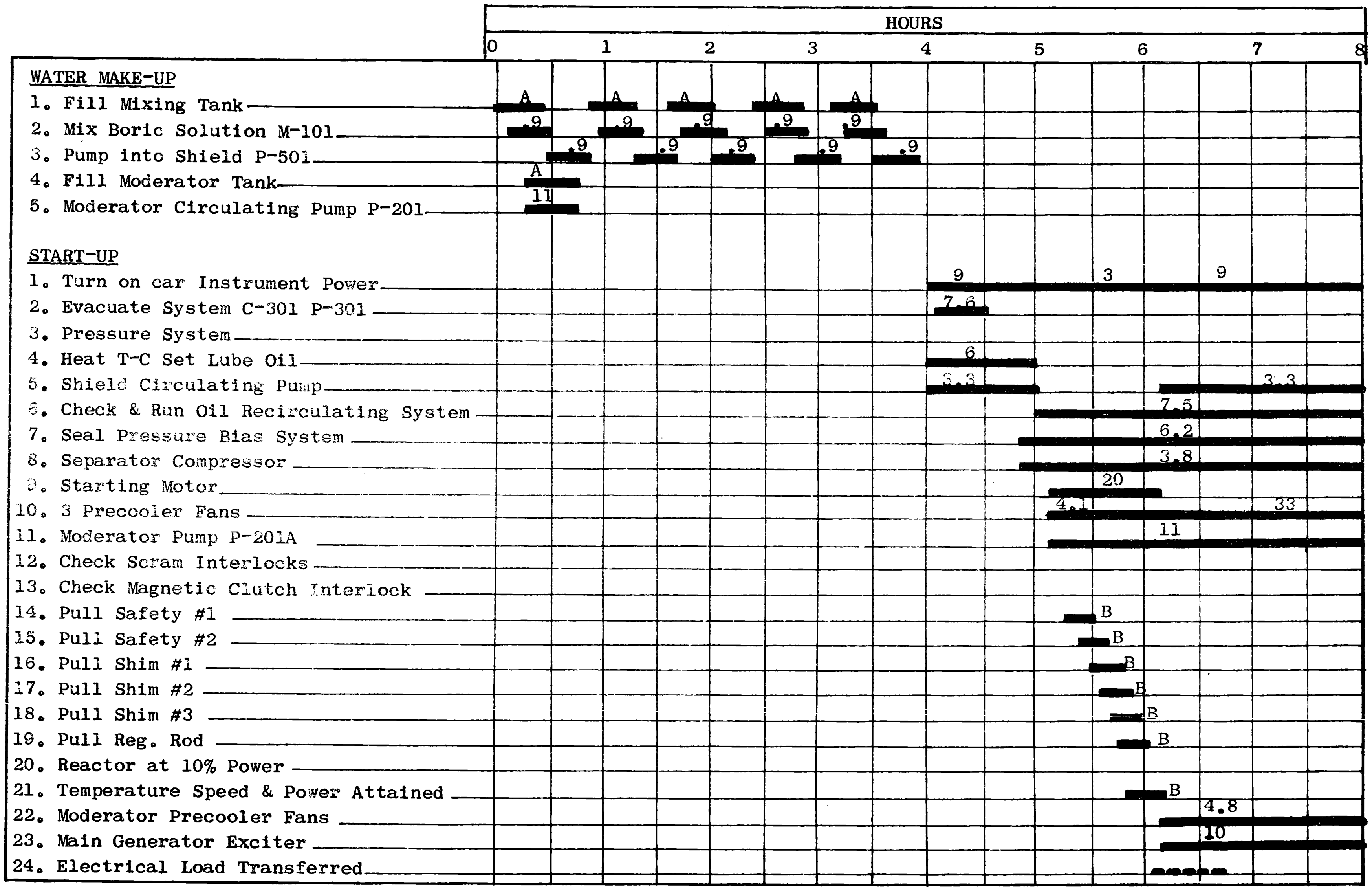
Five specifications were prepared and released in June. These included specifications for the reactor outlet temperature instrumenation, high pressure instrumentation, reactor scram outlet temperature high instrumentation, moderator and lubrication oil temperature, and oxygen instrumentation.

The specification for the vacuum instrumentation was amended.

The specification and bid package for the process temperature instrumentation was approved by IDO, and the purchase requisition issued.

The latest information was incorporated into the graphi panel drawings.

ML-1 AUXILIARY EQUIPMENT POWER SCHEDULE



NOTES:

A - POWER SUPPLIED EXTERNALLY

B - INDICATES POWER INCLUDED IN CAB REQUIREMENTS

NUMBERS ABOVE BARS INDICATE KVA

FIGURE 18

AUXILIARY EQUIPMENT LOAD DEMAND

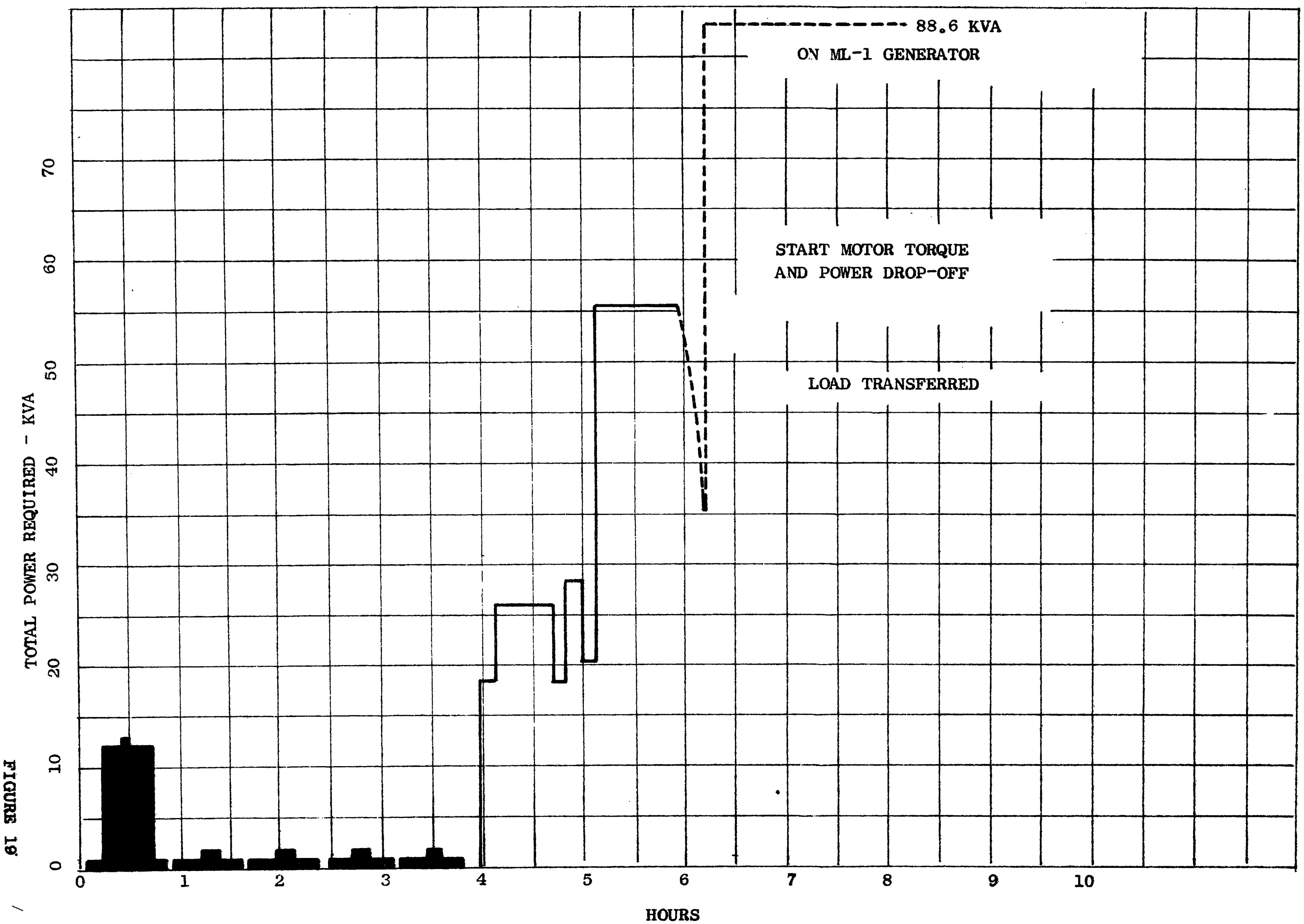


FIGURE 19

ML-1 START-UP SCHEDULE -1 (T_{ti} VS. TIME)

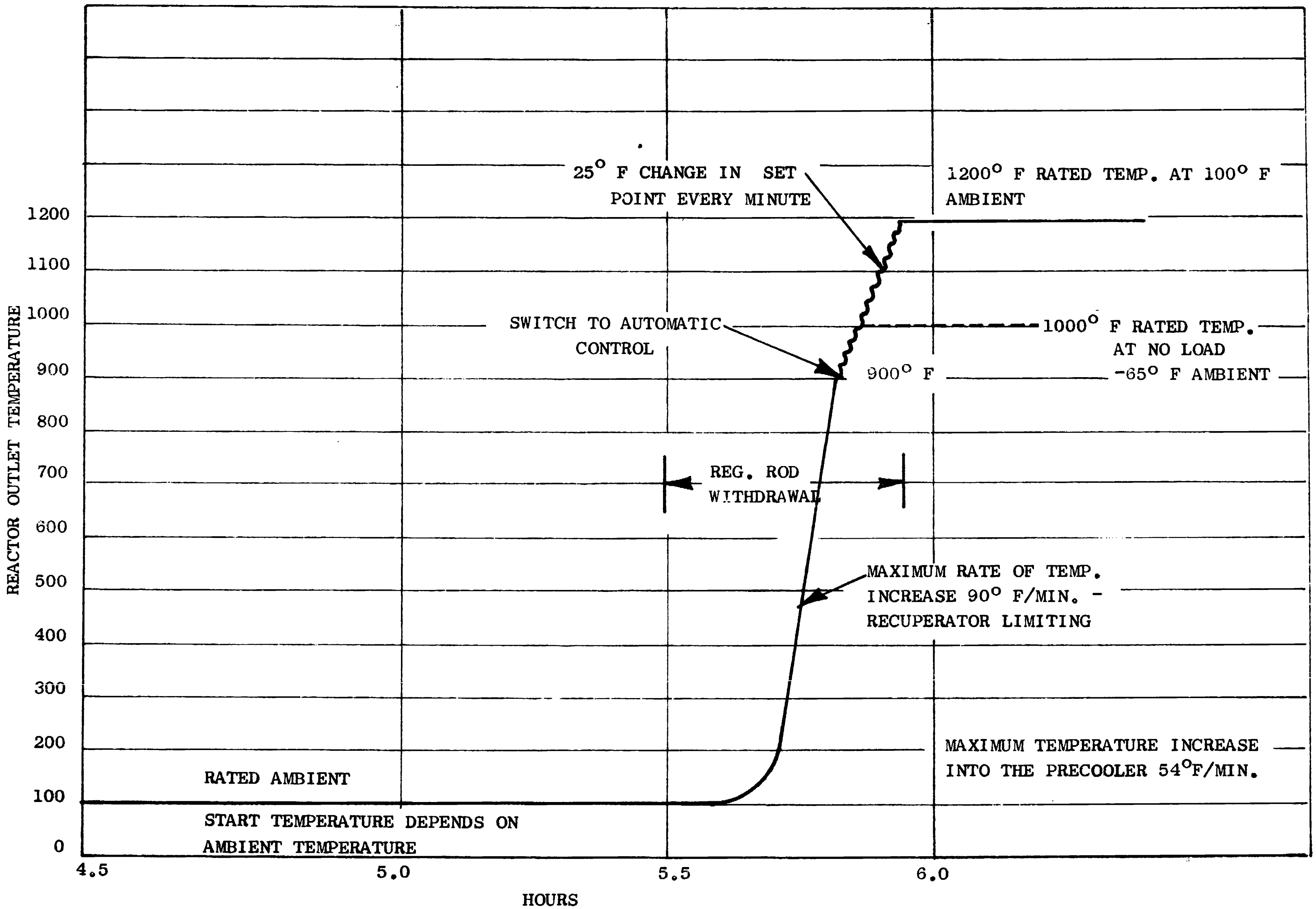


FIGURE 20

ML-1 START-UP SCHEDULE - 2

Compressor Inlet Pressure Versus Time

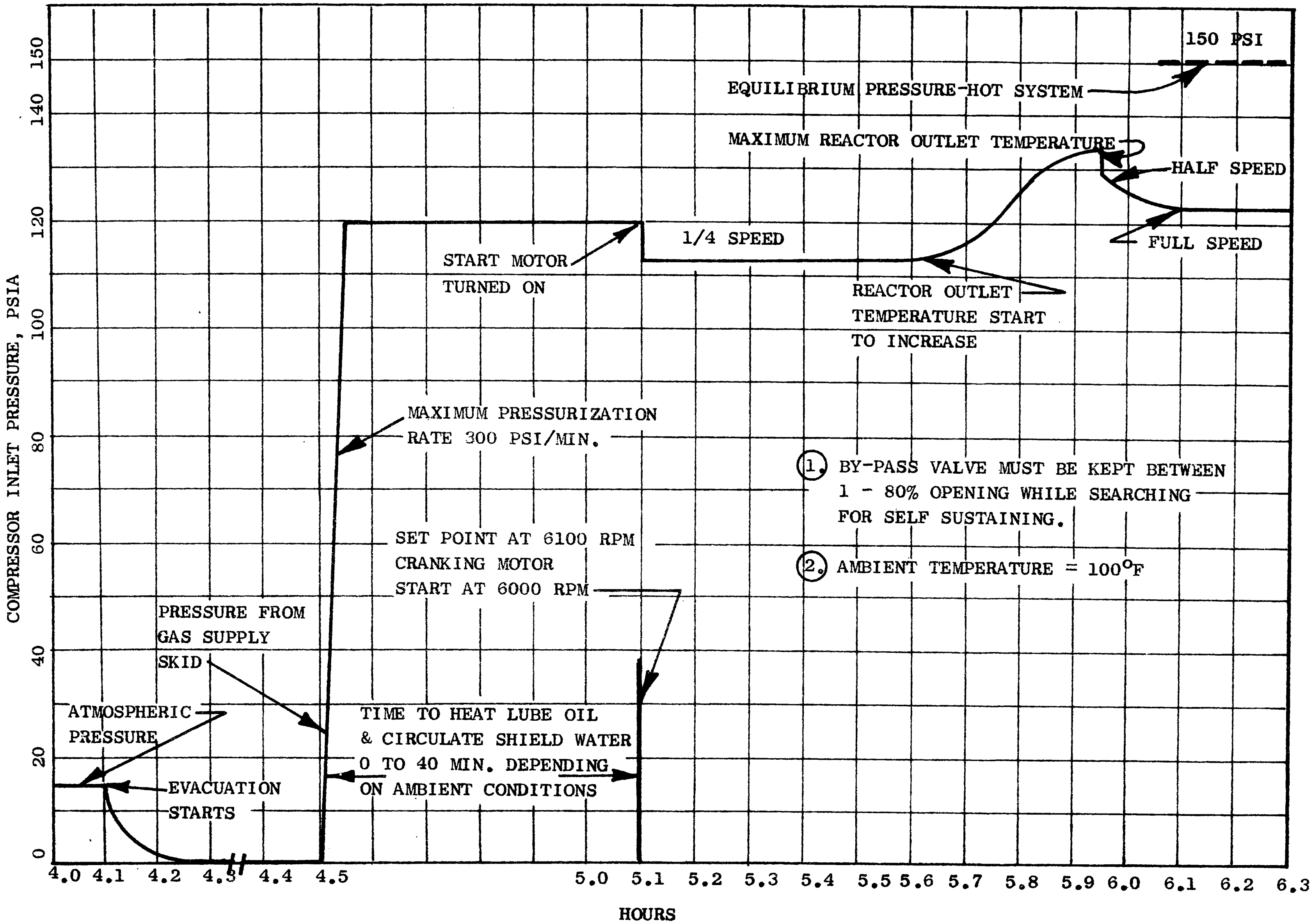


FIGURE 21

ML-1 START-UP SCHEDULE (SPEED VS. TIME)

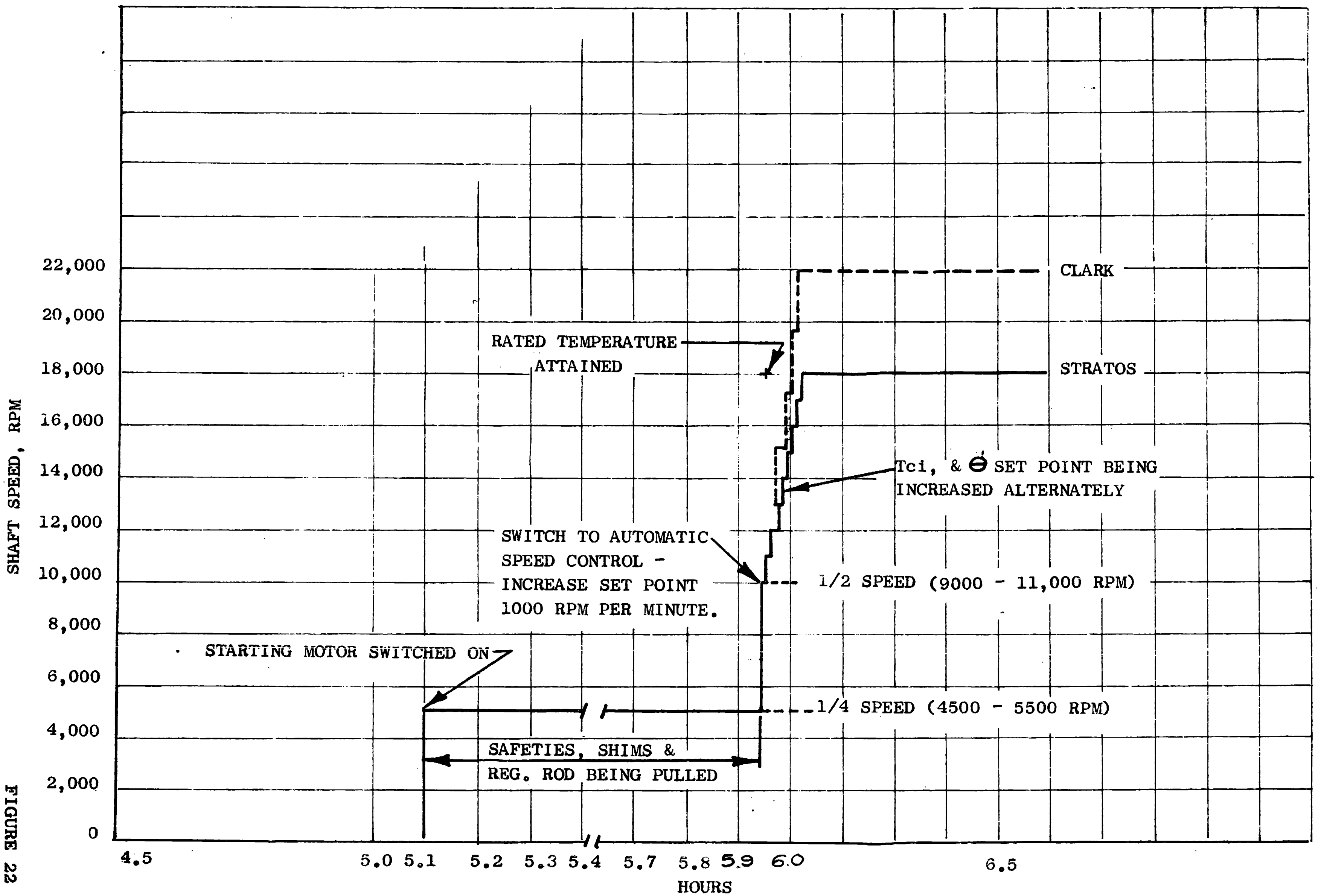


FIGURE 22

Preliminary wiring schematics were prepared for several of the process instrumentation systems.

The conductivity bridge ordered for the conductivity system was not received.

The specification and bid package for the control valves are being prepared.

Preliminary design work was begun on the read-out system for the bearing temperature instrumentation. A system schematic was drawn and the design will be breadboarded and tested.

Special parts were ordered for the speed and temperature controller.

Specifications were written for the vibration instrumentation and for the oil pressure instrumentation for the transfer compressor.

The closing date for bids on the overspeed valve was extended from 17 June to 1 July.

Anticipated Accomplishments - July:

Work will continue on the wiring schematics for the process instruments.

Development work will begin on the conductivity system.

A system for reading the temperatures of bearings will be finalized.

The graphic panel drawings will be released for bid.

7. Power Control (Task 57-8XX)

Summary - January through May:

Specifications were written during this period for all major components of the instrumentation for the control cab and power control except the specifications for the control cables.

Major items purchased include the control cab, the intercommunication system, the battery supply for the emergency power, the voltage regulator, the load bank for testing the alternator and the ML-1 system, and the meters for the power control instrumentation. The air conditioner/heater unit is the only major item still out for bid.

A full scale model of the control cab was built. The mock-up provided detailed information on space available, physical clearance problems, and internal cabling and wiring problems. The information was used to revise the layout of the control cab, greatly improving utilization of space (Figure 23). The control console design was completed and all drawings of the framework released for fabrication. The console is scheduled to be completed in July (Figure 24).

A design change made it necessary to revise the schematic for power instrumention. The design change was in the connection of the potential transformers to the main bus from an open delta to a wye configuration to enable metering single phase to ground loads.

The vendor's preliminary outline drawing and schematic for the load bank was received and reviewed. The load bank will be used in the final test of the alternator and the ML-1 system (Figures 25 and 26).

A new panel for the entrance of the cable into the control cab was designed and fabricated after a review of the rack drawings and construction information.

A special light assembly was designed and the lighting plan completed for the control cab. The lighting level with this plan is 25 foot candles at desk level.

The applicable military specifications will be utilized in specifying the wiring format to be used for the ML-1 system.

The electrical requirements for the auxiliary skids (cable pallet skid, gas drying skid, and waste gas storage skid) were completed.

<u>Accomplishments - June</u>:

The specification for the shock and vibration isolation system was approved and released for bid. Closing date for these bids is 15 July.

Liaison continued with the manufacturers of the load bank. Delivery of the load bank is scheduled for 25 August. There is a possibility of delivery being made as early as 11 August. The unit will be shipped directly to Aerojet, Azusa, to facilitate tests of the alternator for the ML-1 system.

A block diagram was completed to show the equipment and systems in the control cab (Figure 27). The diagram shows the major components in the cab, the anticipated completion and delivery dates, the scheduled installation dates, and the wiring of the over-all system.

Liaison with the manufacturer of the control cab was continued (Figure 28). Delivery of the control cab is scheduled for 28 July at Aerojet, San Ramon.

Work continued on design and specification of control cables. The work should be completed in July.

The power instrumentation schematic was reviewed and two phase sequence relays were added to automatically monitor the three phase power. If incorrect phase sequence is supplied, these units prevent passage of current to equipment that would be damaged by incorrect phase sequence. (These relays close a contact when the applied phase sequence is correct, A-B-C, for example, but remain open if the phase sequence is B-A-C, etc.) The synchroscope circuits were revised for semi-automatic operation by two phase sequence relays.

Anticipated Accomplishments - July:

The air conditioner/heater unit and the shock and vibration isolation system will be purchased.

The specification for the control cable will be completed and released for bid.

Procedures will be set up for wiring the systems according to applicable military specifications.

The radio interference problems will be reviewed, requirements defined, and specifications and procedures set up for the final system. These will be checked and included in the final test program for the ML-1.

E. AUXILIARIES

1. Facility Design (Task 51-510)

Summary - January through May:

The ML-1 facility design was completed and approved during the period. The Hayes-Henry Construction Co. (Idaho Falls, Idaho) was the successful bidder for the construction of the facility. A "Notice to Proceed" was issued 23 May, allowing 185 days to complete the contract. The facility should be ready for occupancy by 1 December.

Aerojet recommended the following changes in order to provide the facility with adequate equipment and accomodation so that the performance of the power plant can be fully evaluated:

1) An enclosed corridor between the control cab and the auxiliary control building.

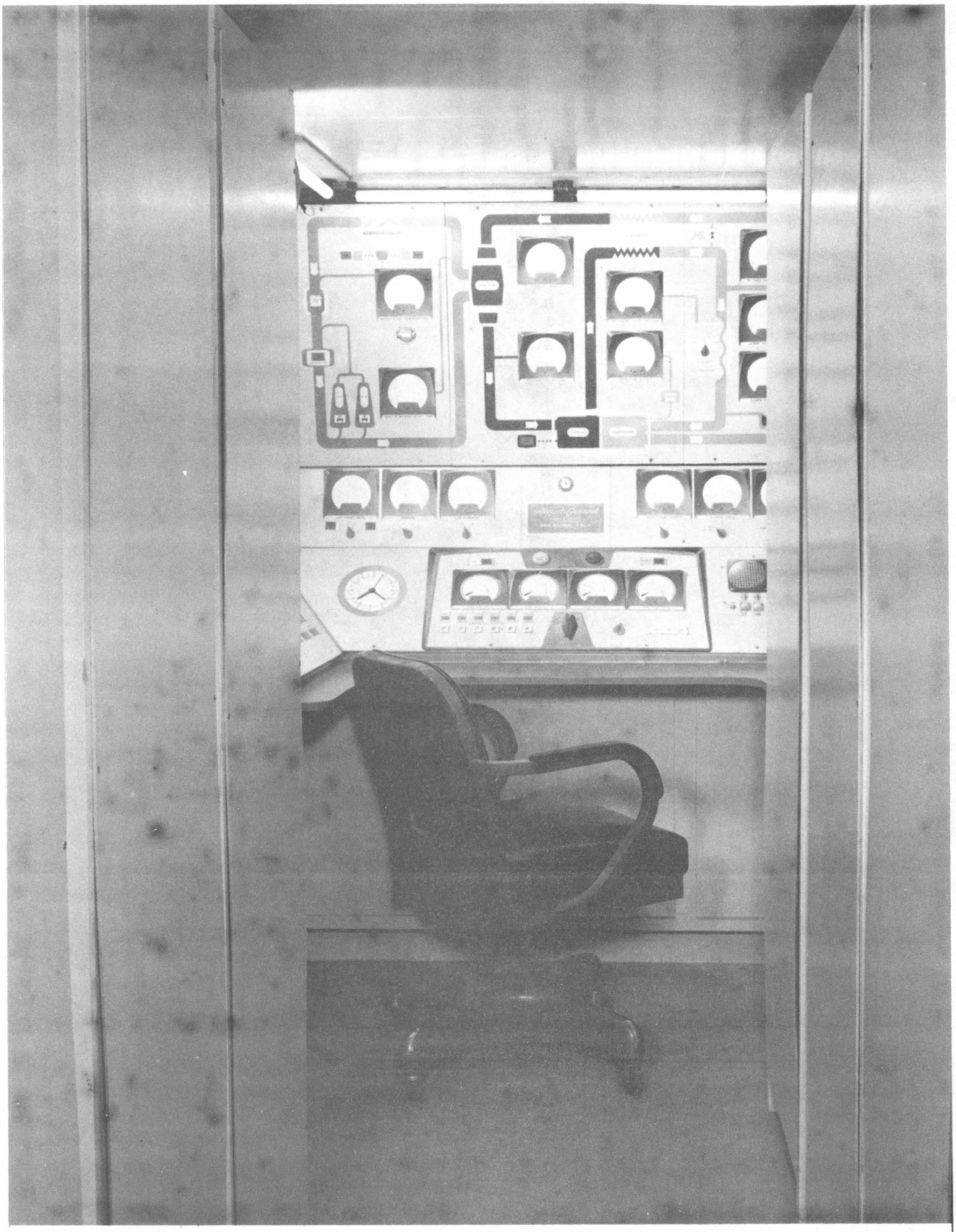
2) A low pressure storage system for the gas coolant.

3) A fission product sampling system.

4) A transducer calibration system.

5) Additional pole and cable installation.

6) Emergency pressurization for the auxiliary control building.



VIEW OF THE INTERIOR OF THE CONTROL CAB MOCK-UP

FIGURE 23

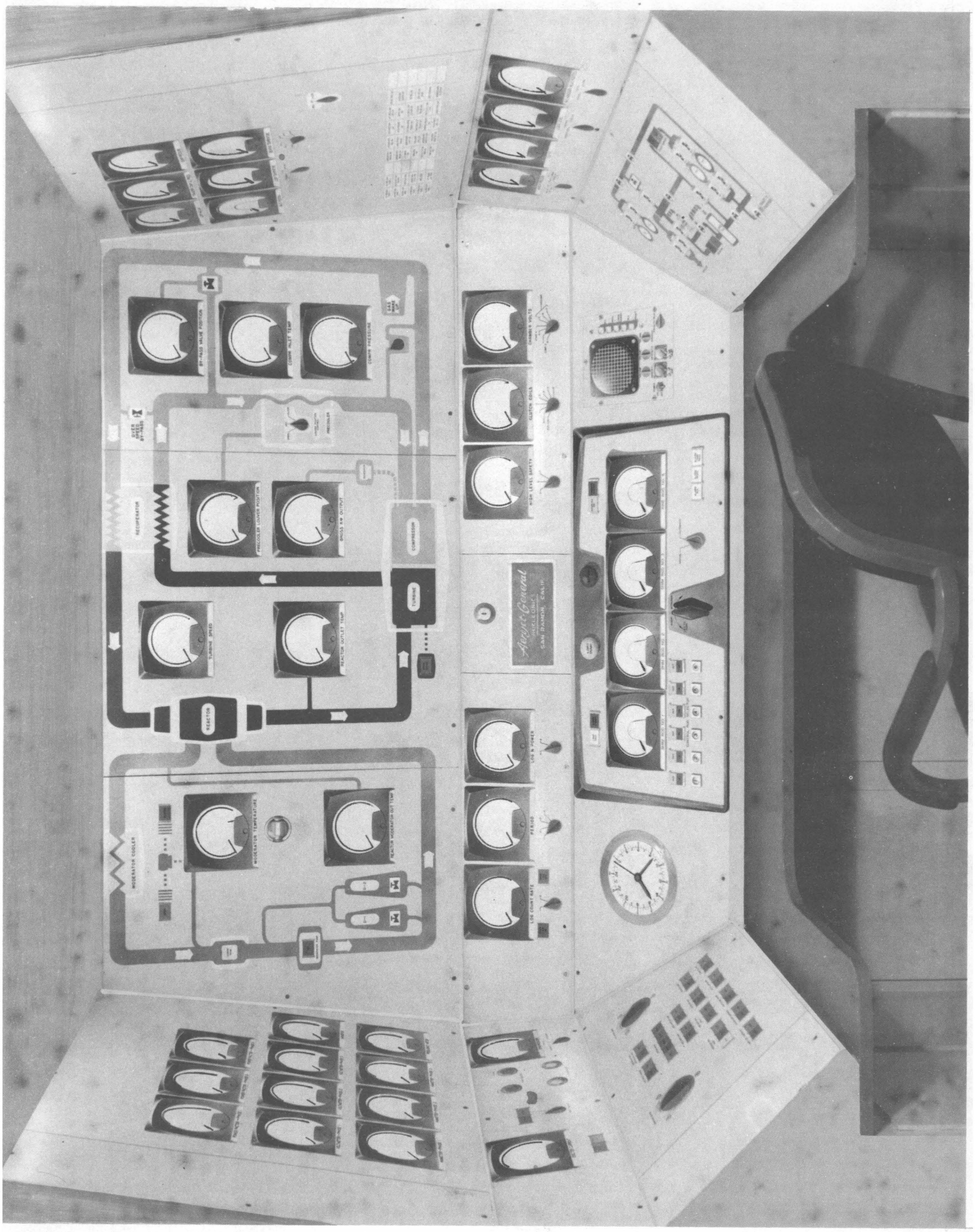

MODERATOR COOLER
REACTOR
TURBINE SPEED
RECUPERATOR
OVER SPEED BY-PASS
BY-PASS VALVE POSITION
MODERATOR TEMPERATURE
PRECOOLER LOUVER POSITION
COMPR INLET TEMP
REACTOR OUTLET TEMP
GROSS KW OUTPUT
PRECOOLER
COMPR PRESSURE
REACTOR MODERATOR OUT TEMP
GAS MAKE UP
TURBINE
COMPRESSOR
LOG COUNT RATE
PERIOD
LOG N POWER
Aerojet-General
SAN RAMON, CALIF.
HIGH LEVEL SAFETY
CLUTCH COILS
CHAMBER VOLTS

FIGURE 24

SCHEMATIC DIAGRAM FOR LOAD BANK
(625 KVA, 4160/2400 Volts, 50/60 Cycle)

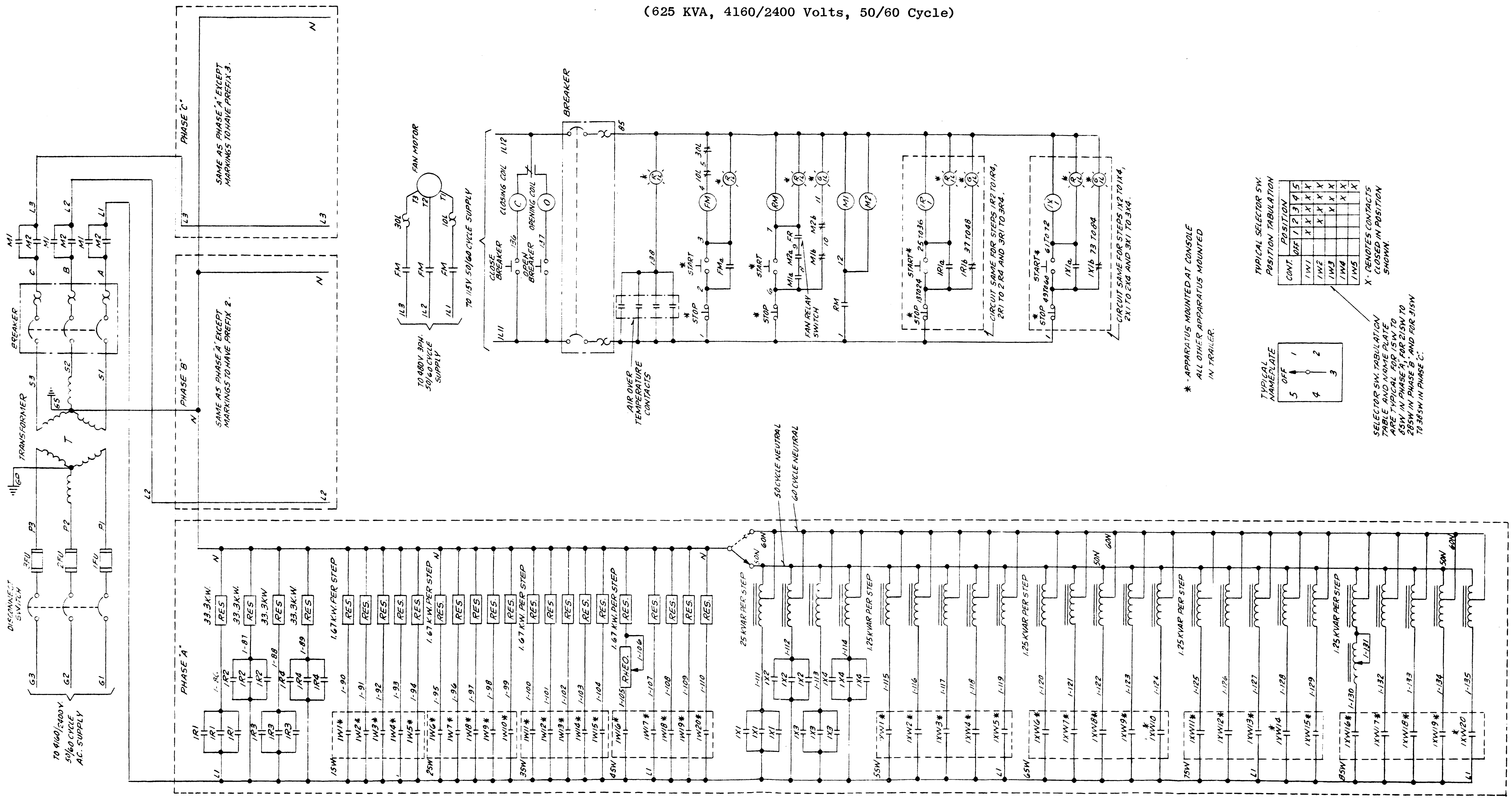


FIGURE 25

PORTABLE LOAD CENTER AND LOAD BANK

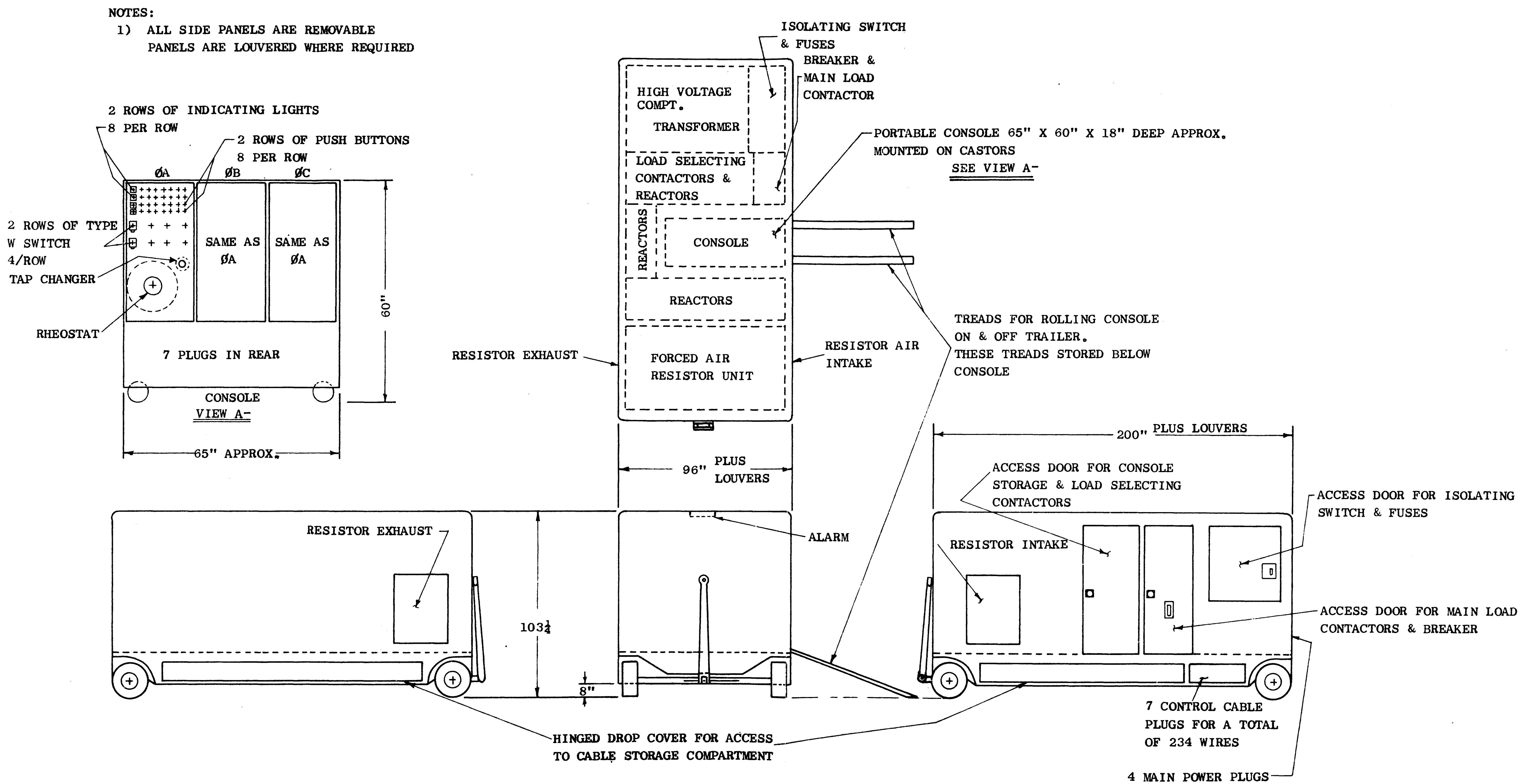


FIGURE 26

BLOCK DIAGRAM OF EQUIPMENT AND SYSTEMS IN THE CONTROL CAB

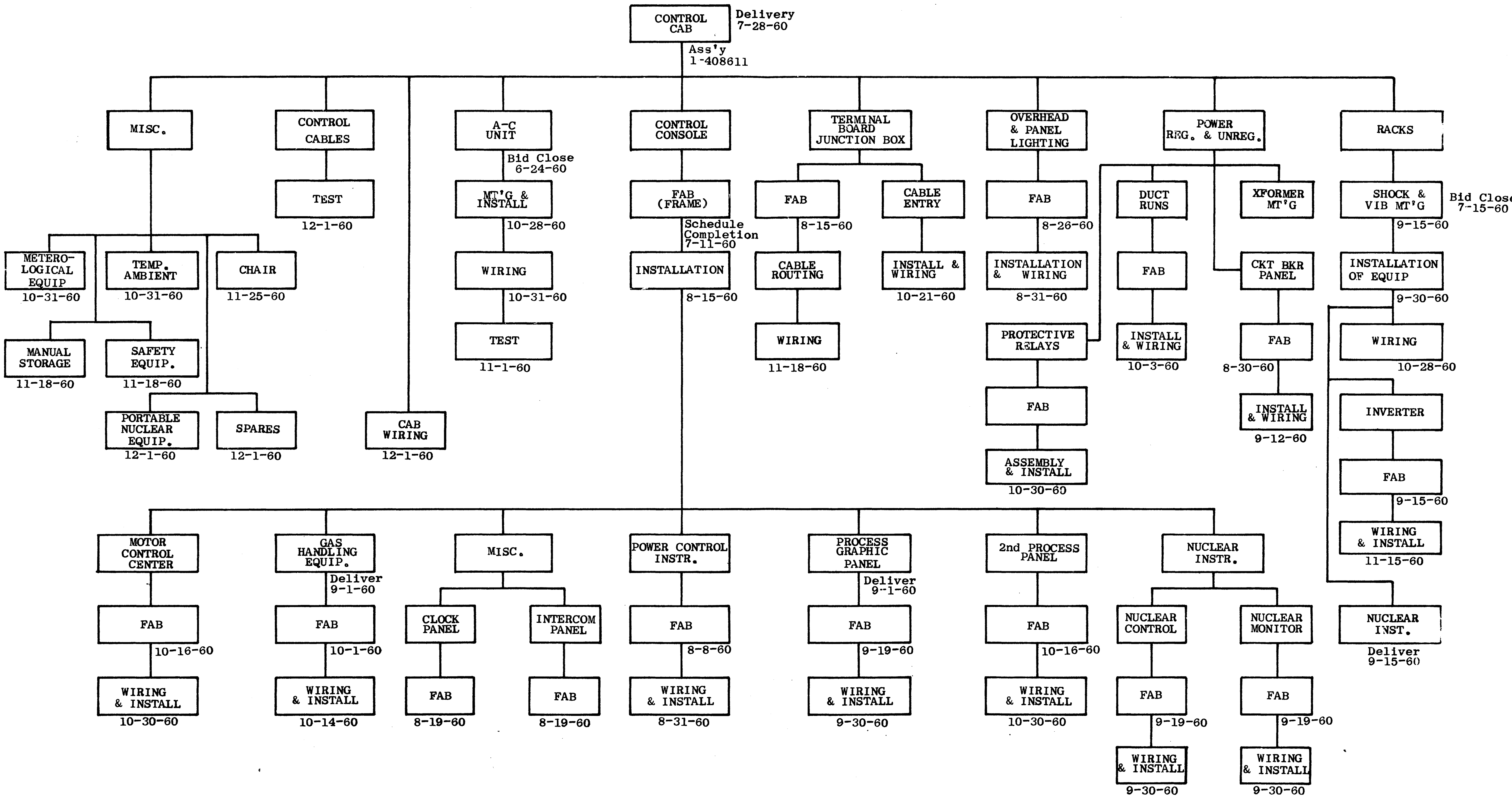


FIGURE 27

ML-1 CONTROL CAB ON M35 TRUCK

FIGURE 28

Accomplishments - June:

Construction of the facility was begun. The access road was graded from the GCRE-I facility, the water stand-pipe was installed at GCRE-I, the leaching pits were dug, the construction sites for the auxiliary control building and for the test building were graded, and installation was begun on the power and signal poles.

Layouts were made to show the location of facility furnishings and test equipment in the auxiliary control building and the test building.

Additional information was supplied on the proposed changes to the facility.

Anticipated Accomplishments - July:

Liaison will be continued at the construction site.

The "Schedule X" items will be shipped to the construction site on 3 July. The material originally was scheduled to be shipped 8 June, but it will not be needed on-site until 8 July.

Engineering support of equipment changes will be continued as requested by IDO.

The coordination and shipment of government-furnished equipment will be continued according to "Schedule X."

2. Shock Mounts (Task 51-520)

Summary - January through May:

Test data from the ML-1 railroad shock tests were analyzed and incorporated into IDO-28555, "ML-1 TRANSPORTABILITY STUDIES." Instrumentation was designed and assembled for component testing of the shock mounts.

Environmental tests were conducted on the present design to determine dynamic response. Test conditions were varied to provide elastomer temperatures of -65, -30, 0, 75 and 150°F.

The shock mount system was analyzed to determine composite shock reduction by the interaction of shock mounts and nylon tiedown systems. Data and conclusions from shock mount dynamic tests are reported in IDO-28555.

Elastomer weight and performance was optimized. A size evaluation test was completed to determine the change in characteristics of the rubber mount as the size is decreased. The outside diameter was decreased and the inside diameter held constant for one series. Both OD and ID were reduced proportionately in the second series. In the first series, a 20% decrease in OD produced a 12% increase in deflection. In the second series, a 39% proportional reduction in OD and ID also produced a 12% increase in deflection. The resonant frequency of the reference elastomer increases only an average of 9% over the predicted shock mount operating range. The weight of the reference elastomer is 25% less than the experimental mount.

Layout sketches of the present reference shock mount design were prepared (Figures 29 and 30). The reference design utilizes skid beams. The design based on a testing program, optimizes the size and weight of the shock mount system.

The two designs are compared in Table 8. The reference skid beam design represents a weight savings of approximately 220 lb in the shock mounts for the power conversion package.

The effect of radiation on the reference silicone elastomer (SE-565U) was evaluated. Data were obtained from HAPO, Richland, Wash. SE-500 series was the best of the silicone group tested and remained flexible after a radiation dose of 10^8R (equivalent of 20 years of full power ML-1 operation). Figure 31 shows that at the end of 5 yrs of full power operation, the hardness will have increased by approximately 10%; tensile strength decreased by 21%; and elongation decreased by 45%. The hardness increases to only 16% even if the operational radiation level was twice as great (1000 R/hr) as predicted. The elastomer safety factor (based upon tensile strength) is approximately 2 at the end of 5 years of reactor operations. The shock isolation properties of the mounts after 5 years of ML-1 operation at full power are shown in Figure 32. The operating curve remains under the maximum allowable transmitted shock throughout the entire environmental temperature range.

Accomplishments - June:

Fabrication specifications were completed for the shock mount assembly. Detail drawings were prepared and the assembly released for bid.

Final design work continues on the skid-beam assembly. The drawings are about 65% complete.

Anticipated Accomplishments - July:

The skid beam assembly design will be completed.

The fabrication contract will be let for shock mount assembly.

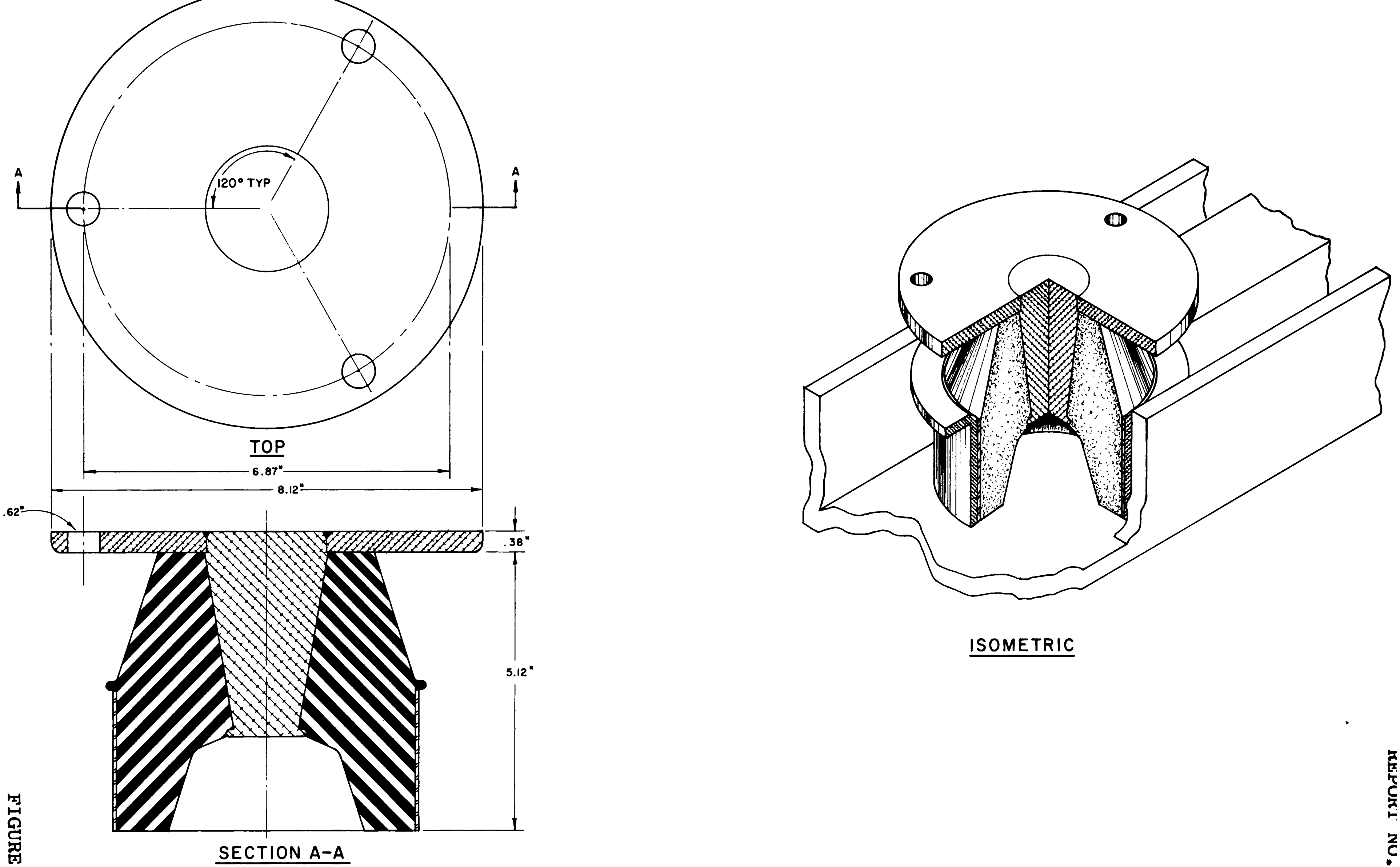


FIGURE 29

SHOCK MOUNT SKID BEAMS
FOR THE ML-1 SHOCK ISOLATION SYSTEM

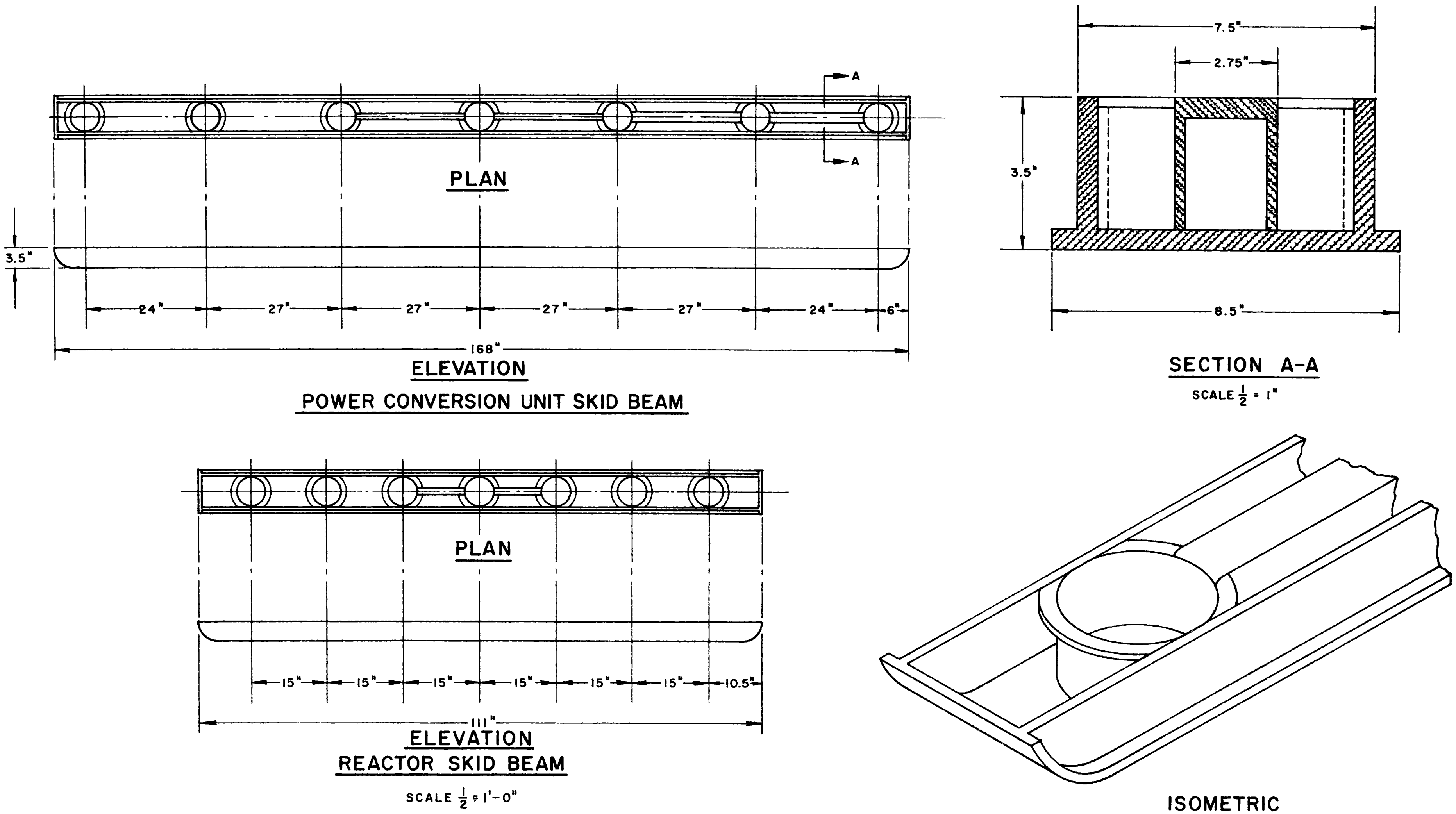


FIGURE 30

EFFECTS OF RADIATION ON SILICONE RUBBER
(GE SE565U)

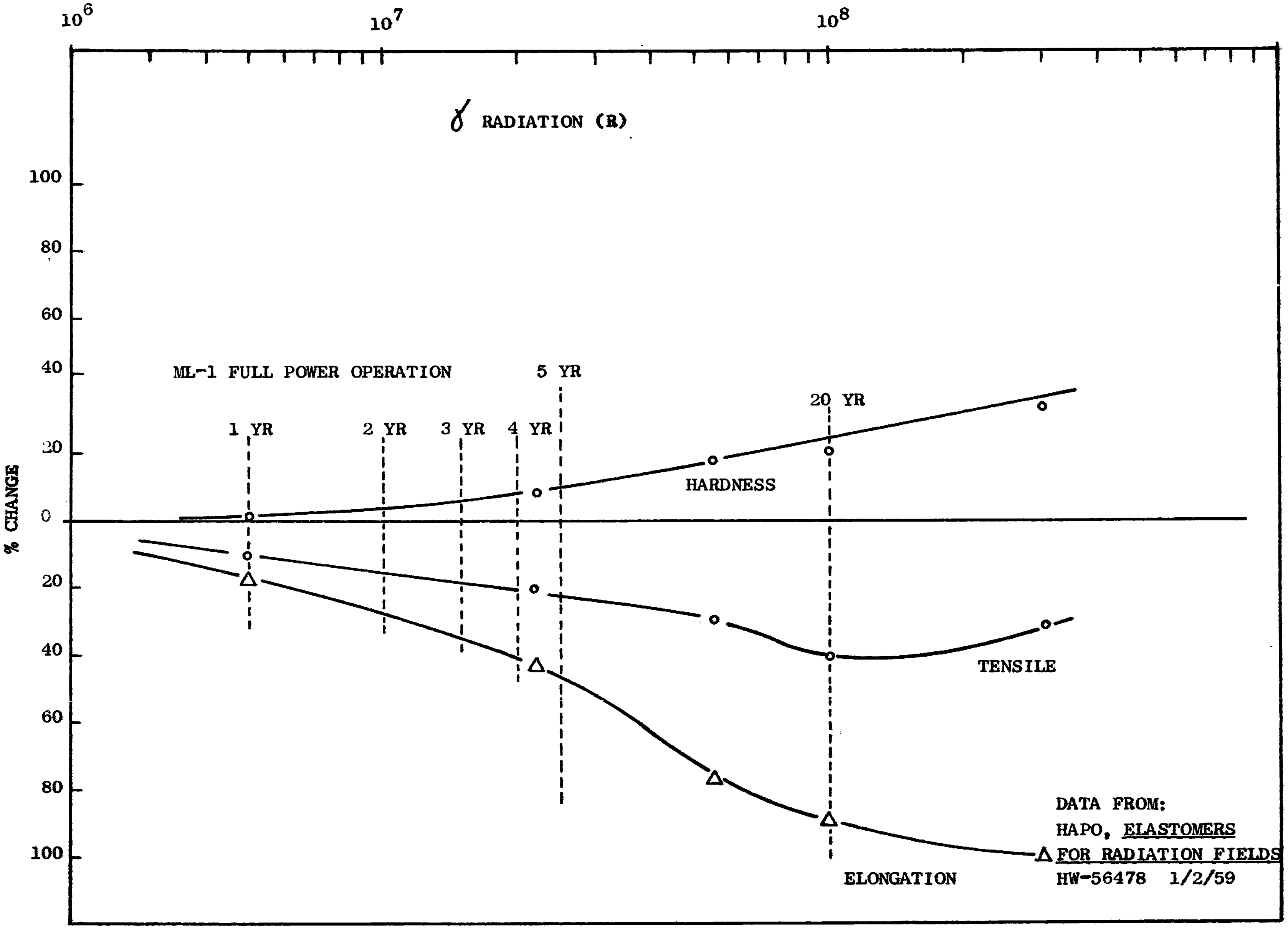
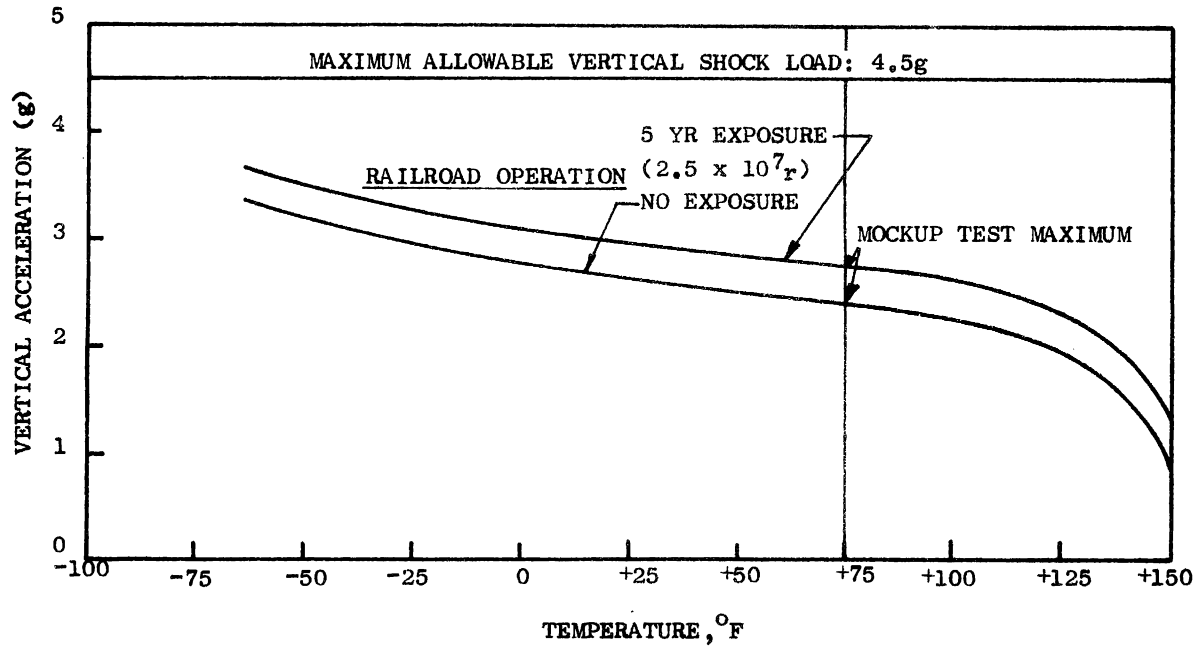


FIGURE 31

MAXIMUM VERTICAL SHOCK LOAD vs OPERATING TEMPERATURE RANGE
(FOR 5 YEAR RADIATION EXPOSURE FULL POWER ML-1 –
BASED ON MAXIMUM SHOCK FROM FULL-SCALE MOCKUP TESTING AT 75 °F)



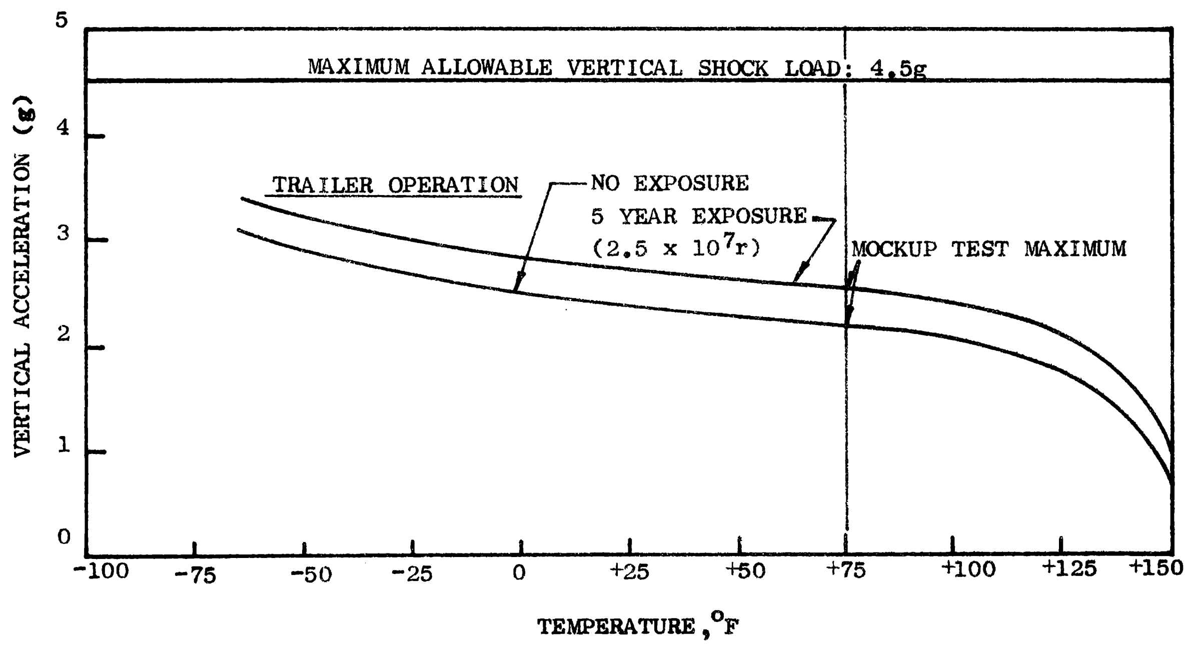


FIGURE 32

TABLE 8 TABULAR COMPARISON OF DESIGNS

PROPERTY	ITEM	INDIVIDUAL ARTICULATED SHOCK MOUNTS	SOLID SKID BEAMS (4 REQUIRED)
SIZE	Rubber Inserts	6.75 in O.D.	5.75 in O.D.
	Number / Pkg	14	14
	Total Required	28	28
	Bottom Plate Contact Size (Reactor)	10 in x 12 in	–
	Bottom Plate Contact Size (P-C Unit)	10 in x 17 in	–
	Bottom Plate Full Size (Reactor)	10 in x 15 in	–
	Bottom Plate Full Size (P-C Unit)	10 in x 20 in	–
	Skid Beam Contact Size (Reactor)	–	8.5 in x 105 in
	Skid Beam Contact Size (P-C Unit)	–	8.5 in x 162 in
	Skid Beam Full Size (Reactor)	–	8.5 in x 111 in
	Skid Beam Full Size (P-C Unit)	–	8.5 in x 168 in
	Height with 1G static load	5.38 in	5.38 in
	Link Lengths Reactor	2 in center to center 5 in overall	None
	Link Lengths P-C Unit	8 in center to center 11 in overall	

PROPERTY	ITEM		Individual Each (lbs)	Individual Quan.	Individual Total (lbs)	Skid Each (lbs)	Skid Quan.	Skid Total (lbs)
WEIGHT *	Rubber Inserts		5.63	28	157.4	4.16	28	116.6
	Top Cone		3.01	28	84.4	3.01	28	84.4
	Bottom Plate Assy.	Reactor	11.5	14	161.0	–	–	–
		P-C Unit	32.9	14	460.0	–	–	–
	Skid Beam	Reactor	–	–	–	99	2	198.0
		P-C Unit	–	–	–	156	2	312.0
	Links	Reactor	0.59	24	14.1	6.0	4(Vert)	24.0
		P-C Unit	1.61	24	38.7	6.0	4(Vert)	24.0
	Pins		0.26	64	16.8	–	–	–
	End Linkage		12.0	8	96.0	–	–	–
	Stainless Steel hoops		–	–	–	1.58	28	44.2
	Nuts & bolts		–	100	10.4	–	100	10.4
	Total Weight		Reactor		360	Reactor		355
			Pwr Conversion		682	Pwr Conversion		465

PROPERTY	Package	Aircraft	Aircraft Allowable Bearing Loads	Individual: Actual Dead Weight Bearing Load	Individual: Factor of Safety	Skid: Actual Dead Weight Bearing Load	Skid: Factor of Safety
BEARING LOADS ON AIRCRAFT FLOOR **	Reactor	C-124	16.6 psi	9.6 psi	1.7	10.8 psi	1.5
		C-130	20 psi	9.6 psi	2.1	10.8 psi	1.8
		C-133	50 psi	9.6 psi	5.2	10.8 psi	4.6
	P-C Unit	C-124	†10 psi	7.3 psi	1.4	7.2 psi	1.4
		C-130	†7.5 psi	7.3 psi	1.02	7.2 psi	1.04
		C-133	50 psi	7.3 psi	6.9	7.2 psi	6.9

* Weight tabulated for shock mount assembly only -- no tie-downs included.
** All bearing loads based on 2" shoring on aircraft floor with a 45° increase of bearing area through the wood.
† Off treadway allowable bearing loads.

3. Field Applications (Task 51-530)

Summary - January through May:

Dynamic drop tests were performed on nylon rope at various environmental temperatures, completing the evaluation of its use in the shock isolation and tiedown system. Seventy-seven tests were performed through a temperature range from -65 to 150°F. Analysis indicated that the nylon rope had adequate shock absorption over the specified range, and the rope was in good physical condition after repeated low temperature shock runs.

Lowering the temperature of the rope from 70 to -65°F lowered pretension from 1000 to 600 lb. This shows that adequate tension will remain in the rope if an aircraft is loaded in a temperate climate and flown to the Arctic.

A complete discussion of nylon testing will be found in the Transportability Studies, ML-1 Nuclear Power Plant, (IDO 28555) April 1960. This report discusses the testing programs undertaken to determine the transportability of the ML-1. The report covers trailer transport, aircraft loading tests, railroad shock testing, and component environmental tests. Detailed appendixes show original data, such as tapes and charts made by various recording instruments, illustrations, time studies for loading operations, and conclusions.

A 16 mm color motion picture was made of the railroad shock tests.

An analysis was made of aircraft emergency landing shock with data obtained in the railroad and dynamic shock tests. The analysis considered an emergency landing speed of 100 mph and included the effects of friction. Accelerations were plotted as a function of time after impact. It is concluded that twelve 5-ft lengths of nylon rope will reduce an emergency landing shock to less than 5 g at rope temperatures down to 0°F. This arrangement is satisfactory since the cargo compartments of all transport aircraft are heated.

A preliminary design criteria was completed for the environmental shelter. The recommended shelter consists of lightweight sandwich-panel construction supported by aluminum frames. The analysis included heat loss calculations, definition of heater types, and recommendations for winterization.

A seminar sponsored by the U. S. Army Snow, Ice, Permafrost Research Establishment (SIPRE) was attended in April. The purpose of this seminar was to acquaint ANPP prime contractors of SIPRE activities and to brief SIPRE people on ANPP projects. The environmental report was reviewed by SIPRE personnel.

A personnel radiation dosage study was performed. The study covered the following subjects:

1) A review of representative transport cycles of ML-1 reactor.

2) Estimates of cumulative personnel radiation dosages for each transport cycle.

3) Loading and handling procedures to insure minimum personnel exposure.

4) Choice of most expedient transport scheme for certain sets of tactical circumstances.

5) Number, organization and deployment of personnel involved in transport cycle.

Five basic transport cycles were shown to be practical for expedient movement of an activated reactor. (An activated reactor is defined as one 24 hr after shutdown with fuel elements and moderator water in place after full power operation for 10,000 hr.) Specific procedures for transport were outlined.

A rough draft of a formal evaluation of the tiedown and the horizontal shock isolation system was prepared. Detailed discussion of the shock isolation properties of the tiedown system, its advantages, and test data were included in the evaluation.

Design and stress analysis were completed for the following hardware:

1) A spreader bar lifting assembly for crane-lifting ML-1 packages.

2) A nylon rope pre-tension device, two of which are to be included as tiedown hardware for each of the two main packages. These devices will replace the 26 turnbuckles per package specified earlier. The devices will rapidly stretch the nylon rope to 2500 pounds before it is inserted into the tiedown system. The nylon element will approach and then maintain a pre-tension of 1000 to 500 lb. The device is normally operated by two men. It is equipped with a spring-type load indicator/safety overload feature.

Accomplishments - June:

Detail drawings of the loading hardware were started and are about 25% complete.

A rough draft was completed for a study of removing the decay heat from the reactor during transport. Power availability on the transport media, maximum non-stop flight times, aircraft pressurization and cargo temperatures were summarized, and various methods of cooling were discussed.

A layout design was completed for a mating device to expedite coupling the reactor package to the power conversion package. The mating pin will align the packages to within 0.06-in. each time they are coupled. The alignment pins also will correct for about ½-in. of package misalignment.

Anticipated Accomplishments - July:

Detail drawings will be completed for the spreader bar and the pretensioning device.

A dosage study report and a tiedown evaluation report will be published.

Design of lightweight high-strength shackles will be initiated.

4. Systems Integration and Liaison (Task 51-200)

Summary - January through May:

A piping and instrument (P and I) diagram was completed for the primary, or normally operating, process systems. This diagram illustrates the process equipment on the reactor and power conversion skids and includes the primary gas system, the lubrication system, and the moderator and shield water system (Figure 33).

A second piping and instrument diagram was prepared for all of the process systems on the auxiliary skids, including the gas storage skid, the gas make-up skid, the make-up water treatment skid, and the reactor drying skid (Figure 34).

The primary system diagram shows the lubrication requirements for the Stratos t-c set. An overlay was prepared, showing the Clark t-c set requirements.

Supplementary process design data has been prepared in conjunction with the P and I diagrams. This includes operational and analysis instrument lists, mechanical equipment list, valve list, pipe line list, and outline piping specification. These lists contain the basic process requirements for each item and refer to specification and purchase order numbers.

Accomplishments - June:

P and I diagrams were completed for the primary and the auxiliary systems and approved. The supplementary lists were completed in a preliminary form.

Anticipated Accomplishments - July:

The P and I diagram for the Clark t-c set will be completed and approved. The supplementary process data lists will be released for review in a preliminary form.

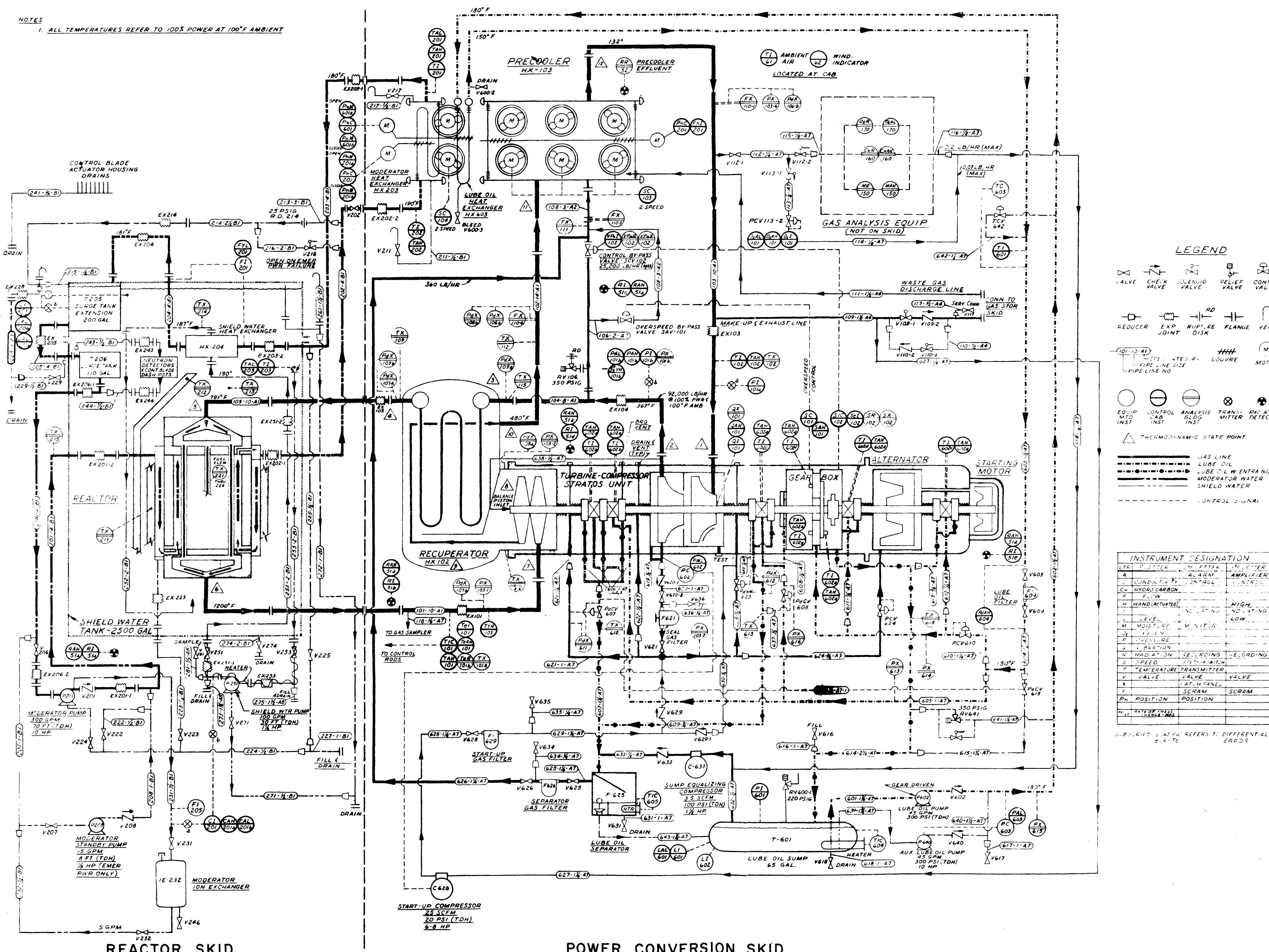
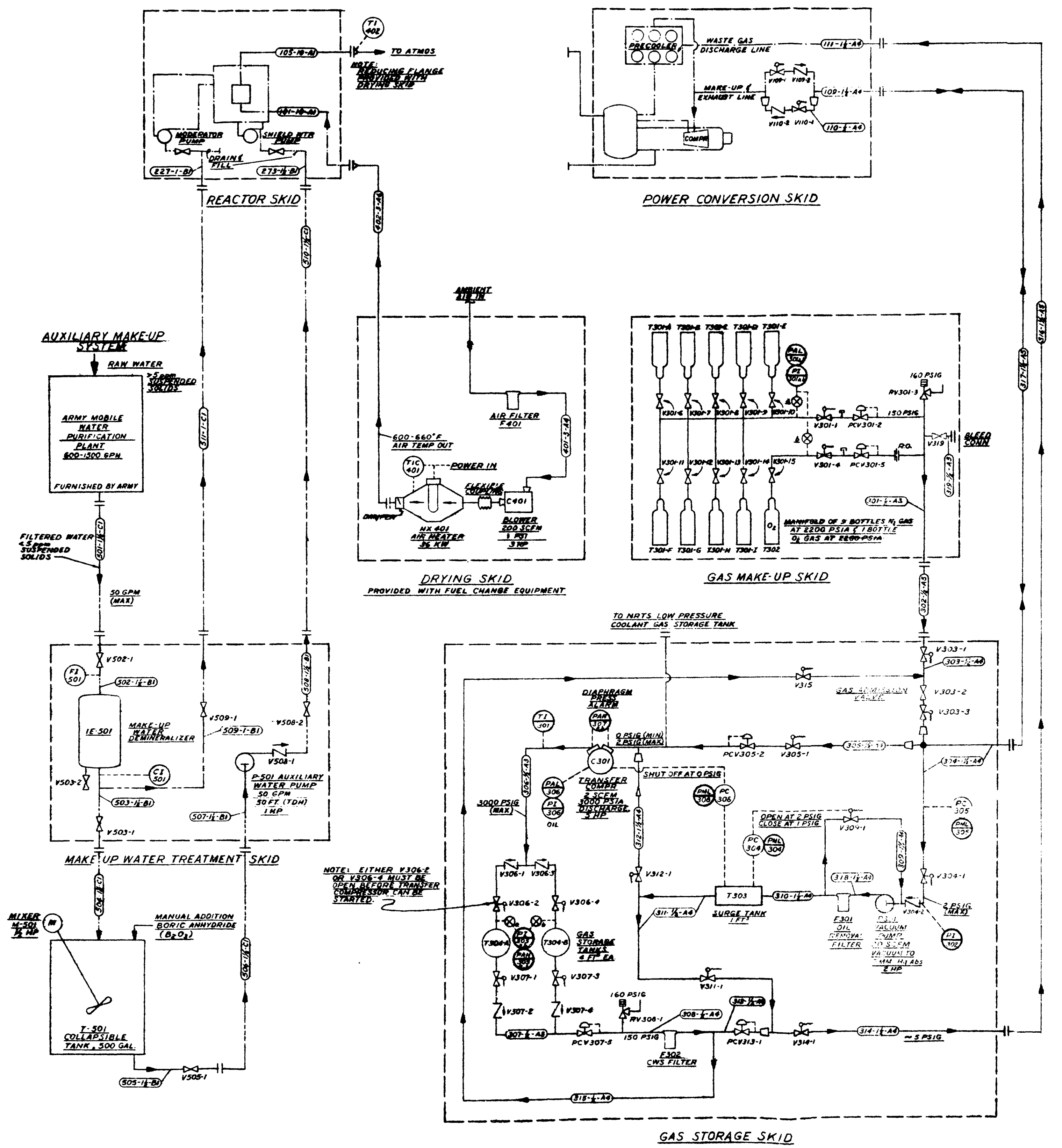
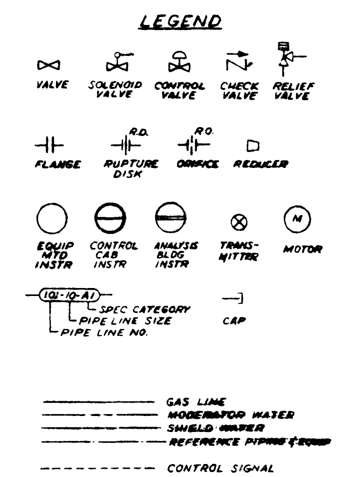

NOTES
1. ALL TEMPERATURES REFER TO 100% POWER AT 100°F AMBIENT
PRECOOLER
HX-103
MODERATOR HEAT EXCHANGER HX 203
LUBE OIL HEAT EXCHANGER HX 403
CONTROL BLADE ACTUATOR HOUSING DRAINS
SHIELD WATER HEAT EXCHANGER
REACTOR
SHIELD WATER TANK-2500 GAL
RECUPERATOR
HX 102
TURBINE-COMPRESSOR STRATOS UNIT
GEAR BOX
ALTERNATOR
STARTING MOTOR
GAS ANALYSIS EQUIP
(NOT ON SKID)
WASTE GAS DISCHARGE LINE
MAKE-UP & EXHAUST LINE
OVERSPEED BY-PASS VALVE SAV-101
CONTROL BY-PASS VALVE
LOCATED AT CAB
MODERATOR PUMP
MODERATOR STANDBY PUMP
MODERATOR ION EXCHANGER
SHIELD WTR PUMP
START-UP GAS FILTER
SEPARATOR GAS FILTER
LUBE OIL SEPARATOR
SUMP EQUALIZING COMPRESSOR
LUBE OIL SUMP 65 GAL.
START-UP COMPRESSOR
25 SCFM
20 PSI (TDH)
6-8 HP
LEGEND
INSTRUMENT DESIGNATION
REACTOR SKID
POWER CONVERSION SKID

FIGURE 33

PIPING AND INSTRUMENT DIAGRAM FOR THE PROCESS SYSTEMS ON THE AUXILIARY SKIDS, ML-1





INSTRUMENT DESIGNATION			
LTR	1ST LETTER	2ND LETTER	3RD LETTER
A		ALARM	AMPLIFIER
C	CONDUCTIVITY	CONTROL	CONTROL
CH	HYDROCARBON		
F	FLOW		
H	HAND(ACTUATED)		HIGH
I		INDICATING	INDICATING
L	LEVEL		LOW
M	MOISTURE	MONITOR	
O_2	OXYGEN		
P	PRESSURE		
Pn	POSITION	POSITION	
R	RADIATION	RECORDING	RECORDING
S	SPEED	SAFETY or SWITCH	SWITCH
T	TEMPERATURE		
V	VALVE	VALVE	VALVE
X		PATCH PANEL	
Y		SCRAM	SCRAM

FIGURE 34

5. Fluids Processing (Task 55-400)

Summary - January through May:

The engineering specification was prepared for the ML-1 moderator water de-mineralizer, and bids were evaluated. The component will be procured by Task 58-300, Reactor Auxiliaries.

· Detail design was initiated on the gas storage system and gas make-up systems. The final design will be completed when equipment drawings are received from the vendors. The gas transfer compressor and vacuum pump were ordered. Engineering specifications were issued for the high pressure storage spheres, solenoid valves, and gas admission control valve.

The U. S. Army Corps of Engineers was requested to supply drawings and military specification on pumps and collapsible tanks for use in the make-up water system.

Methods of boron analysis in the field were developed in the laboratory. These techniques will be used to ensure that the quantity of boron in the anhydrous boric acid will satisfy safety and shielding requirements.

A hot air drying test was performed with a prototype fuel element soaked for 24 hr in water to saturate the insulation. The test element was dried completely in two hours by a flow of 600^{o}F air at the rate of 16 lb/hr through the element. These conditions simulated the average temperature and flow conditions to which the ML-1 fuel elements will be exposed during reactor drying periods after flooding the core.

Detail design was started on the reactor drying equipment and completed except for final checking of dimensions. Procurement was initiated on longer lead items such as the blower, the temperature controller and the heat elements. The equipment will be able to deliver about 1000 lb/hr at 600^{o}F, and will be mounted as an integral assembly on a skid base.

The detail design of the ML-1 cable storage skid was initiated and completed during the period, and procurement initiated. The cable storage skid will store four 550-ft lengths of power and control cable during transport. The cable reel is motor-operated.

Accomplishments - June:

Design of the gas make-up and storage systems continued. The vendor drawing of the gas transfer compressor was reviewed and comments forwarded to the vendor. The bids for solenoid valves were evaluated. A manually-positioned needle valve was substituted for the remotely operated, variable orifice gas admission valve.

Final checking of the dimensions of the reactor drying equipment design was completed and the drawings released for fabrication. Procurement of material continued.

Procurement of material for the cable reel skid continued. The lower skid base was fabricated.

A specification was prepared for the make-up water de-mineralizer. Advance quotations were requested covering the 500-gallon collapsible tank.

Anticipated Accomplishments - July:

Design of the gas handling system will continue, and information from the vendors will be incorporated when received. A purchase order will be issued for the solenoid valves.

Major components of reactor drying equipment will be procured and fabrication completed on the skid base, heater chamber, and electrical panel.

Procurement of materials for the cable reel storage skid will be completed. The cable reel spools and support assemblies will be fabricated.

A purchase specification will be issued for the make-up water demineralizer. Development of the equipment needed for the boron test kit will be initiated.

6. Environmental Testing and Support Equipment (Task 51-550)

A draft of environmental testing procedures for the ML-1 was prepared during January and issued for comment. The draft defined the procedures for shock and vibration tests, environmental tests, and thermal shock tests. It also summarizes the facilities and test equipment needed at San Ramon for these tests.

Work on this task was halted in February when the responsibility for performing environmental tests was given to the tasks responsible for procuring the equipment.

7. Mechanical Power Conversion Equipment (Task 55-800)

Summary - January through May:

a. Arrangement of the Power Conversion Skid: The feasibility of decreasing the width of the power conversion skid to provide better access during shipment on the C-130 aircraft was studied in January. The study showed that the narrower skid would involve a re-design of the pre-cooler and recuperator which would limit performance. The re-design also would seriously delay fabrication of these components. It was decided to retain the original width (113-in.).

The overall length of the power conversion skid was increased from

162 to 168-in. The additional length provides for optimum arrangement of piping between the recuperator and the reactor, and additional space for the t-c set lubrication system. The combined reactor and the power conversion package dimensions are still compatible with the use of a "Hyster" trailer.

The arrangement drawing of the power conversion skid was brought up to date in February to show the latest equipment dimensions, the change to an eight-fan pre-cooler and the final recuperator dimensions 49-in. in diameter by 81-in. long (including insulation). The changes in dimension were the result of optimization for effectiveness and pressure drop. A study was initiated to determine the feasibility of combining the pre-cooler, moderator cooler and the oil cooler in one unit.

A six-point support system was firmly established in April for the t-c set alternator and recuperator. The recuperator is rigidly mounted to the skid floor structure by four legs which are symmetrical about the vertical centerline of the rotating equipment. The alternator is mounted on sliding feet to accommodate thermal expansion.

Alternate methods of supporting the recuperator were reviewed in May in an attempt to reduce the maximum moments at the turbine discharge/recuperator inlet flange. The most practical system uses a trunnion at each end of the recuperator. This system would reduce the moment at the turbine discharge/recuperator inlet flange by 50%, but would transfer an excessive load to the pre-cooler inlet flange. However, a study indicated that the anticipated maximum moment at the t-c set flange would be about 40% less than previously estimated, due to the flexibility of the recuperator shell. Consequently, the study of alternate mounting systems was discontinued.

The 1/8 scale model of the power conversion assembly is being used to establish assembly procedures for installing and assembling the power conversion components in the available space.

b. Skid Structure: Aluminum was selected in January as the best material for the structure of the power conversion skid. The main advantages of aluminum are high resistance to shock and corrosion, high ratio of weight to strength; ready availability, and ease of fabrication. Design of the weld areas was based on the allowable stress for 6061-T6 aluminum. A study showed it was not feasible to use the structural floor members for lubricating oil sumps due to the pressures and temperatures involved.

The structure of the skid floor was analyzed to determine the maximum moments imparted to the recuperator shell. The moment, based on an infinitely stiff recuperator shell, was calculated to be 500,000 in.-lb applied to the turbine discharge flange or the supports opposite the flange. The study showed that the longitudinal forces from transportation shocks and operating conditions should be transferred to the skid structure at the reactor side of the recuperator. A relatively simple six-point support system (four on the recuperator and two on the alternator shell) was selected.

The analysis of the basic structure of the power-conversion skid was essentially completed in April. Stress diagrams were prepared for the truss in all critical conditions, and sizes were determined for the truss member, the floor members and the sheet thicknesses. Layout, assembly and detail drawings were initiated for the skid structure.

The deflection of the skid structure under the most severe load conditions and the resulting deflections and loads in the t-c set, recuperator, and pre-cooler were studied in May. The results showed that the most critical transportation conditions for the turbine discharge/recuperator inlet flange occur under a combined load of 4.5 g upward and 5 g aft. However, the flange is designed to withstand higher combined loads. The deflection of the power conversion skid is about 0.75-in. from the highest to the lowest corner when the reactor and the power conversion skids are connected and supported at opposite corners. This condition is not critical since it primarily results in a change of attitude of the t-c set and the recuperator rather than the imposition of stress on the components. However, the minimum wall thickness of the 3-in. tubular truss members was increased to 0.187-in. (from 0.125-in.) to reduce skid deflections.

The tie rods and tubular chords in the upper plane of the skid structure were incorporated into the pre-cooler structure in May. This design change improved accessibility and eliminated interference between the pre-cooler duct inlet and structural members.

c. Main Piping: The heat exchanger manufacturer established in January that at least a 14-in. pipe between the recuperator and the pre-cooler was required to minimize pressure drop. The increase in size made it necessary to eliminate the expansion joint in the line and to mount the pre-cooler on springs. It was decided that the manufacturer of the heat exchanger would supply the interconnecting pipe, and that the piping between the compressor and the recuperator would be included as part of the t-c set.

A proposed layout of the piping between the pre-cooler and the recuperator, and between the pre-cooler and the compressor was received from the vendor in March. The layout was reviewed and alternate routings were suggested to the vendor.

The design of insulation for the turbine inlet and compressor discharge ducts was influenced by the requirement for reflective multi-layer internal insulation in the piping for the reactor. The insulation originally selected was predicted on the need to flood the reactor with water during fuel element changes. Preliminary information showed that a metal-encased blanket-type insulation was superior to the reflective type, particularly since a period of operation might reduce the reflective properties.

The designs of the pressure-balanced expansion joints were reviewed. These expansion joints will be used in the main piping to minimize the loads on the piping and other components. Two types were considered, an elbow joint and an expansion joint. Calculations were initiated to determine the amount the bellows would move as the result of thermal expansion.

The routing and design of the recuperator to pre-cooler piping was established in April. The pipe will incorporate two vaned, mitered elbows.

The routing of piping between the pre-cooler and the compressor was simplified by incorporating a compact expansion joint assembly.

Specification control drawings were initiated in May for the expansion joint. Evaluation of the internal insulation materials for the turbine inlet and reactor inlet line continued.

d. Pipe Joints, Flanges and Gaskets: A reference flange design was selected in April as a result of testing a number of designs. This reference design uses Flexitallic gasket and bolted flanges. Each flange was specially designed to use minimum diameter and weight to meet the operating conditions. These flange joints are bulkier than the previous design without any increase in weight. As a result, adequate assembly space will be provided for either design.

A joint made up of standard 300-lb flanges with a Flexitallic gasket (0.125-by 0.75-in.) passed leak tests while being subjected to combinations of pressure and bending moment.

A standard flat-face flange joint was adopted as the reference design during May in place of the tongue and groove type previously specified for the recuperator discharge/reactor inlet and the recuperator discharge/pre-cooler inlet connections. The new reference flange has one face recessed to contain the gasket seal. The design facilitates the removal of the recuperator by eliminating the need to remove the main piping. Wherever possible the dimensions of the flange gasket groove were standardized.

e. By-pass System: The preliminary piping layout was drawn for the control by-pass piping and related equipment. This layout is being modified as firm dimensions of components are received.

Preliminary proposals were received in April for the relief valve, were reviewed, and the preparation of a revised procurement specification was initiated.

f. Instrumentation:

A study of the requirements of the proposed instrumentation was initiated in March. The study included the preparation of an installation skid.

A preliminary design was prepared of the connections for the thermocouple and pressure transducers. These connections will be brazed to the component housings of the main piping, and will provide a leak-proof seal that can be replaced without affecting either the piping or the componenets.

g. Skid Model: A new 1/8 scale wooden model of the power conversion skid was completed. It incorporates all of the latest changes.

The full-scale model of the power conversion skid was revised and is being kept current with the latest decisions.

Accomplishments - June:

a. Skid Structure and Mounting of Main Components: The skid structure layout was revised to incorporate the new shock isolation system and provide attachment points for the linkage needed to transfer longitudinal loads from the skid to the elastomer beam.

b. Main Piping: The maximum differential expansion of any joint was found to be less than 0.30-in. in calculating the expansion joint movements due to thermal expansion. Calculations are being made to determine the movement of joints during transportation due to the flexibility of the assembly. Specification control drawings are being prepared for the expansion joints.

The design of the turbine inlet screen is being studied. This screen will prevent entry of any large corrosion product particles into the turbine. Such a screen is being considered for temporary use at the compressor inlet to collect debris after assembly or overhaul.

Evaluation of piping insulation continues because complete information on alternatives was not available.

c. Pipe Joints, Flanges and Gaskets: A 10-in. Marman Conoseal joint (with gaskets 0.060-in. thick) met all leakage requirements during tests wherein it was subjected to the complete series of combined pressure and bending moments during temperature cycling from ambient to 900^{o}F.

The Flexitallic gasket joint (with standard 300-lb flanges) passed four thermal-cycling tests. Six more tests will be made.

Gaskets were ordered and fabrication initiated on a lightweight Flexitallic gasket joint such as will be used at the compressor inlet connection. The completed joint will be tested.

d. By-pass System: Work continued on the layout drawing of the components and the piping of the by-pass system.

The procurement specification for the relief valve is being revised due to changes in the gas make-up system.

The particulate filter will be eliminated from the by-pass system because an equivalent filter is provided in the t-c seal gas system.

e. Instrumentation: The study of the instrumentation requirements and the installation drawing were broadened to include the turbine discharge temperature and pressure probes. Special probes and bosses are being designed because of the configuration of the connection between the turbine exhaust and the recuperator.

Work was begun on a layout of the process instrumentation.

f. Component Arrangement: Work continued on the study to establish assembly procedures for the power conversion components.

g. Scale Model: Fabrication continued on the full scale model. Models are complete for the Clark t-c set, alternator, recuperator, pre-cooler, compressor inlet and outlet ducts, recuperator/pre-cooler duct, and lubrication oil sump. The pre-cooler structure mock-up is being made.

h. Materials and Lubricants: Materials for use in the expected radiation field were studied. The materials include construction materials, elastomers and lubricants.

Anticipated Accomplishments - July:

The skid frame assembly drawings will be completed and released for fabrication.

Work will continue on the main piping drawings.

Proposal requests will be sent to manufacturers of expansion joints.

The procurement specification for the by-pass relief valve will be completed and quotations will be requested.

Work will continue on the study of the turbine inlet screen.

Work will be initiated on a study of a temporary screen for the compressor inlet.

The full-scale models of the main loop components and piping will be completed and work will start on the models of the by-pass and lubrication system.

Evaluation will be completed on the piping insulation. The type of insulation will be selected, and work initiated on the layout of the design.

Thermal-cycling tests will continue on the Flexitallic gasket joint.

Testing will start on the lightweight Flexitallic gasket joint.

F. THE ML-1A

Summary - January through May:

The ML-1A program was planned in this period as it will be executed during fiscal years 1961 and 1962. The goal of this program is to produce a set of drawings, specifications and operating and maintenance instructions for use in a bid package. These items are to be completed by 31 May 1962.

Searches were made of applicable government specifications and regulations for each of the three parts of the program: drawings, specifications and manuals. Proposed work scopes were drafted as a basis for orientation meetings with specialists in the U. S. Army Corps of Engineers.

Detailed lists were prepared to show the items to be delivered to the customer, including assemblies and sub-assemblies for which there will be both drawings and specifications; and chapter and sections headings for the manuals and the hazards summary report.

Accomplishments - June:

The scope of work for the ML-1A project was established as follows:

1) Prepare operating and maintenance manual drafts in the form of an ML-1 "maintenance package" according to AR 750-6. The end product of this effort will be a preliminary draft of operators' and organizational maintenance manuals in accordance with the format set forth for Department of Army -10 and -20 Technical Manuals. Insofar as possible, the procedures set forth in the maintenance package will be "job tested" at the ML-1 operating site.

2) Prepare the ML-1A summary hazards report in accordance with Army standards governing hazards reports for military field reactor plants.

3) Prepare the ML-1A specifications, including general and detailed specifications for the commodities and processes necessary to produce the ML-1A power plant. Specifications will also include complete materials lists, parts, sub-assembly and assembly lists, and a detailing of services and fabrication methods involved. Specifications will be prepared in accordance with Standardization Manual M-205, Military Outline of Forms and Instructions for Preparation of Specifications.

4) Prior to drawing publication, the ML-1 design will be reviewed in the light of operating experience with the ML-1. Similarly, the materials used in the ML-1 system, the assembly tooling employed during fabrication, and the tolerance and surface finish requirements will be reviewed in the light of operating experience and fabrication history.

The final draft of the plan recommended for the ML-1A program was completed.

Anticipated Accomplishments - July:

The ML-1A program plan will be published.

Implementation of the ML-1A work scope will be begun.

IV. FUEL ELEMENT DEVELOPMENT

A. SUMMARY

1. Major Events:

a. January through May: Drawings for the IB-2L were released in January and core fabrication initiated. The loading of this element was revised in May as a result of the critical experiment to equalize surface temperatures by increasing the loading in the outer pins and eliminating the fuel in the central pin.

A preliminary design study indicated that the seven-pin fuel element does not significantly improve performance over that obtainable with the 19-pin design. A modification of the IB-2L 19-pin system has greater promise.

A corrosion test specimen of Hastelloy X exposed for 5000 hr in air at 1750°F showed 0.0016-in. penetration. This compares with 0.0015-in. penetration in reference gas (99.5 vol% N_2 + 0.5 vol% O_2).

BeO-UO_2 capsule irradiation was completed with about 2 atom % U-235 burn-up at maximum surface temperature of 1740°F. No significant changes in density, dimensions or appearance were noted.

The IB-2T-2 irradiation test was completed in May after about 800 hr of operation, including 1147 thermal cycles between 1000 and 1600°F without any evidence of malfunction.

b. June: The irradiation of the GCRE-I plate-type element (I-3P) was completed on 27 June after 429 hr of operation.

The IB-2T-1 test was initiated in May and has operated 809 hr (as of the end of June) without evidence of malfunction.

Hot cell examination of the IB-2T-2 element revealed no significant change in the element.

2. Problem Areas: Preliminary experiments show that UO_2 and BeO-UO_2 pellets oxidize readily at 1750°F when exposed to gas with trace quantities (2 to 3 ppm) of oxygen.

3. Schedules: Fuel element development is about on schedule at the end of the report period.

B. I-3P FABRICATION AND IN-PILE TESTS (Task 23-950)

Summary - January through May: Failures of blower bearings and belts delayed the insertion of this test element. The blowers were returned to BMI for re-work and testing. When a bearing or a belt failed, a standby blower was put in operation for the remainder of the cycle. If a belt failed, it was replaced during the between-cycle shutdown. If a bearing failed, it was replaced with a spare unit during shutdown.

The I-3P element was inserted into the loop during the ETR shutdown that started 23 May.

Accomplishments - June: Irradiation of this element began 5 June and terminated on 27 June after 429 hr of successful operation. With the ETR at 175 mw, the element operated between 61 and 67 kw at an inlet temperature of 670°F and an outlet temperature of 1150°F. The pressure drop was 5.2 psi at 1630 lb/hr flow. The static pressure was 195 psig. The element was shipped to the GCRE-I site and stored after it was removed.

When irradiation began on the I-3P, it was apparent that two parameters of the element would be different from those predicted. Thermal measurements showed that the element was operating at higher than predicted power, and the pressure drop across the element was lower than predicted. These parameters did not vary consistently from their predicted values and it was obvious that at least one parameter was in error. The lack of available parameters to perform the necessary heat balance made it impossible to determine the source of the error.

Anticipated Accomplishments - July: No further work will be performed on this task.

C. FUEL ELEMENT IB

1. IB Analysis (Task 21-1XX)

a. Fuel Analysis

Summary - January through May:

1) Pin to Pin Power Ratios for the ML-1: HECTIC calculations were made to determine the most desirable power distribution in the ML-1 fuel element. A typical calculation for a range of power ratios for a system using 19 pins is shown in Figure 35. A minimum temperature is predicted in a region where the outer row of pins has about 35% more power per pin than the intermediate ring of pins. A temperature of 1420°F is predicted for this ratio.

ML-1 PIN TEMPERATURES [3 RING SYSTEM]

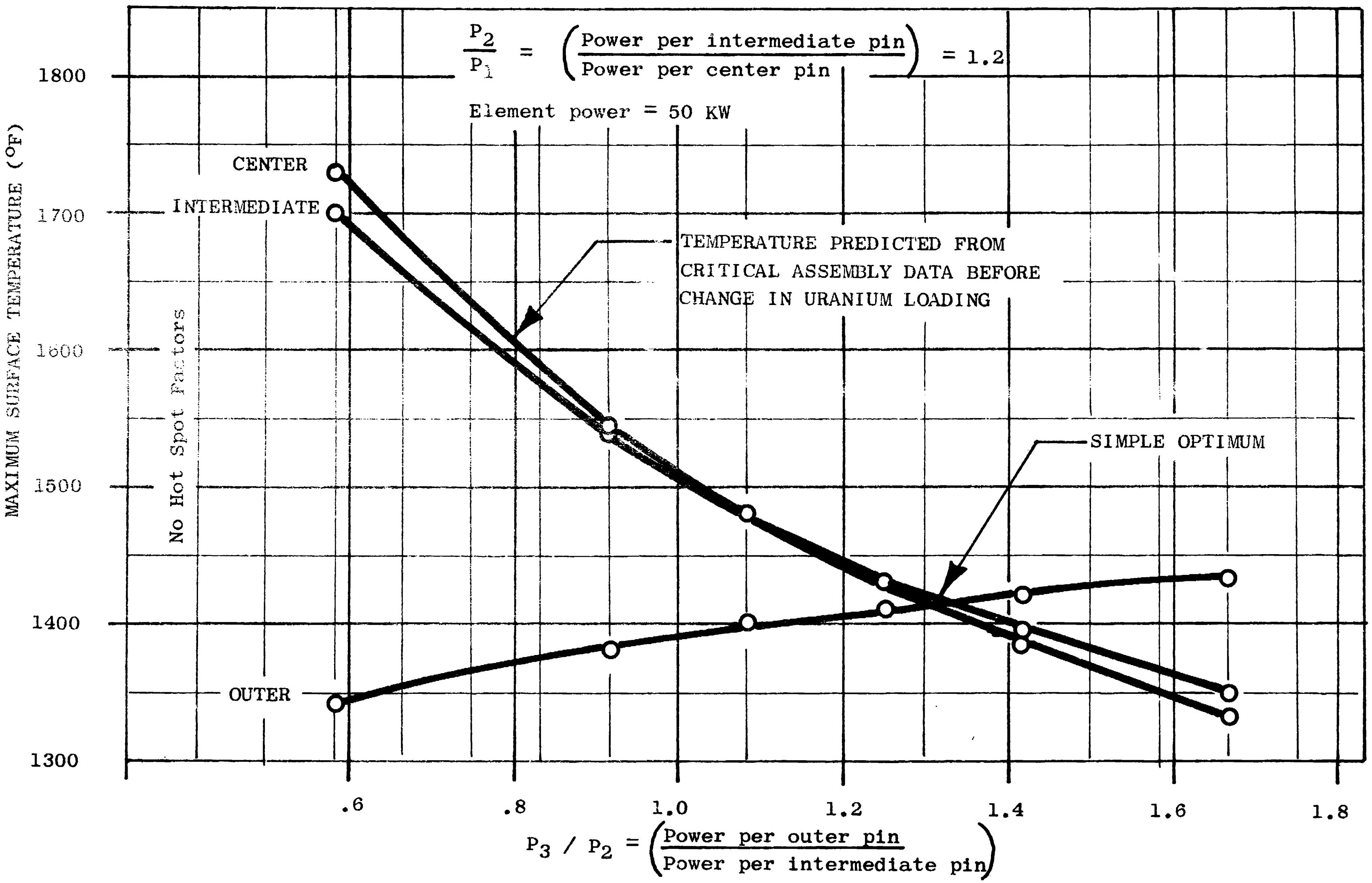


FIGURE 35.

ML-1 PIN TEMPERATURES [2 RING SYSTEM]

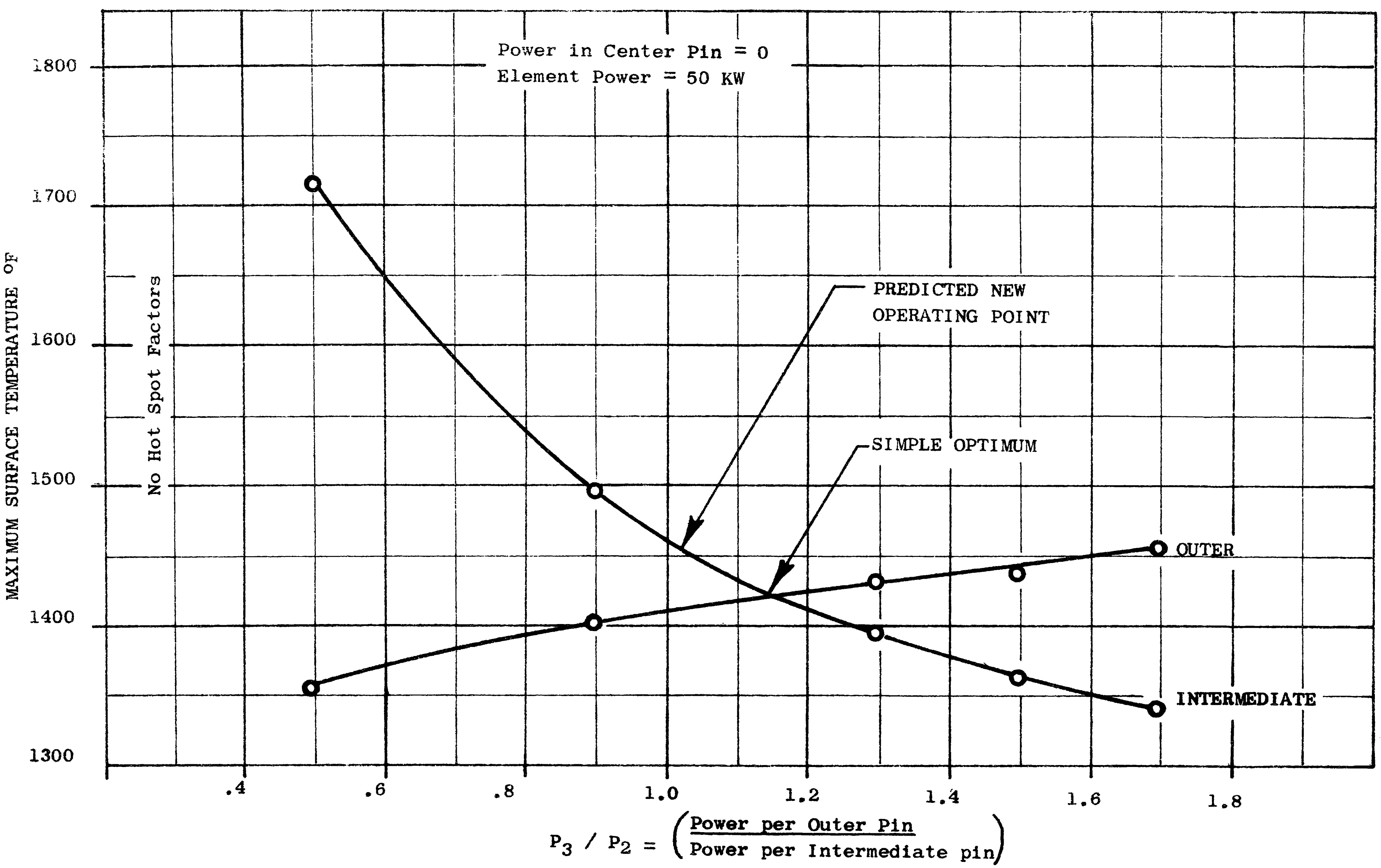


FIGURE 36

Measurements in the ML-1 IB critical experiment showed that pin to pin power ratios were as low as P_3/P_2 = 0.8 (power per outer pin to power per intermediate pin) producing a predicted temperature of 1600°F, 180°F above a possible minimum. Uranium was added to the outer row of pins and the central pin was left unfueled to avoid this high temperature. The predicted temperature for a bundle with an unfueled central pin is shown in Figure 36. The new configuration has a predicted typical P_3/P_2 = 1.1, and a predicted nominal temperature of 1460°F. Average heat flux ratios are, of course, increased.

2) Pressure Drop for the ML-1: It is desirable, in achieving a minimum pressure drop in a core, to flatten radial power as much as possible. Preliminary calculations and experiments on the power distribution from cell to cell indicated a radial peak to average ratio of 1.1. Using measured data on pressure drop, and this ratio, a pressure drop of 11.6 psi through the element was calculated for the fuel element at reference conditions. The 15 psi quoted in Appendix B allows a safety factor.

3) After Heat in the ML-1: Calculations were made for three cases in which the reactor is cooled without full coolant flow: for normal scram; for loss of coolant; and for shipping with the moderator drained. In the case of a normal scram, the turbine cools the core as it coasts to a stop. It was found that the maximum pin temperature in a fuel element drops from a hot spot temperature of 1750°F to 1160°F in 40 seconds, then rises to a peak of 1630°F after 550 seconds.

In the case of a scram and loss of coolant occurring at the same time, the temperature rises from 1750°F to a peak of 2210°F in 145 seconds after scram.

It was found that the moderator water should not be completely drained if the reactor is to be shipped 24 hr after running one year. The multiple shields insulate the fuel elements from ambient air to an undesirable extent when the moderator is drained. Natural convection of moderator water, however, is sufficient to adequately cool the reactor. It was impossible to evaluate the effect of air circulation within the core region, but this effect was considered unimportant. For the above reasons, the reactor with a radioactive core will be shipped only with moderator water in the system.

4) Fission Product Release in the ML-1: An analysis was made of the possibility of oxidation of fuel increasing the release of fission products. The analysis was based on the following assumptions:

1) A small leak is defined as one in which fission gases escape but the fuel is not oxidized. The minimum release from such a leak is based on a drop of 50°F in temperature across the gas gap between the UO_2 and the cladding. The maximum release from a small leak is based on a 0.0015-in. gas gap filled with nitrogen coolant.

2) A large leak is defined as one in which fission gas release is accompanied by oxidation of UO_2, a defect more than 0.001- to 0.005-in. equivalent diameter. The minimum release from a large leak is based on a temperature drop of 50°F across the gas gap between the UO_2 and the cladding, plus 1/10 of the volatile fission products in the oxidized fuel. The maximum release from a large leak is based

on a 0.0015-in. gas gap filled with nitrogen coolant, plus 2/3 of the volatile fission products in the oxidized fuel.

3) Fission product gases escape from unoxidized fuel by diffusion.

4) The diffusion coefficient for fission gas release is that given in WAPD-173 and TID-7546.

5) The UO_2 pellets are assumed to remain intact and centered in the cladding.

6) The reactor has been operated with a large leak for sufficient time to oxidize one inch of UO_2, about 400 hr in reference gas. Oxidation occurs at the inlet (cold) end of the fuel pin.

7) Dose rates assume that all iodine activity will be concentrated as a point source in the pre-cooler. All other radioactive isotopes (primarily xenon) are assumed to be contained in the gas storage spheres.

8) Attenuation is based on 0.25-in. of steel surrounding the source, and air elsewhere.

The release from one faulty pin was calculated, based on the above assumptions. The results are shown in the table below:

RELEASE FROM ONE OXIDIZED FAULTY PIN

	Small Leak	Large Leak
Total activity in system, curies	5.5 - 15.2	10 - 50
Total activity after 24 hr, curies	3.3 - 9.1	6 - 30
Iodine activity after 24 hr, curies	1.38 - 3.8	2.5 - 12.5
Radiation level 25 ft from pre-cooler*, 24 hr, mr/hr	3.5 - 9.5	6.3 - 31.0
Radiation level, 10 ft from gas storage spheres, 24 hr, mr/hr	5.5 - 15.2	10.0 - 50.3

*Distance noted is about the distance to the cab of the truck.

5) General Heat Transfer: The ML-1 fuel pins are constructed with an average radial clearance of 0.002-in. between the pin and the pellet. This gap is initially filled with helium gas. Obviously the pellets will not be truly centered, thus giving rise to a temperature gradient around the pin just as a gradient occurs due to non-uniform power generation and radial variation of the heat transfer coefficient. A code (PIT) was written to study the factors contributing to temperature increases of this kind. This code can be used to calculate the temperatures in a pin with an offset fuel pellet, with several internal power distributions, when there are radial variations in the heat transfer coefficient, and in the local bulk gas temperature.

Calculations were made to evaluate the relationship between tube to pellet clearance, gas conductivity and wall temperature (Figure 37).

PIN TEMPERATURES WITH NON-CENTERED PELLETS

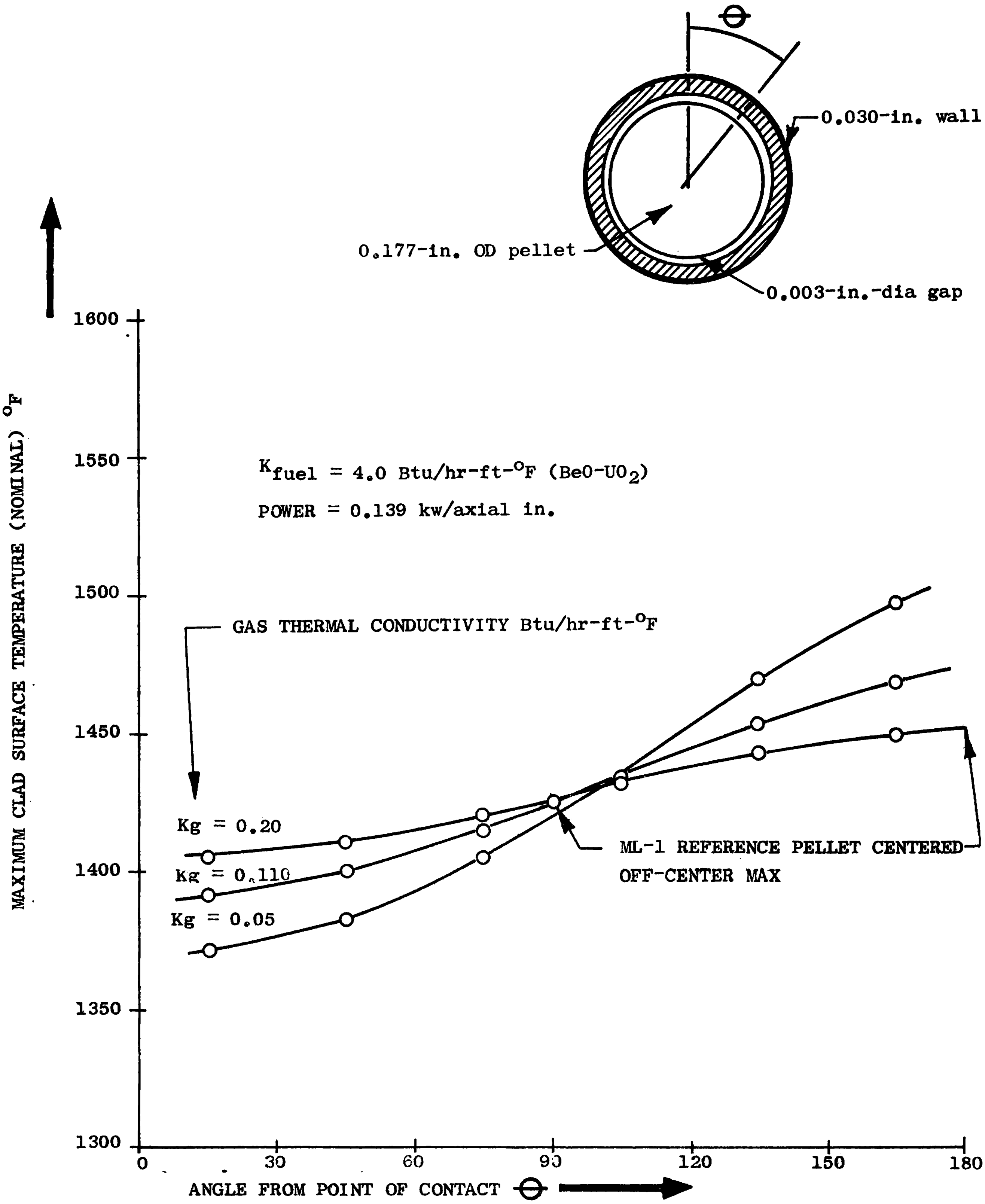


FIGURE 37

MAXIMUM SURFACE TEMPERATURE FOR THE ML-1 FUEL PIN

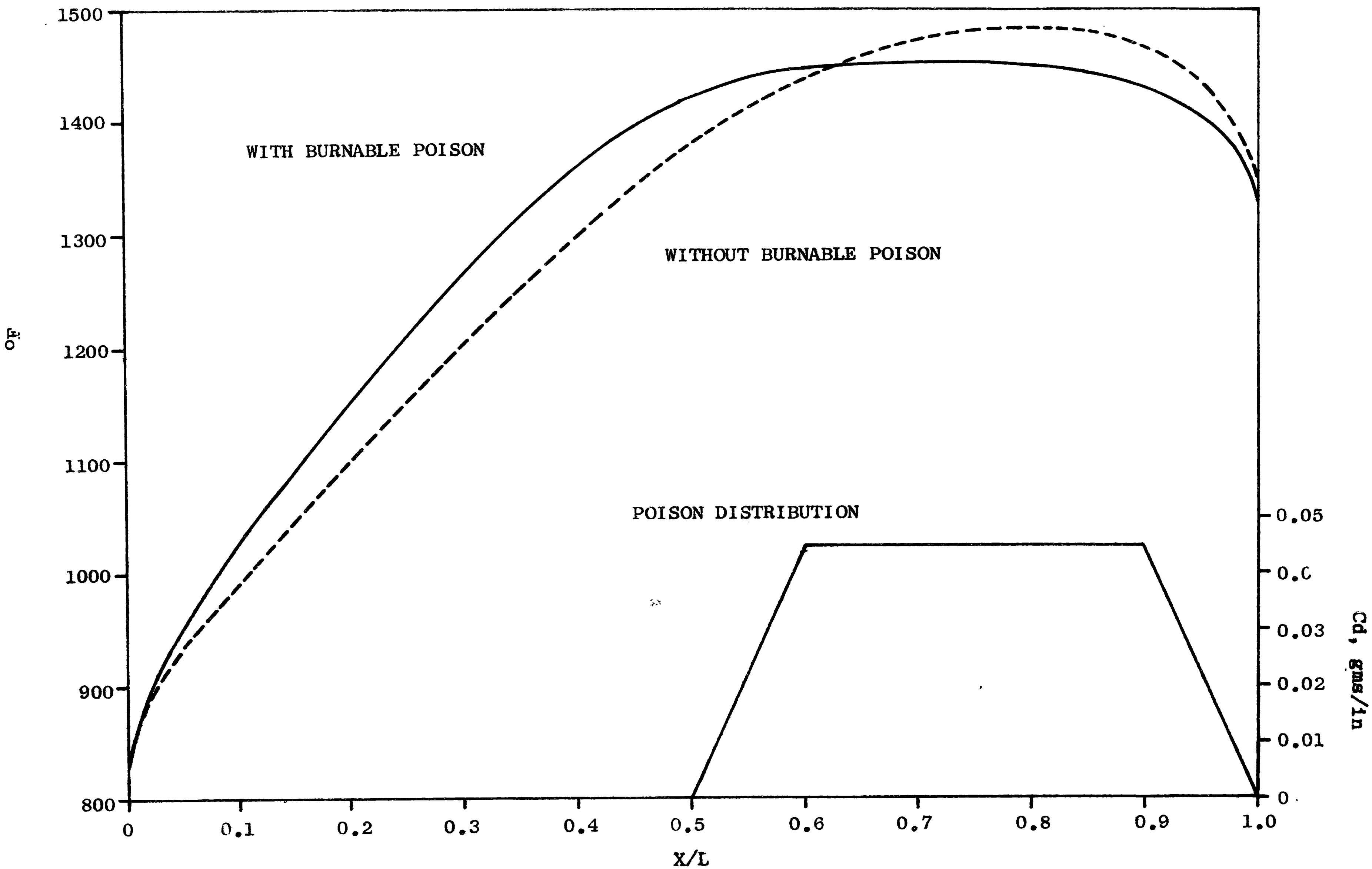


FIGURE 38

The curve is for $BeO-UO_2$ - the lower conductivity of UO_2 fuel would produce a different curve. In this case, the offset causes a temperature increase of $30^{\circ}F$.

The change in pin wall temperature for a normal scram was calculated to be $40^{\circ}F$/sec decrease.

The predicted hot spot and nominal axial temperature distribution for the ML-1 core with burnable poison is compared to the nominal distribution without burnable poison in Figure 38.

The selection of pin to pin power ratios for the core is based, in part, on the amount of intermixing of coolant assumed to occur in the gas as it passes through the element. Dye studies showed only a small amount of mixing occurred. It was found that the mixing parameter changed the predicted wall temperature by only $40^{\circ}F$ (nominal) when the parameter varied through all reasonable values. It also was found that reducing the thickness of the wall from the reference dimension (0.030-in.) to 0.015-in. increased the temperature of a nominal pin by $25^{\circ}F$, thus indicating the importance of conduction through the pin wall in equalizing temperatures.

The HECTIC code, for predicting temperatures in the ML-1 core, uses detailed power input and normal heat transfer correlations, except that constants can be corrected as they are determined from out-of-pile tests. The code, checked against the IB-1αT in-pile element, was found to be correct within $46^{\circ}F$. There was clear indication in the IB-2T experiment that analytically optimum power distribution results in what the code predicts to be a minimum temperature, but there seemed to be a consistent trend towards experimentally measured temperatures about $100^{\circ}F$ higher than those predicted. The amount of power the IB-2T-1 element sees is not certain, however. It thus is difficult to evaluate either the accuracy of the code or the suitability of the constants used. The experimental results will be studied in a later section under Task 24-2XX.

The IB-9R and the IB-10R elements, both to be run in the GCRE-I, also will be predicted by HECTIC and analyzed as heat transfer experiments.

The opinion has been held for some time that a seven pin fuel element might have advantages over a 19-pin element, particularly in regards to cost. A detailed design study was made of the suitability of a seven-pin design for the ML-1, and the design compared to a redesign of the 19-pin system. The conclusion was that improving the 19-pin system was the best choice since the seven-pin design would save only about 10% and there is a reasonable probability that performance would be inferior. In the seven-pin design, it would be necessary to use finned tubing to provide enough heat transfer to increase the hA product 50%. There was doubt that adequate heat transfer could be readily achieved.

Analysis showed that the 19-pin system could be improved substantially by increasing the inner diameter of the liner from 1.426- to 1.552-in., and increasing the pin diameter from 0.241- to 0.275-in. This would reduce nominal temperatures by 40°F and hot spot temperatures by 70°F. The re-designed 19-pin fuel element would have the same pressure drop as the current design. There is room for 40% more fuel in the new design, thus providing for a wider range of diluent. The new design does not require finned surfaces for heat transfer. An element of this type is being considered for the second core of the ML-1.

Accomplishments - June:

1) Heat Transfer: HECTIC inputs were written and problems were run to determine the influence of non-uniform power distribution across a fuel element near a control rod or near the edge of the core. The results will be used in selecting orifices for IB-2L and ML-1 wherein it is desired to provide fuel element temperatures resulting in a minimum highest temperature in the core.

HECTIC inputs were written for a new fuel element configuration using pins 0.275-in. in diameter with walls 0.030-in. thick.

Sample problems run with the PIT code demonstrated that the code is operational.

Additional evaluation was completed for heat transfer in the IB-2T-1 fuel element. More can be learned from the relationship between heat transfer predictions and the temperatures actually encountered in this element. (Final results will be reported by Task 24-2XX.)

Inputs were prepared from the HTR code to evaluate accidental loss of coolant, considering a non-power generating central pin, increased conductivity in the insulation, and increased total power per pin. (This is closely connected with the experimental study of the predictions for accidental loss of coolant in the ML-1.)

2) IB-3L and ML-1 Second Core: The basic fuel for the second core will be $BeO-UO_2$, and perhaps UO_2. The larger fuel pins for this design permit greater choice of potential fuel. It appears that 40% diluent could be used in the inner seven pins. More diluent can be used if thinner walls are used for the pins.

In addition, the temperatures of the outlet gas were re-estimated for the GCRE-I elements, allowing for the actual size of the orifice as installed and the shift to a 71 element core from a 61 element core.

Anticipated Accomplishments - July:

Data will be evaluated from the GCRE-I outlet gas and from the IB-9R and IB-10R thermocouples.

A test plan will be outlined for accidental loss of coolant in the GCRE-I reactor. This work will be performed with the GCRE Operations Test Planning and Evaluation group.

Design work will continue for the second core. The problems associated with shimming and burnable poison will be investigated from the standpoint of heat transfer.

Further consideration will be given to orifices for the IB-2L and ML-1 based on information from the critical assembly experiment.

b. Reactor Physics

Summary - January through May:

1) Intracell Problems: The prediction of intracell flux and power distributions is a major problem in ML-1 core design. The usual calculational procedure of homogenizing the fuel pins into annular rings and then solving the problem in one-dimensional cylindrical geometry has been shown to be inadequate. This method fails to account for neutron streaming between the fuel pins and leads to a grossly exaggerated flux and power dip through the fuel element.

The source-modified I_2 calculational method was developed as a means of compensating for neutron streaming between the fuel pins. I_2 is a one-dimensional code for the IBM-704 using the P_3 approximation to transport theory in cylindrical geometry. The problem is set up in the usual homogenized fashion and then sources and sinks are inserted in the regions between the rings of pins. These sources and sinks may then be adjusted so that the calculation agrees with experiment. The same source-sink arrangement may be used for the calculation of fuel elements which do not differ greatly from the one to which the calculation was normalized.

The source-modified I_2 method has been shown to give quite accurate results for small ranges of fuel loading. It does, however, show considerable error when used to calculate situations that deviate widely from the normalizing point. Several assumptions and inadequacies included in the method prevent accurate calculation over a wide range.

The method, of necessity, assumes a constant neutron temperature throughout the fuel cell. This assumption is recognized to be fallacious. The flux depression through the fuel pins cannot be properly treated when homogenized into annular regions. Geometrical effects cannot be treated explicitly. The normalized sources and sinks compensate for all of these effects and since the individual effects cannot be separated from the total, the method cannot be expected to give accurate results for conditions which deviate widely from the normalizing point.

Since the source-modified I-2 method must be normalized to experiment, it cannot be used to predict new and unusual fuel element designs. It should be emphasized, however, that the method provides a powerful tool for predicting intracell flux and power distributions when experimental data is available for similar conditions.

Other one-dimensional and two-dimensional approaches to the intracell problem have been investigated with little success. Since the fuel element is two-dimensional and extremely heterogeneous, this is not surprising. Although it may be possible to separate the geometric and neutronic effects in a one-dimensional calculation, the best hope for an analytical solution to the intracell problem lies in the use of two-dimensional machine code calculations.

The extreme heterogeneity of the fuel element seems to dictate the use of transport theory to obtain accurate results. Unfortunately, no two-dimensional transport theory machine codes are available at this time. One such code (TDC) is expected to be available in four to six months, and perhaps will alleviate much of the uncertainty associated with pin-type fuel elements. An alternative approach is to use a two-dimensional diffusion theory code (PDQ). The nuclear constants used would be modified to give the same results as transport theory for a single pin in one dimension. This method is under investigation but no definitive results have been obtained. The use of Monte Carlo techniques has been investigated but found to be unsatisfactory for analysis of the ML-1 fuel element.

<u>2) Experimental Determination of Pin-to-Pin Power Ratios</u>: Since an analytical solution of the intracell problem is very difficult, several detailed experiments were performed to gain information about this problem. The intracell power ratios from these experiments are given in Table 9.

To establish a point of reference for interpretation of the table: an "optimum" power ratio, P_3/P_2, of outer ring pin power to mid ring pin power, is about 1.35 for a 19 pin element and about 1.15 if the center pin has no fuel. (It was previously felt that a power ratio of 1.0 was an "optimum", but subsequent analysis and experiment have indicated the values given above.)

The first intracell experiments were done in the ML-1-IA critical experiment and used uranium foils in Inconel tubes to simulate the fuel pins. It should be noted that the effective "pellet" diameter was 0.162-in. Shortly thereafter, the IB-2ØT element was irradiated in the BRR. This was the first test element to utilize UO_2 and to have fuel pellets with the reference diameter of 0.177-in. This element exhibited a greater flux and power dip than the previous elements. This was as expected due to the higher fuel loading and larger pin diameter. The fuel loading for the IB-2L core for GCRE was selected on the basis of a theoretical extrapolation from this point.

Table 9. INTRACELL POWER RATIO DATA

CORE	ELEMENT	CORE LOCATION	g U-235/ INNER PIN	g U-235/ OUTER PIN	FUEL DIAMETER in.	THERMAL POWER			TOTAL POWER		
						P_2/P_1	P_3/P_1	P_3/P_2	P_2/P_1	P_3/P_1	P_3/P_2
ML-1-IA	1	1,Center	31.30	13.26	0.162	1.23	1.21	0.98	1.09	0.91	0.83
"	2	1,Center	59.98	18.38	0.162	1.25	1.24	0.99	1.18	0.94	0.80
"	2	12,Mid.	59.98	18.38	0.162	1.19	1.20	1.01	1.16	0.97	0.84
"	2	45, Edge	59.98	18.38	0.162	1.20	1.16	0.97	1.13	0.96	0.85
"	3	12,Mid	49.94	23.90	0.162	1.20	1.44	1.20	1.18	1.18	1.00
"	4	12,Mid	49.76	23.72	0.162	1.25	1.50	1.20	1.19	1.18	0.99
BRR	2ØT	Refl.	65.5	20.1	0.177	1.09	1.79	1.64	1.09	1.79	1.64
ML-1-IB	#1	1,Center	75.0	26.6	0.177	----	----	----	1.17	1.07	0.92
"	#1	49,Edge	75.0	26.6	0.177	1.34	1.88	1.40	1.21	1.29	1.07
"	#2	1,Center	75.0	20.2	0.177	1.33	1.36	1.03	1.19	0.87	0.73
"	#2	49,Edge	75.0	20.2	0.177	1.37	1.39	1.02	1.24	0.96	0.77
"	#1'	1,Center	75.0	26.6	0.177	----	----	1.38	----	----	0.95
"	#1'	49,Edge	75.0	26.6	0.177	----	----	1.47	----	----	1.09

P_1 = Power generated in center pin

P_2 = Power generated in each of six mid-ring pins

P_3 = Power generated in each of 12 outer pins

#1' = #1-type element without fuel in center pin

A series of intracell flux and power measurements were made on May 1 in the ML-1-1B critical experiment. The test elements were of reference size and had fuel loadings in the range predicted for ML-1-I. As may be seen from the table, these elements showed power ratios in the range indicated by the earlier power ratio experiments and much lower than the power ratios seen in the IB-2ØT experiment. In retrospect, this apparent anomaly can be easily explained on a qualitative basis.

The initial power ratio experiments were done in the ML-1-IA critical experiment (loaded with about 20 kg of U-235). The IB-2ØT element had a heavier fuel loading and was run in the BRR which has a very soft thermal neutron spectrum, hence the power ratio was much higher. The elements tested in the ML-1-IB critical experiment had a heavier fuel loading than any of the previous elements, but the thermal spectrum to which they were exposed was also much harder since the core contained about 35 kg of U-235. Due to this difference in thermal neutron spectrum, the fuel pins were not as "black" as those in the IB-2ØT element and the resulting power ratio was lower. The problems associated with the prediction of thermal spectra are being investigated.

<u>3) Fuel Loading Selections - IB-2L and ML-1-I</u>: The fuel loading was selected for IB-2L and tentatively selected for ML-1-I after analysis of data from the IB-2ØT element. Fully enriched UO_2 (75 gm U-235 pin) was chosen for the inner seven fuel pins while the outer 12 pins were to contain 23 gm of U-235 as fully enriched UO_2 in a BeO matrix. This selection was aimed at obtaining near optimum pin surface temperatures while providing sufficient excess reactivity to assure criticality with less than 61 fuel elements. Inconel-700 and Haynes-25 poison shim liners were designed to be wrapped around the fuel elements and thereby permit operation of the ML-1 with the desired excess reactivity and exactly 61 fuel elements.

When the data was received from the ML-1-IB critical experiment, it became obvious that this fuel loading selection would result in excessive surface temperatures in the fuel pins. This problem would be alleviated either by decreasing the loading of the center seven pins or by increasing the loading of the outer twelve pins. The fuel for the center pins had been ordered, however, so any change in composition was deemed impossible. A sufficient increase in the loading of the outer pins to provide a desirable temperature distribution would increase the reactivity of the system so that the shim liners in ML-1 would be inadequate to permit operation with 61 elements.

A compromise fuel loading was re-selected for both cores. The center pin will contain no fuel, the six mid-ring pins will each contain 75 gm of U-235 and each of the outer twelve pins will contain 30 gm of U-235. This will provide a near optimum power distribution without causing an excessive increase in reactivity.

<u>4) Burnable Poison Selection - IB-2L and ML-1-I</u>: The reactivity effects of the burnable poison for IB-2L and ML-1-I were studied with two-group perturbation theory. The reactivity worth of the IB-2L cadmium distribution was established as 2.2% to give an operating lifetime

of 10,000 hours at full power. The shape of the burnable poison distribution was selected to improve the axial power distribution. The poison foil is made of copper-cadmium alloy containing 0.40 gm of cadmium per fuel element. In ML-1-I the poison is located nearer the outlet end of the fuel element and results in about a 30°F reduction in the maximum surface temperature of the fuel pins (excluding hot spot factors).

A more detailed analysis of the burnable poison will be done using two-group, two-dimensional perturbation theory. PAMPER (an IBM-704 computer code) was written to convert two-dimensional diffusion theory results (PDQ) into weighting functions used in perturbation theory. A burn-up code will be written, using these perturbation theory weighting functions. This will permit calculation of burnup effects in two dimensions with minimum expenditure of computer time.

5) ML-1-I Neutron Source: The neutron source for ML-1 must have a lifetime of 50,000 hours, be capable of starting a new core loading 10,000 hours after shutdown and have sufficient strength to be detectable at the shield water tank. A radium-beryllium source with a strength of 3 x 10^7 neutrons/sec will meet these requirements. It will be mounted in a vertical tube in the moderator water near the periphery of the core.

Accomplishments - June:

1) Development of Technique: Two analytical methods of representing the reactivity worth of ML-1 control blades were developed. A two-group, two-dimensional perturbation theory technique appears to have considerable promise and will be compared with experimental data from the critical experiment. This method utilizes perturbation theory weighting functions derived from PDQ calculations by use of the PAMPER code.

A purely analytic representation of control rods in a cylindrical reflected core was developed. This procedure will require use of a computer to solve the flux equations. It is not felt that this technique will be as good as perturbation theory for ML-1 but could have considerable use for other reactor systems.

The PAMPER code for computing two-group, two-dimensional perturbation theory weighting functions was checked out and is ready for use. A short FORTRAN code was written to punch input data cards for PAMPER directly from the PDQ output tape. This eliminates many hours of keypunching time and greatly reduces the possibility of errors.

Work has been initiated on problems associated with burn-up; fuel depletion; and fission product poisons.

2) ML-1-1B Critical Experiment: Power ratio and intracell flux data was analyzed and I_2 machine code calculations were normalized to the experimental data. This normalization will permit calculations to be made on ML-1 with more confidence.

3) ML-1-I Design Calculations: The UO_2 loading of the BeO-UO_2 outer fuel pins was set at 70.5 wt% (30.0 gm U-235 per pin). The inner six fuel pins will contain fully enriched UO_2 (75.3 gm U-235 per pin) and the center pin will contain no fuel. This selection gives the best pin-to-pin power ratio within the limits of criticality considerations.

The burnable poison was selected for ML-1. It will be a copper-cadmium alloy containing 0.4 gm of cadmium per element. The poison foil will be located near the outlet end of the fuel element to improve the axial power distribution.

Reactor physics constants for ML-1 are being re-evaluated with information from the critical experiment. This will permit a more accurate evaluation of criticality and burn-up calculations.

Blueprints of the ML-1 core were studied and nearly all of the components reduced to the form of volume fractions for neutronic calculations.

Anticipated Accomplishments - July: Control blade calculational methods will be checked out and compared with experimental results.

Two-dimensional, two-group perturbation theory will be studied as a means of determining long-term burn-up effects.

Data will be analyzed as it is received from the ML-1-IB Critical Experiment.

Criticality studies will be continued. Consideration will be given to the time dependent effects of reactor operation.

2. IB Fabrication Development (Task 21-2XX)

This task was broken into two parts and is reported under Tasks 21-6XX and 21-7XX.

3. IB Loop Tests, Out-of-pile (Task 21-3XX)

Summary - January through May:

a. Fluid Flow Tests: The first fluid flow tests were run on the IB fuel element configuration in November 1958. No attempt was made to find the optimum design at that time since the IB element was then considered only a back-up design. When the IB element became the reference design for the ML-1, a more thorough program was planned to determine the best possible configuration. Two geometric parameters were considered because of their influence on pressure drop: the diameter of the pin, and the configuration of the pin spacer. Tests were made of five spacer shapes and three pin diameters (0.240-, 0.245-, and 0.250-in.). (The IB element uses 19 cylindrical pins arranged symmetrically inside a cylindrical tube.)

Results of fluid flow tests on the pins show that there is negligible change in friction factor for the diameters tested although pressure drop changes significantly because of the change in flow area. (The effect of pin diameter on friction factor is shown in Figure 39.)

Tests on airfoil spacers and full-length spiral wire spacers (a smooth tube was also tested as a control) showed less pressure drop for the spiral wire configuration. (The results are plotted in Figure 40.) After the full-length spiral wire spacer was chosen as the reference design, tests were run to determine the effect of changing the number of spirals (Figure 41). The results of the tests showed that there is little difference in friction factor, but that the friction factor increases slightly as the number of spirals increases. Information for future designs was gathered by testing one seven-pin model with longitudinal fins and peg-type spacers (Figure 42). This configuration showed poor distribution of flow which would lead to large differences in temperatures around the pins.

The above tests were performed in a water loop. One of the models tested in the water loop was re-tested in the gas loop to demonstrate that the accuracy of the results was not affected by the use of water instead of gas as the working fluid. The results showed that the working fluid has no significant influence in the correlation (Figure 43). The 5% apparent difference is caused by the experimental error ($\pm$ 3% for the water loop data and $\pm$5% for the gas loop data) and by the difficulty in accounting for the effects of the inlet geometry in the two specimens. The water loop not only has lower experimental uncertainty but is easier to operate. It was used for all other fluid flow tests.

The bearing spacer design was selected to back-up the full-length spiral wire spacer design. The first longitudinal cross-section chosen for the bearings was 30° ramp nose section and 7° ramp tail section. A streamlined cross-section (B-2) was designed to improve the pressure drop, and tested (Figure 44). The drag coefficient for the original shape (1.30) was improved to 1.00 for the new shape.

A fluid flow model was built with an arbitrary gap between the pin and the full-length spiral wire. (Thermal cycling tests showed that the wires elongate, forming a gap of varying magnitude.) This flow model was used to provide information on which to base an estimate of the effect of such a gap on pressure drop. A gap of 0.32-in. was found to increase the friction factor by 7% (Figure 45).

b. <u>Heat Transfer Tests</u>: The fluid flow tests mentioned above eliminated all except two configurations. Heat transfer tests were run on these two configurations, using the thermal capacitance discharge method. This form of test only yields information on the average, or apparent, heat transfer coefficient for the whole element. It does not yield information on the variation of coefficient around the circumference of the pins, on the local effect at the spacers, or on the variation in the entrance region of the element. The results of tests on the model with 48 bearing spacers show that the heat transfer coefficient for this configuration is 35% above that predicted by the Colburn equation (Figure 46). Models were also tested with 16 and 32 spacers to find correlation for the IB configuration without spacers. The results indicate that the correlation for the reference configuration without spacers is 14% above that predicted by the Colburn equation for a smooth round tube (Figure 47).

The reference design (full-length spiral wire spacers) also was tested using the thermal capacitance method. The results show that the heat transfer coefficient for a model with 16 wire spacers is 17% above, and a model with 18 wire spacers is 23% above that predicted by the Colburn equation for a round tube (Figures 48 and 49).

The results of the tests reported above are valid only for cases with small differences in wall to gas temperatures. For large differences in temperature, the heat transfer correlation must be corrected to account for the effect of large variations in temperature-dependent properties in the gas film next to the wall. In the absence of data, this effect can be estimated by applying a correction, such as $(T_w/T_g)^{0.575}$ to $StPr^{2/3}$ recommended by Kays and London in "Compact Heat Exchangers". For the ML-1, the maximum predicted wall to gas temperature ratio is 1.36, the correction calculated from the above reduces the heat transfer coefficient by 19%. Thermal discharge tests, run to confirm the accuracy of the assumed correction, showed that the proper correction was $(T_w/T_g)^{0.25}$ (Figures 50 and 51). The final heat transfer correlation for the IB fuel element geometry with 18 full-length spiral wire spacers is:

$$St\ Pr^{2/3}(T_w/T_g)^{0.25} = 0.027\ Re^{-0.2}$$

The correction for temperature-dependent properties with this correlation results in reducing the isothermal heat transfer coefficient by only 8% for a temperature ratio of 1.36.

c. Thermal Shock Tests: Thermal shock tests were run to demonstrate that the IB-2T fuel element would operate safely during the first in-pile test. The model used for the thermal shock test was the IB-10M', a mock-up of an element for the IB-1L core. For the purposes of this test, there are no significant differences between the IB-10M' and the IB-2T. The model was thermally shocked 40 times between 1000 and 120°F (it is estimated that during the lifetime of the element, the IB-2T will be subjected to 40 cycles from 1700 to 800°F at a rate of 10°F/sec). The average rate of temperature change of the metal surface for the first 20 sec of each shock was 22°F/sec. No mechanical damage to the model was apparent after the test.

d. Drying Test: A test was run to measure the efficiency and speed of the drying procedure planned for use with the ML-1 reactor after the core has been flooded with water during the fuel change. The Thermoflex insulation in each fuel element will absorb and hold some of the water after the reactor is drained. The reactor will be dried by forcing air at 600°F through the system at the rate of 1000 lb/hr. The results of the test showed that the insulation for each fuel element will absorb 247.4 grams of water, and that this water will be evaporated after passing 16.4 lb/hr of 600°F air through the element for two hours.

EFFECT OF PIN DIAMETER ON FRICTION FACTOR

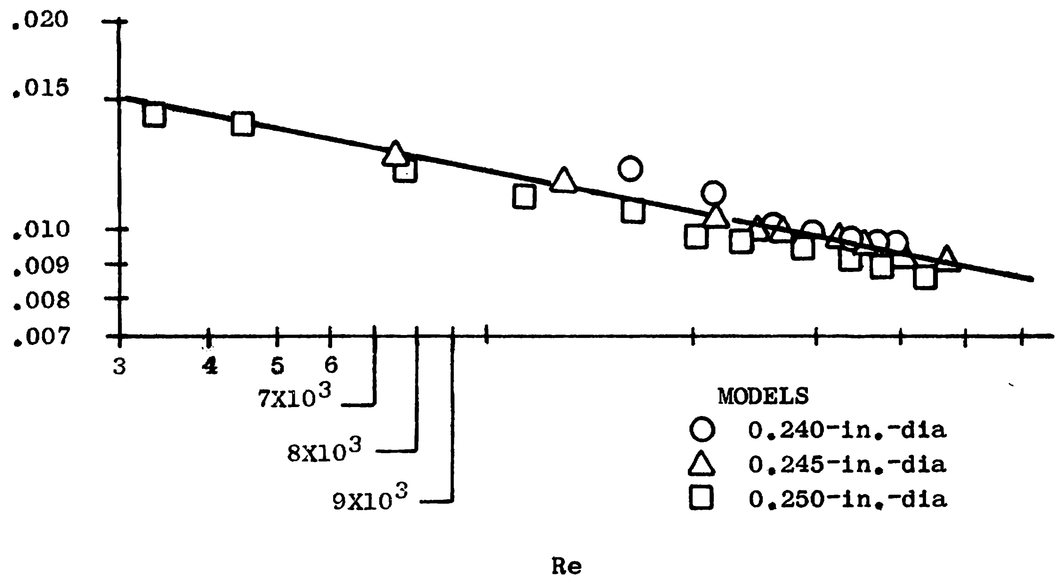


FIGURE 39

COMPARISON OF FRICTION FACTORS FOR THREE PREFERRED CONFIGURATIONS

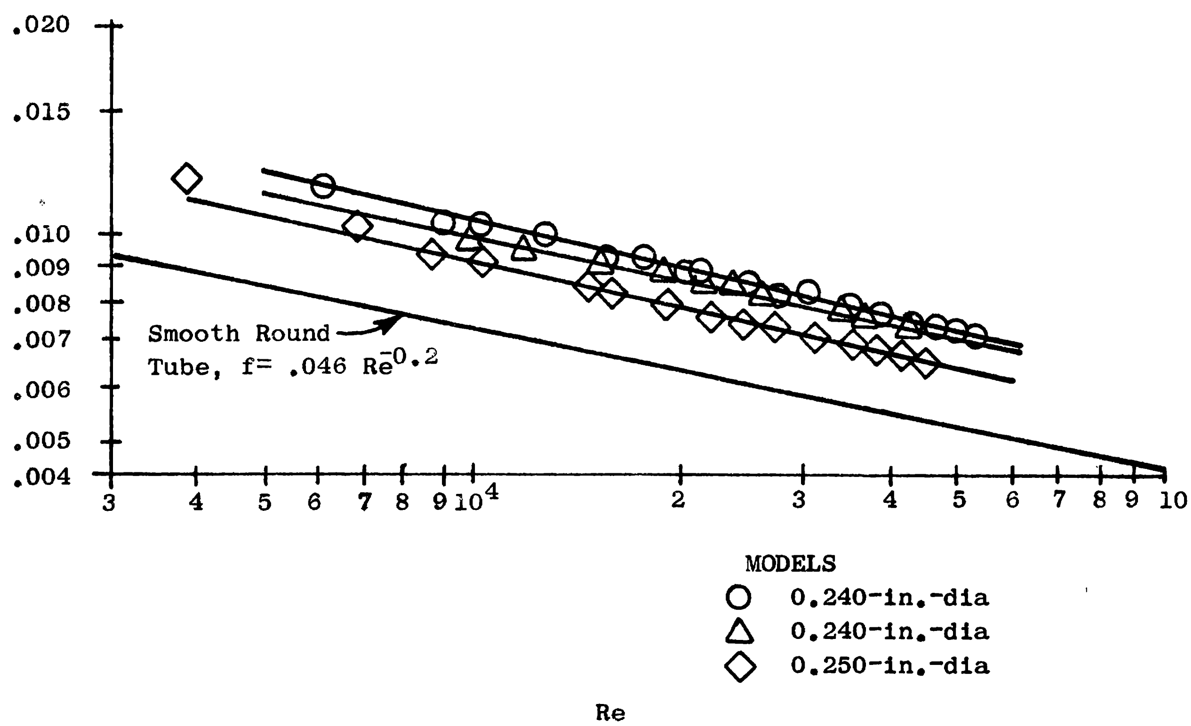


FIGURE 40

EFFECT OF NUMBER OF COMPLETE SPIRALS OF FULL-LENGTH WIRE SPACERS ON FRICTION FACTOR

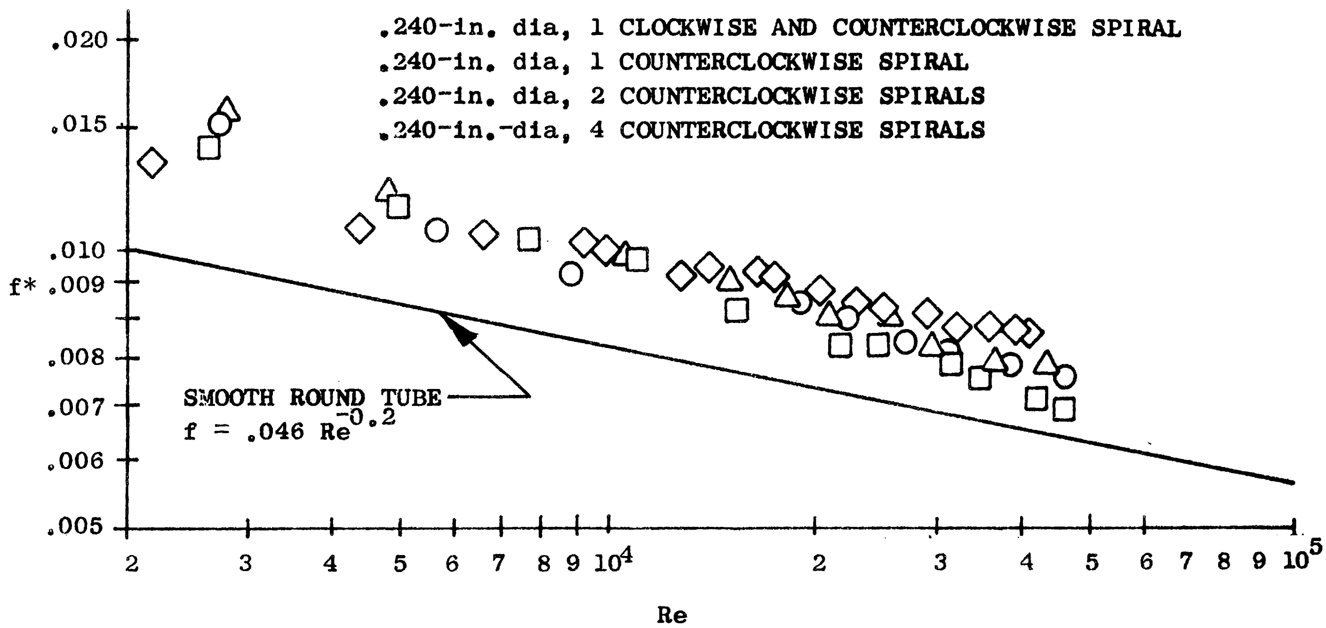


FIGURE 41

FRICTION FACTOR OF SEVEN PIN ELEMENT

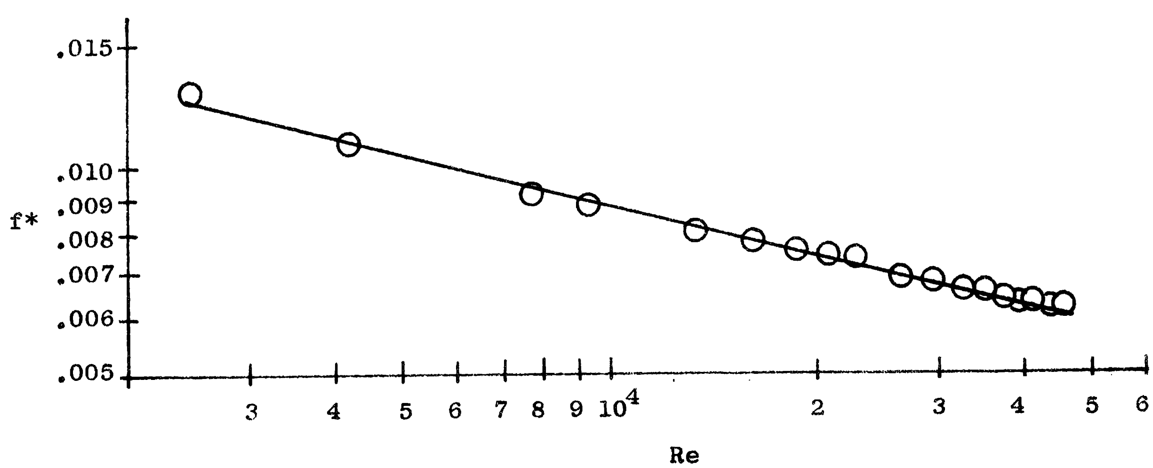


FIGURE 42

COMPARISON OF PRESSURE DROP DATA FROM WATER AND GAS LOOPS
(IB-4M MODEL WITH 16 FULL-LENGTH SPIRAL WIRE SPACERS)

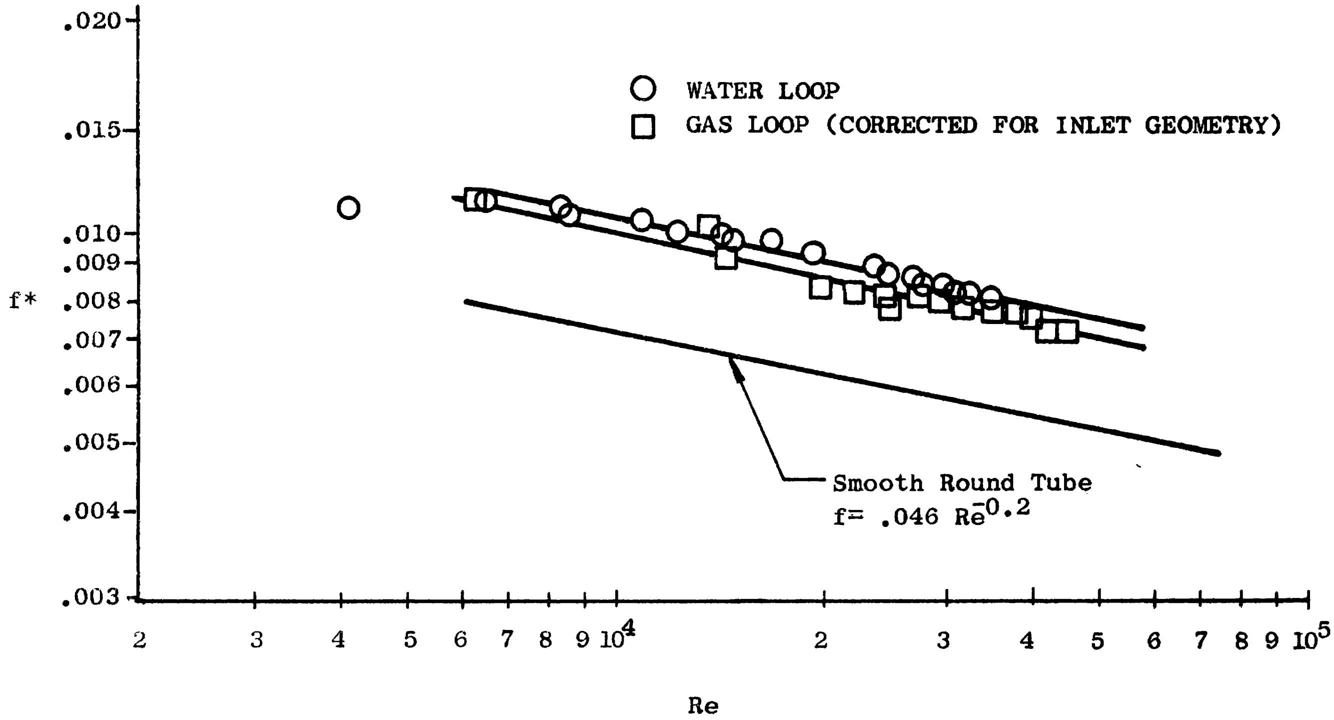


FIGURE 43

VARIATION OF OVERALL FRICTION FACTOR WITH NUMBER OF BEARING SPACERS

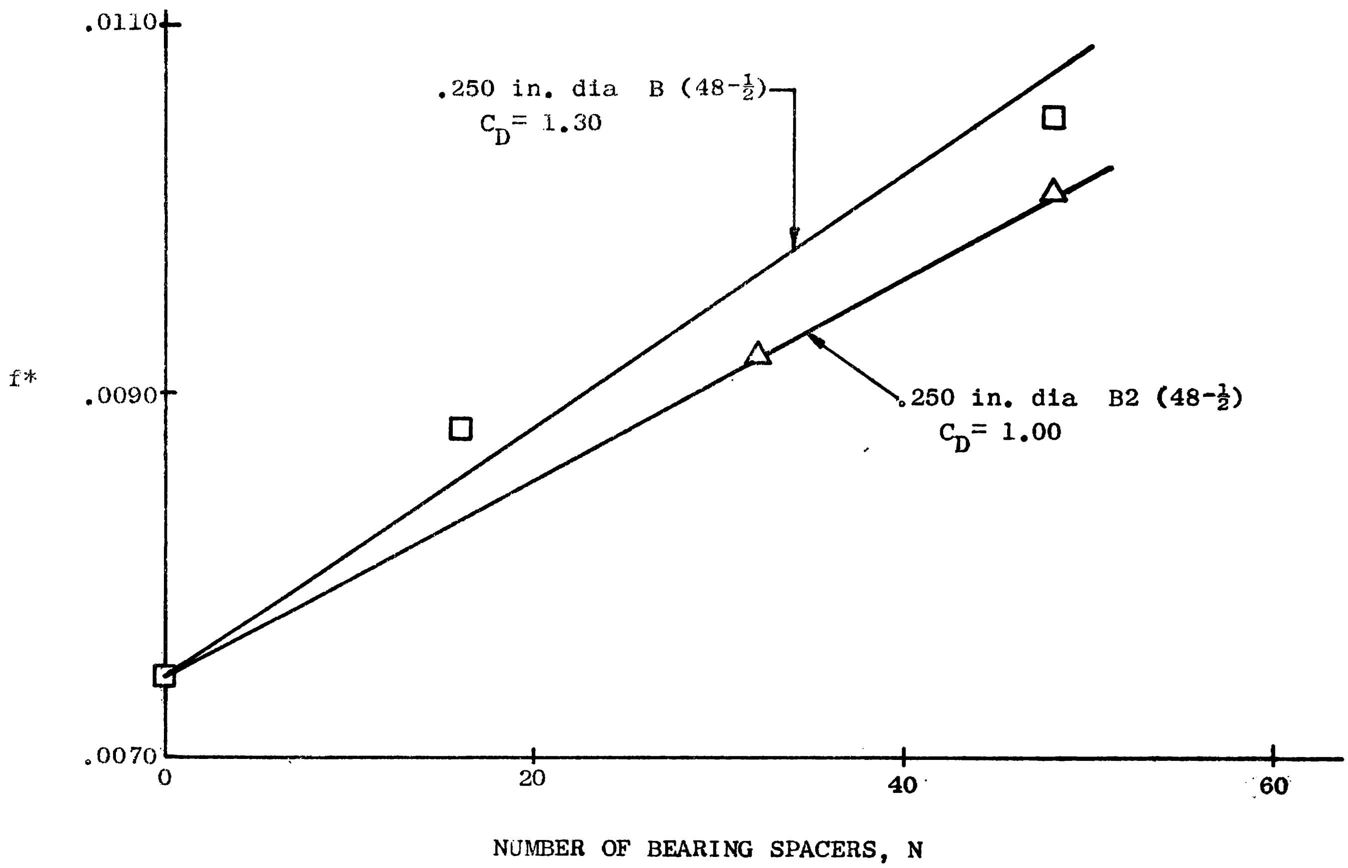


FIGURE 44

COMPARISON OF FRICTION FACTORS FOR GCRE-IB MODELS WITH WIRE SPACERS, WITH AND WITHOUT GAP

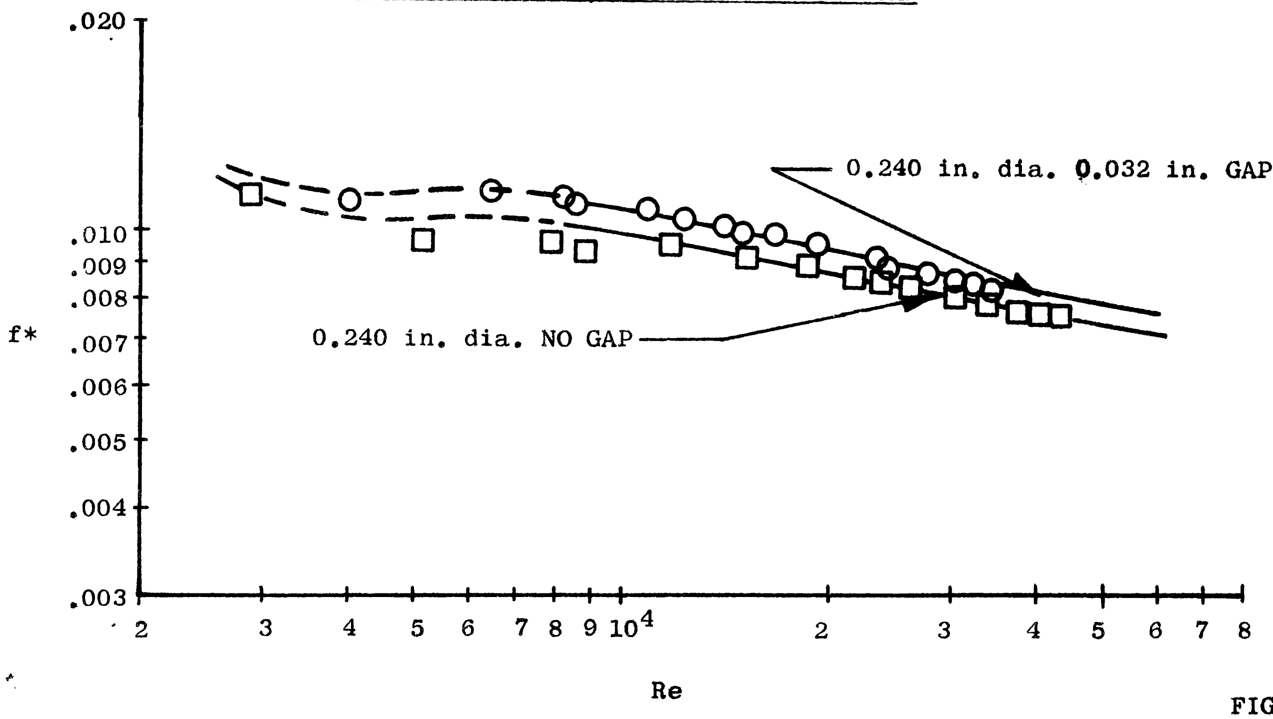


FIGURE 45

HEAT TRANSFER CORRELATION FOR MODEL WITH 48 BEARING SPACERS

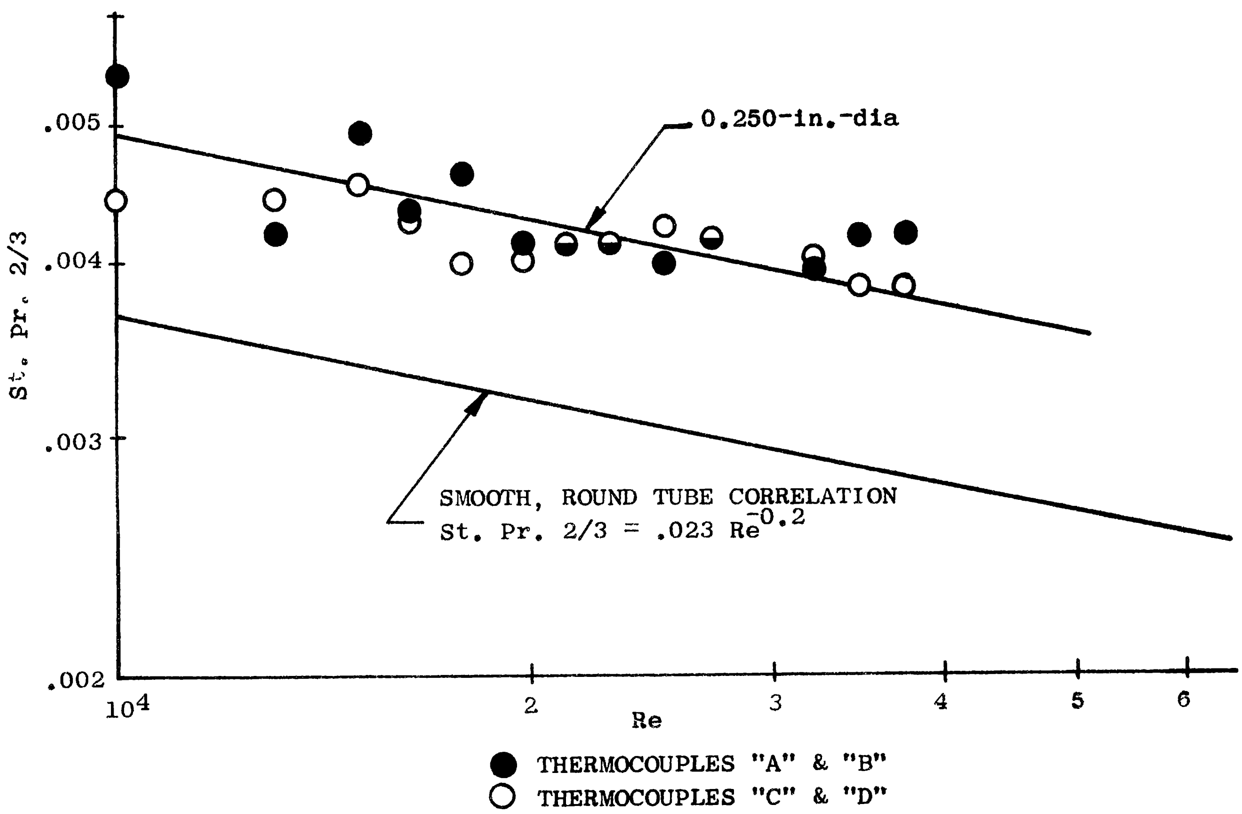


FIGURE 46

COMPARISON OF HEAT TRANSFER CORRELATIONS FOR MODELS WITH 16, 32, and 48 BEARING SPACERS AT RE = 30,000

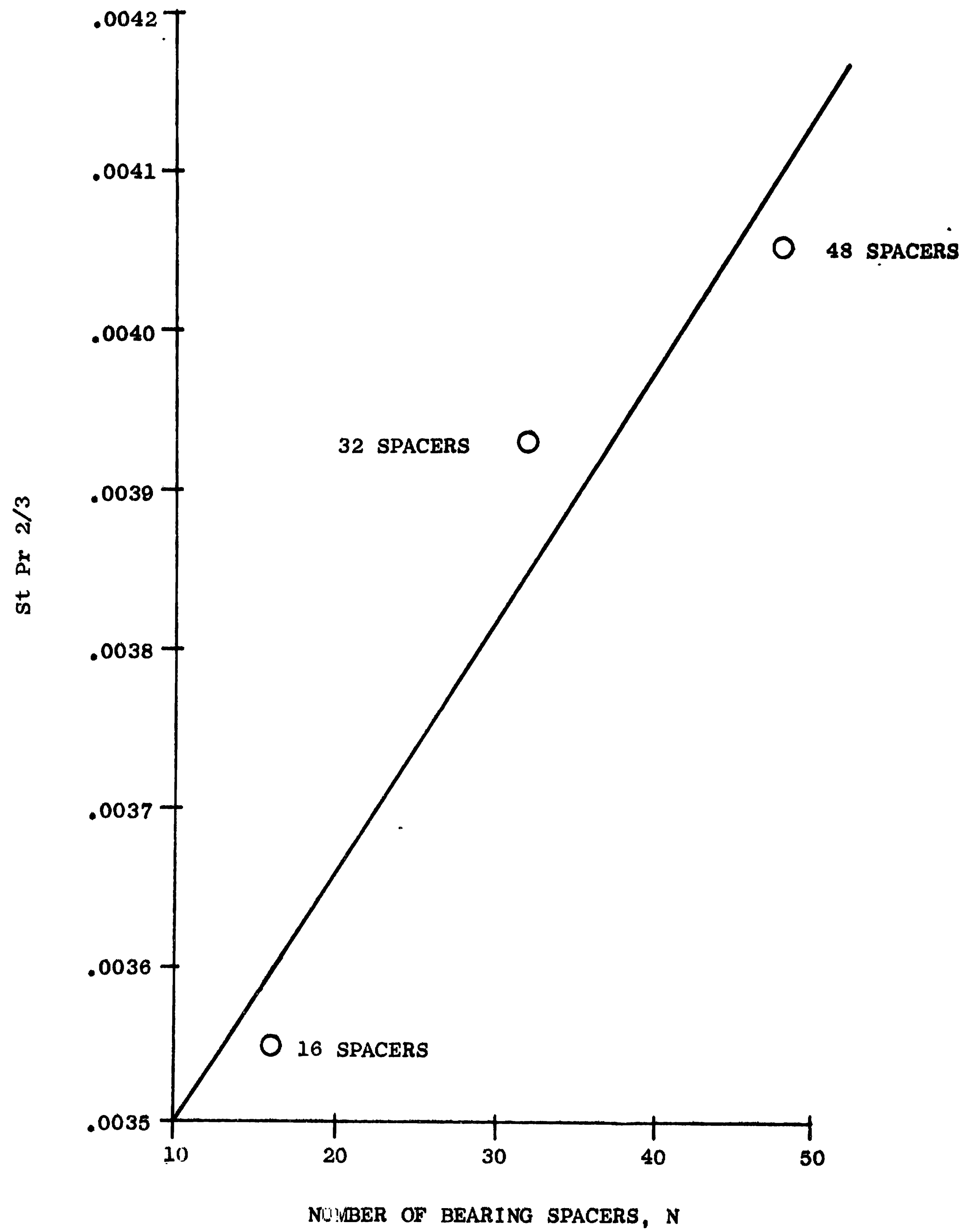


FIGURE 47

HEAT TRANSFER CORRELATION FOR 1B-FUEL ELEMENT MODEL
(WITH 16 FULL LENGTH SPIRAL WIRE SPACERS)

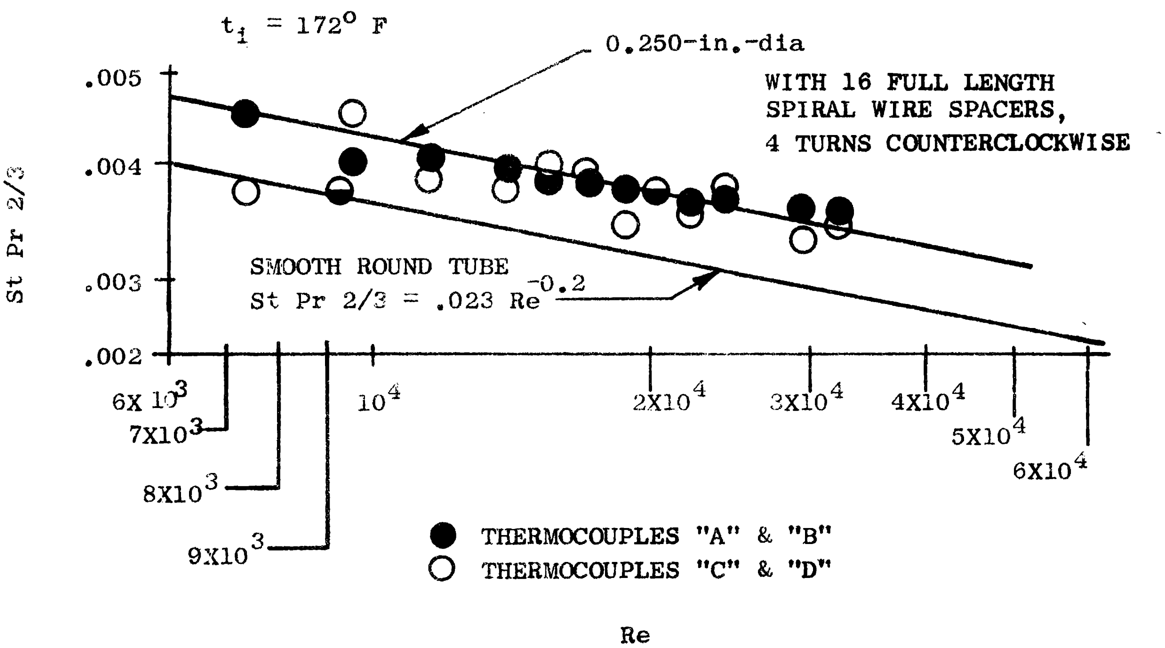


FIGURE 48

HEAT TRANSFER CORRELATION FOR MODEL
(WITH 18 FULL LENGTH SPIRAL WIRE SPACERS)

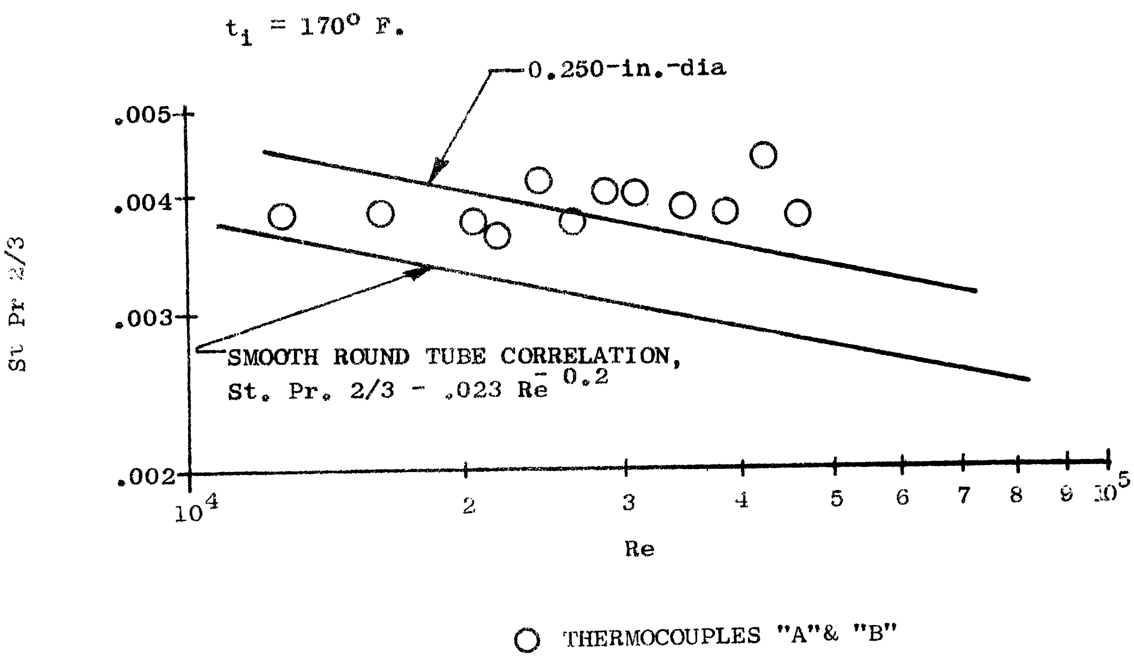


FIGURE 49

PLOT OF DATA FROM THERMAL CAPACITANCE DISCHARGE TESTS

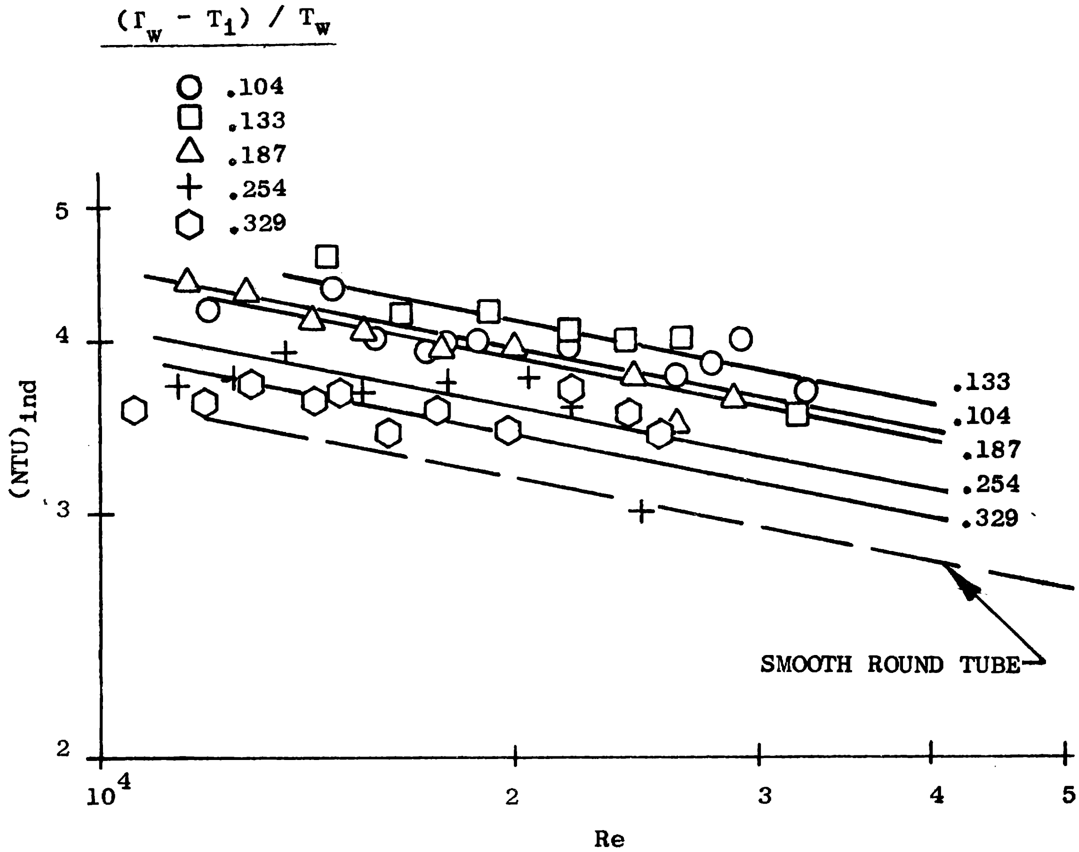


FIGURE 50

DETERMINATION OF THE EXPONENT, n, FOR THE TEMPERATURE DEPENDENT PROPERTIES CORRECTION TO THE ISOTHERMAL HEAT TRANSFER CORRELATION (REYNOLDS' ANALYSIS) RE = 30,000

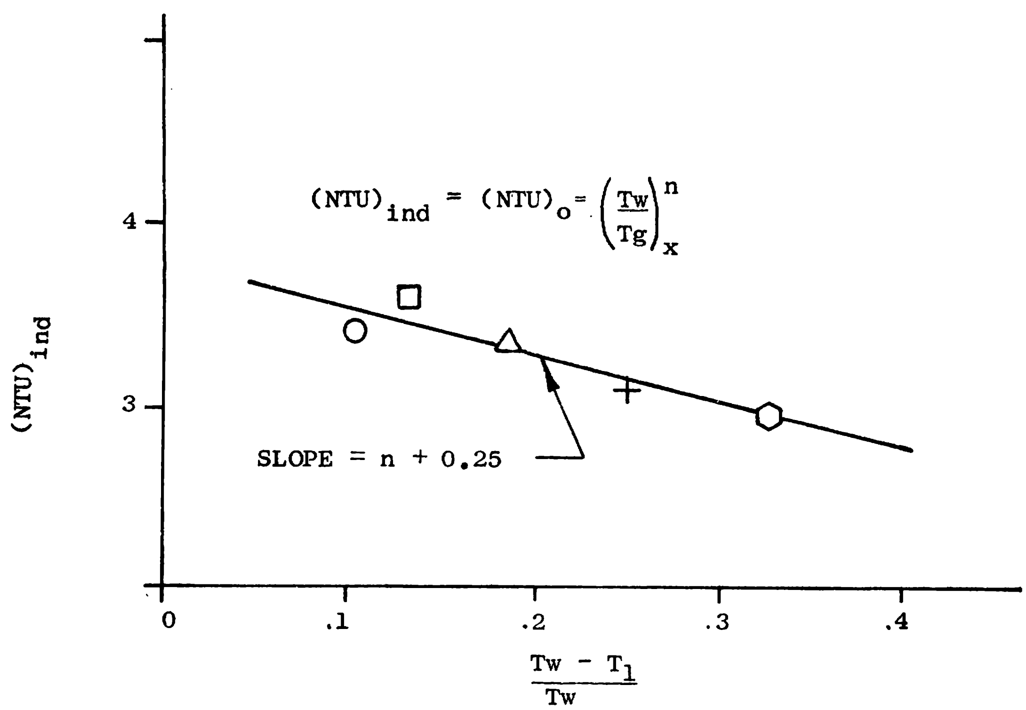


FIGURE 51

Accomplishments - June:

The friction factor was measured in the Reynolds number range from 900 to 50,000 on a model of the IB-9R in-pile fuel element. Eight flow control orifice sizes were calibrated.

A pitot-static probe was installed in the model of the IB-9R and calibrated for the nominal cold position, for the estimated hot position, and for several other positions made possible by fabrication tolerances. The Pitot constant proved to be insensitive to position with the IB-9R fuel element.

The friction factor for the prototype model of the ML-1 was measured in the Reynolds number range from 900 to 50,000. This friction factor agreed well with the friction factor measured six months ago on the first model of the IB element. Flow control orifices are being calibrated with the prototype model of the ML-1 fuel element.

Four mass transfer tests were run, the first two to develop technique. Improvements were made in the procedure for measuring the radius and in the device for measuring pressure, based on the first two tests. The third test was successful, and the fourth was run to determine the reproducibility of data and to provide additional evidence. The data was reduced and is consistent for the two runs.

An electrically-heated test section was designed for the IB fuel element.

Anticipated Accomplishments - July:

Data from the mass transfer tests will be evaluated further.

The flow control orifices will be calibrated for the ML-1 fuel element.

Mass transfer tests will be continued to determine the variation of the ratio of local heat transfer coefficient around the pins to the average heat transfer coefficient at a cross-section.

Material will be purchased for an electrically heated test section, and fabrication will start.

4. Materials Evaluation (Task 21-4XX)

Summary - January through May:

a. Gas Corrosion Tests: (Note: The following material covers only the corrosion studies being performed under the ML-1 program. Those studies performed for the GCRE-II program are reported in that section of the report. This separation is for reporting purposes only: the work was carried on simultaneously in the same work area.)

Hastelloy X and Inconel (the reference and back-up alloys for cladding fuel pins) were exposed to the ML-1 reference coolant gas (99.5 vol% N_2 + 0.5 vol% O_2) and air for periods up to 5000 hr at 1750°F, the ML-1 hot spot temperature. Results of metallographic examination and weight measurements are shown in Table 10.

TABLE 10. RESULTS OF LONG TERM GAS CORROSION TESTS AT 1750°F
(Reference - Hastelloy X - and back-up - Inconel - fuel cladding alloys at 300 psi in 99.5 vol% N_2 + 0.5 vol% O_2, and air at 1750°F)

	HASTELLOY X		INCONEL	
Time, (hours)	Penetration (inches)	Weight Change (gm/cm^2)	Penetration (inches)	Weight Change (gm/cm^2)
1000	0.0010	+0.00070	---	---
2500	0.0012	+0.00118	0.0017	+0.00160
5000	0.0015	+0.00118	---	+0.00183
1000 (air)	0.0020	+0.00050	0.0009	+0.0086
2500 (air)	0.0027	---	0.0023	---
5000 (air)	0.0016*	-0.00212	0.0020	-0.00054

*on the basis of a single specimen

Hastelloy X and Inconel demonstrated excellent corrosion resistance for periods up to 5000 hr. Corrosion tests are continuing to obtain information on the effects of the full 10,000 hr of operating life. The extent of attack on these alloys after 5000 hr at 1750°F are illustrated in Figures 52 through 57. Figures 52 and 53 are photomicrographs at 250x of the alloys in the as-received condition. Figures 54 and 55 show the extent of corrosion in 300 psi reference gas (99.5 vol% N_2 + 0.5 vol% O_2) and Figures 56 and 57 show the extent of corrosion in 300 psi air.

Exposure to gas at elevated temperatures reduces the romm temperature ductility of nickel alloys. This reduction is particularly noticeable on Hastelloy X. Data on the strength and ductility of Hastelloy X at room temperature after exposure to corrosion is shown in Table 11 on the next page. This reduction in ductility could cause poor fatigue strength and reduced notch resistance. (Improved ductility after exposure is an objective of an alloy modification task discussed later in this section.)

b. Creep Tests: Long term creep tests were performed to provide design data at the temperatures and stresses expected in operating the ML-1. The relative secondary creep rates of Hastelloy X and Inconel 702 are illustrated in Figure 58. These tests were begun before Inconel was designated the back-up alloy for cladding fuel, but the creep of Inconel 702 is considered similar to that of Inconel.

TABLE 11. AVERAGE TENSILE STRENGTH (SHORT TIME, ROOM TEMPERATURE) OF HASTELLOY X AFTER GAS CORROSION

Exposure	Ultimate Tensile Strength, psi	0.2% Offset Yield Strength, psi	% Elongation
REFERENCE	114,900	66,200	43
2500 hr, 1750°F, 300 psi Ref. Gas	107,800	50,000	31
5000 hr, 1750°F, 200 psi Ref. Gas	92,000	55,200	15
5000 hr. 1750°F, 300 psi Ref. Gas	103,100	49,500	36
1000 hr, 1850°F, 300 psi Ref. Gas	104,800	51,000	28
2500 hr, 1850°F, 300 psi Ref. Gas	35,600	55,300	4
2500 hr, 1750°F, 300 psi Air	93,400	48,200	33
5000 hr, 1750°F, 300 psi Air	97,500	54,600	23

c. Tube Tests: Early experience with Hastelloy X tubing showed that empty tubing collapses when subjected to 300 psi external pressure at 1600 to 1750°F. Pellets were placed in Hastelloy X tubing of the reference size, and the space between the pellets deliberately varied. These samples were exposed to 300 psi external pressure at 1750°F to determine the effects of external pressure on tubing containing fuel pellets. The results of 500 hr at 1750°F at 300 psi external pressure are shown in Figure 59.

The Hastelloy X tubing buckled severely (creep buckling) wherever there were large gaps between fuel pellets. The magnitude of the buckling was unexpected.

An investigation now is being made of the collapse of Hastelloy X tubing (with ML-1 tolerances) without space between pellets. The mode of collapse and the effect on corrosion will be determined. This investigation also will evaluate the effect of several factors on the uniformity of collapse. These factors include the inner diameter of the tubing and the tolerances for outer diameter of the pellets.

d. Fuel Oxidation: A potential problem in operating the ML-1 is the oxidation of fuel through leakage of coolant gas into defective, hot fuel pins. In the first experiments, clad UO_2 pellets were exposed to the reference atmosphere through a defect in the cladding. The results showed that oxidation caused the cladding to bulge. X-ray diffraction analysis of the oxidation product and data on weight changes revealed that U_3O_8 was formed.

Later tests demonstrated that UO_2 pellets readily oxidize to U_3O_8 in the presence of even trace amounts of oxygen. In these tests, unclad BeO-UO_2 pellets were exposed to air at 300 psi at 1750°F, and bare UO_2

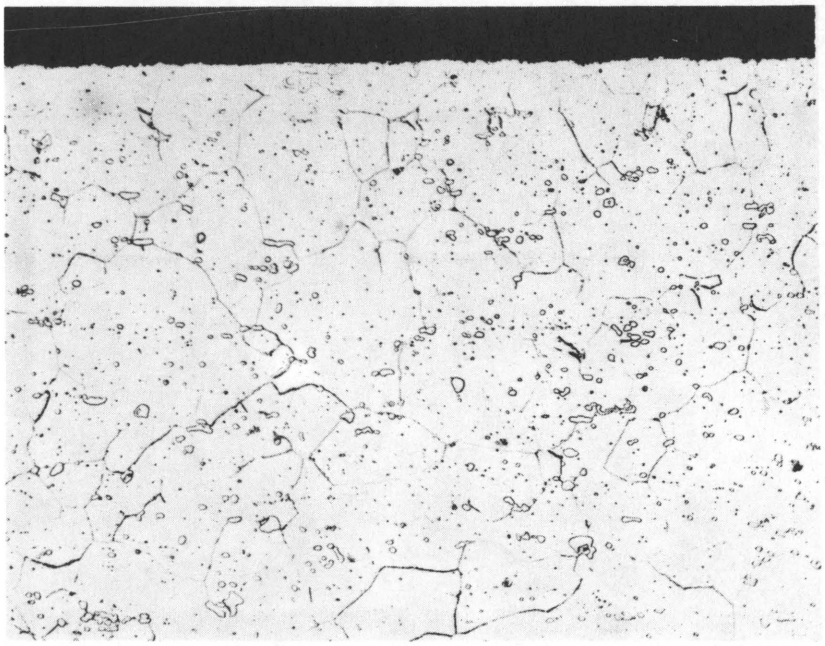


FIGURE 52
HASTELLOY X-AS-RECEIVED AT 250 X

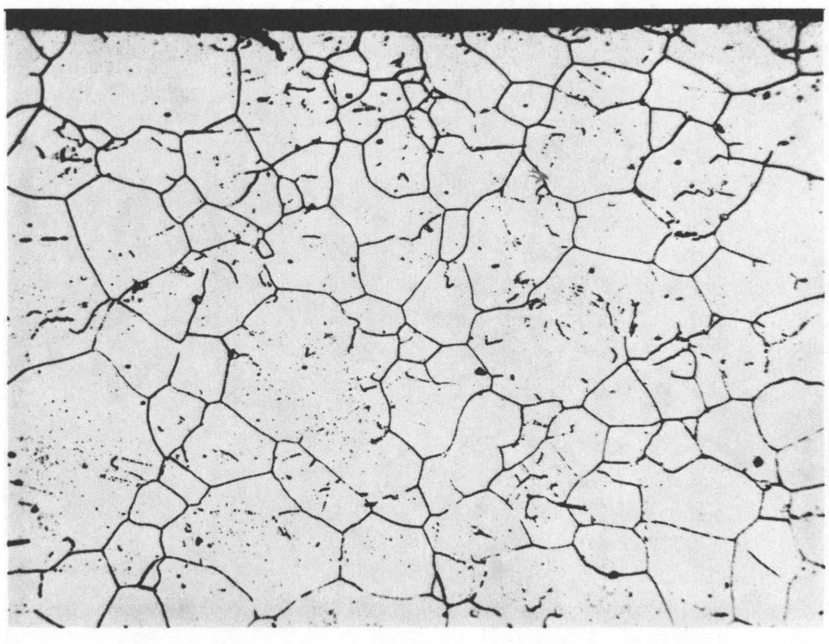


FIGURE 53
INCONEL-AS-RECEIVED AT 250 X

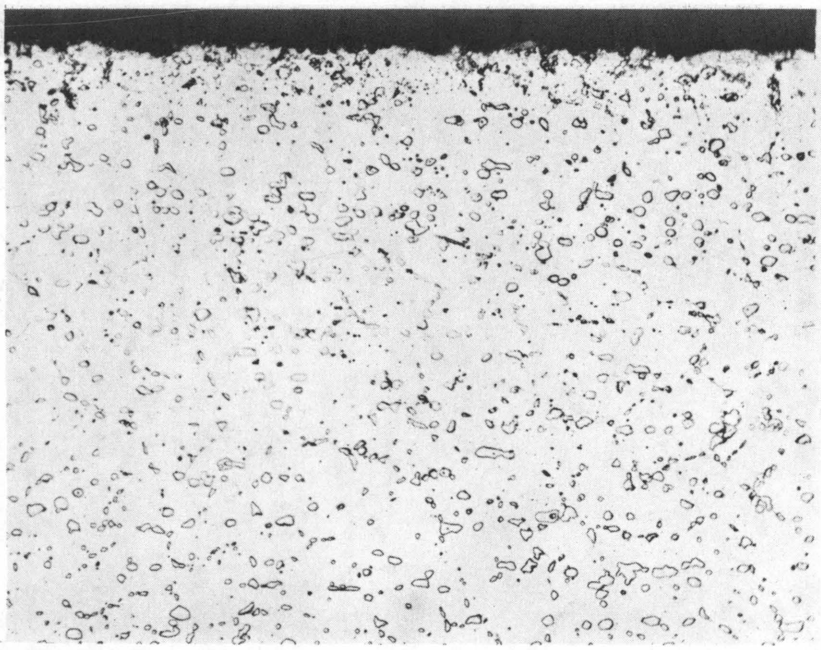


FIGURE 54
HASTELLOY X AFTER 5000 HR AT 1750°F in 300 Psi 99.5 VOL % N_2 + 0.5 VOL % O_2.250X

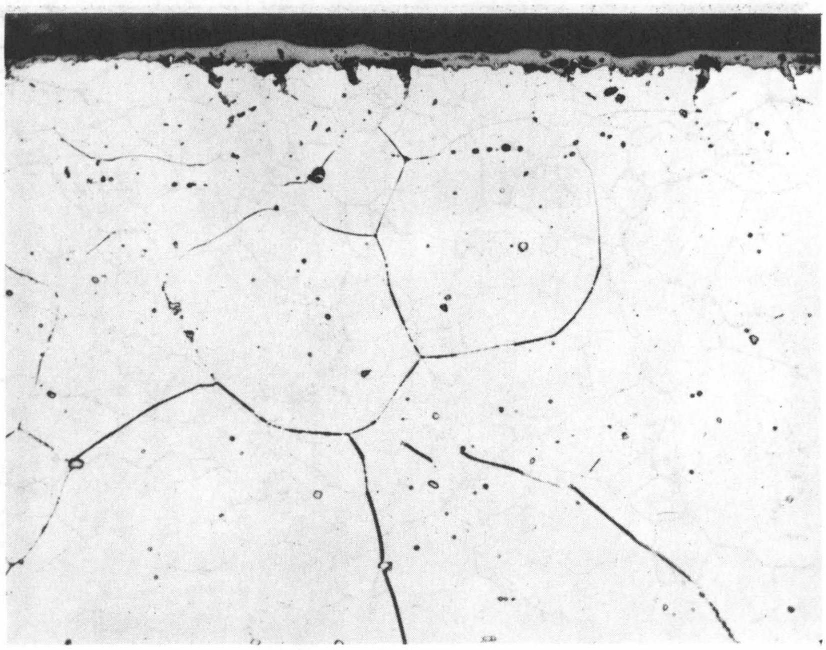


FIGURE 55
INCONEL AFTER 5000 HR AT 1750°F IN 300 Psi 99.5 VOL % N_2 + 0.5 VOL % O_2.250X

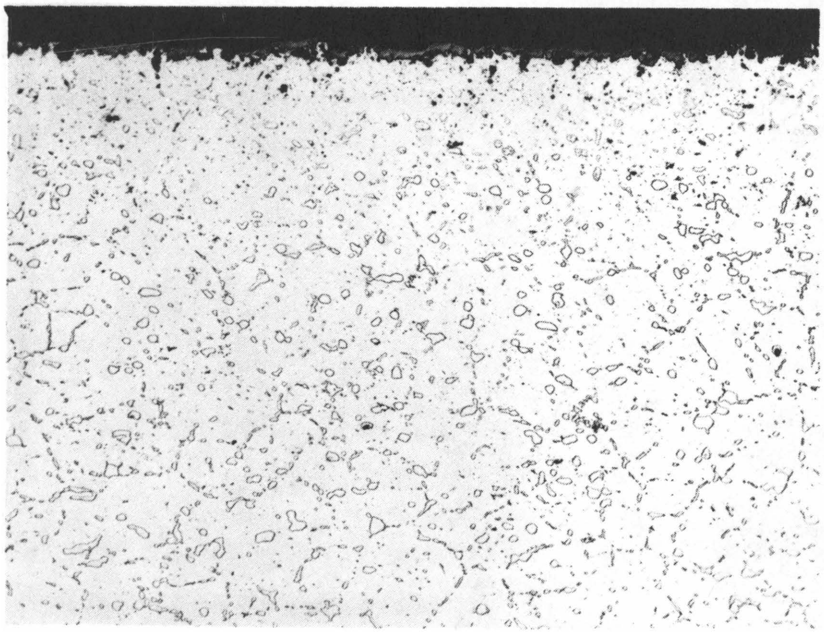


FIGURE 56
HASTELLOY X AFTER 5000 HR AT 1750°F IN 300
Psi AIR .250X

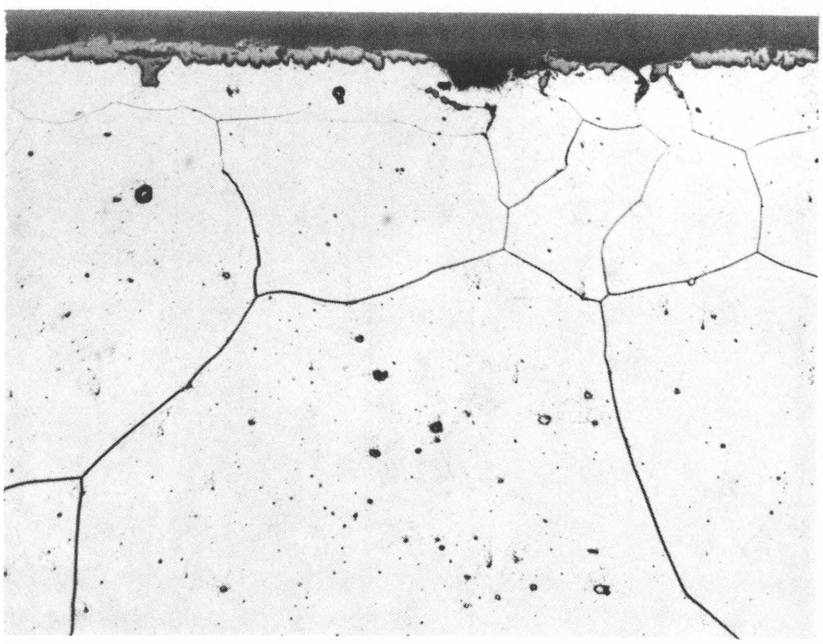


FIGURE 57
INCONEL AFTER 5000 HR AT 1750°F IN 300
Psi AIR. 250X

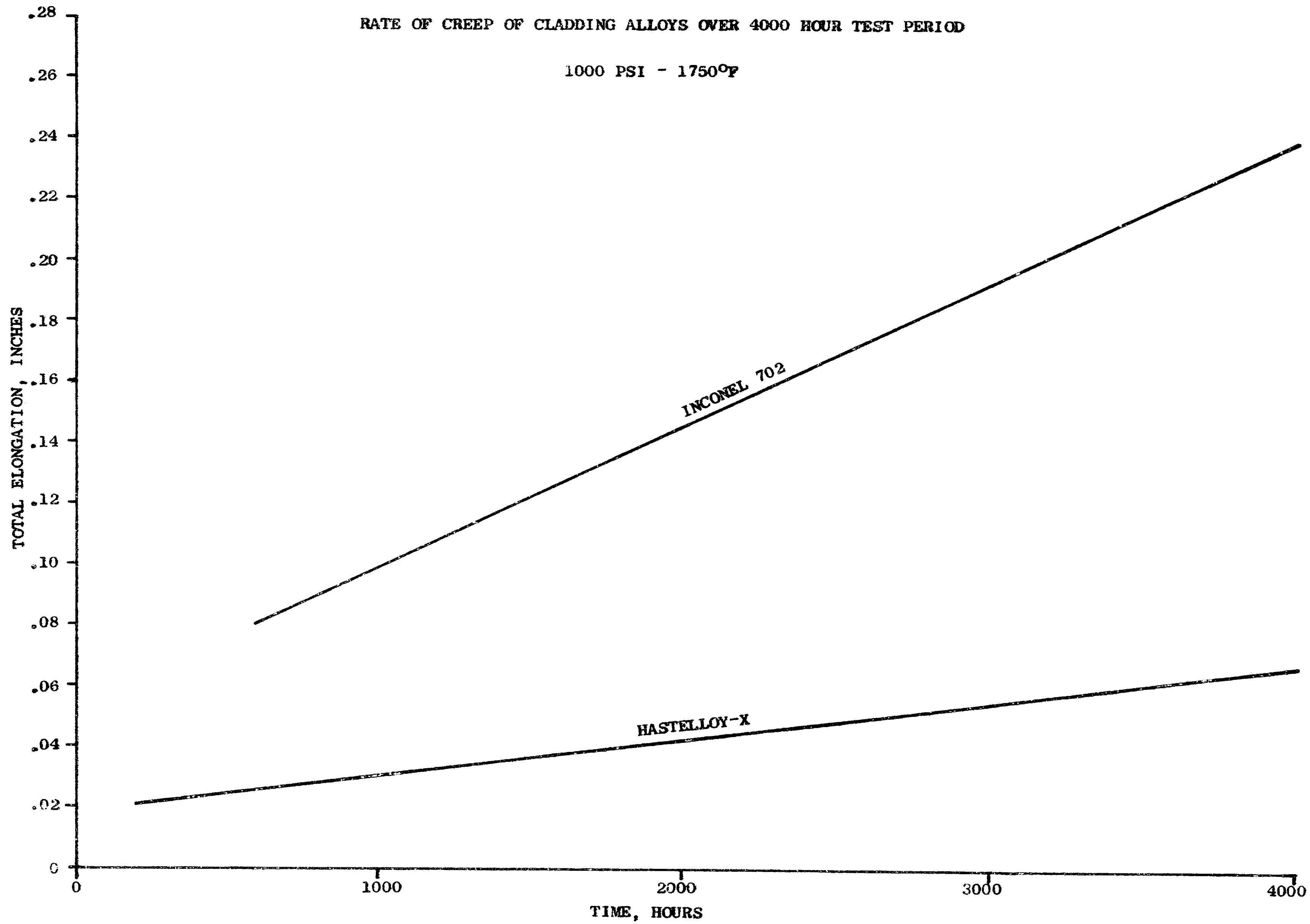

RATE OF CREEP OF CLADDING ALLOYS OVER 4000 HOUR TEST PERIOD
1000 PSI - 1750°F
TOTAL ELONGATION, INCHES
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
INCONEL 702
HASTELLOY-X
0
1000
2000
3000
4000
TIME, HOURS

FIGURE 58

TUBES OF PELLETS AFTER BEING SUBJECTED TO EXTERNAL PRESSURE

(AFTER 500 HOURS AT 1750° F, 300 PSI EXTERNAL PRESSURE, HASTELLOY X)

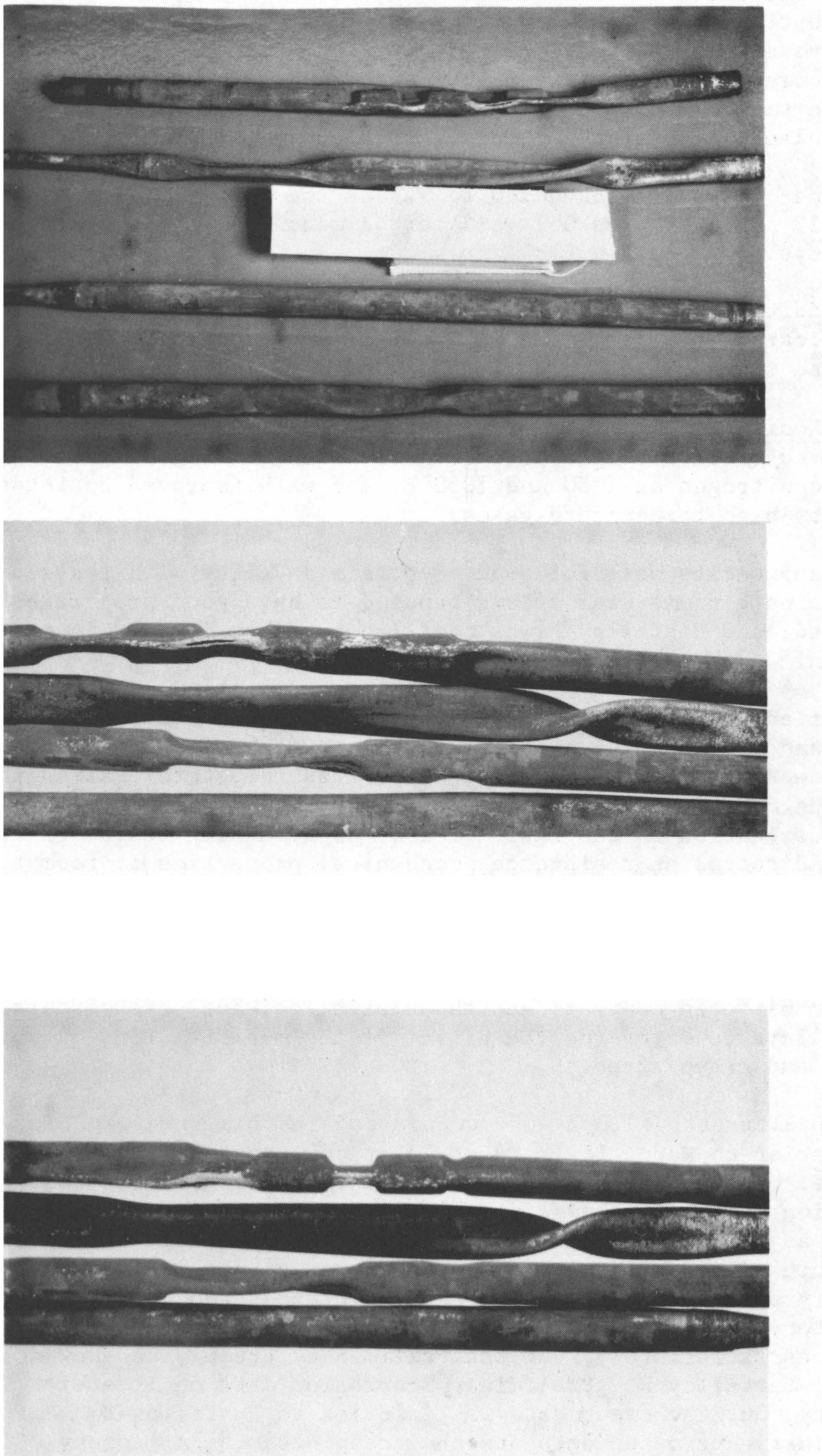


FIGURE 59

pellets were exposed to high purity (about 2 to 3 ppm oxygen) nitrogen for 1000 hr at 1750°F. Possible solutions to the oxidation problem include the use of alternate coolant gas (to prevent oxidation), or the use of particle coatings (such as Al_2O_3, BeO, Ni, Cr, Ni-Cr) to prevent oxidation and to improve retention of fission gas. The tests performed with high-purity nitrogen gas demonstrated that even two to three parts/million of oxygen were sufficient to oxidize the UO_2 to U_3O_8: greater than normal corrosion also was observed on the cladding alloys in this test.

Further tests are scheduled to assess the compatibility of a mixture of 99.9 vol% nitrogen plus 0.1 vol% carbon monoxide with UO_2 and reference nickel alloys.

In addition, a limited program was started to determine the feasibility of coating UO_2 particles with ceramic. Details cannot be reported here because the work is classified.

e. <u>Alloy Modification</u>: The goals of this effort are to produce an alloy with improved creep strength at 1750 and 1850°F, with good ductility after exposure to nitrogen at 1750 and 1850°F, and with improved resistance to corrosion by high temperature gases.

Two approaches were followed to obtain an alloy with these properties: Alternate commercial alloys reputed to have good properties were investigated; and Hastelloy X was modified by minor changes in chemical composition.

Modified Hastelloy X alloys (Table 12) were fabricated into test specimens and screened for creep strength and corrosion resistance. The results show that yttrium reduces the elevated temperature strength and improves the corrosion resistance. Six alloys were selected for additional investigation on the basis of 1000 hr screening tests for creep strength and corrosion resistance, mechanical properties at room temperature, and metallographic examinations. (The alloys selected for further investigation are marked * in Table 12.) Three lines of investigation are being followed: Studies of X-ray diffraction and fluorescence to evaluate structural changes; vacuum fusion analysis to determine the increase in nitrogen content; and the statistical analysis of data on modified alloys to determine the effect of the modifications on corrosion resistance and creep strength.

Seven alternate alloys were considered in this investigation. All proved inferior to Hastelloy X in at least one characteristic. The chemical analyses of these alloys are tabulated in Table 13. The results of gas corrosion tests are shown in Table 14. Evaluation of these alloys is summarized as follows: The Martin alloys were unsuitable from the standpoint of both creep strength and corrosion resistance. Nichrome V showed satisfactory corrosion resistance, but the creep strength at 1750°F was unsatisfactory. Preliminary corrosion data on Nichrome V-Nb (columbium modified) was satisfactory, but the preliminary creep data showed it was inferior to Hastelloy X. Preliminary corrosion data on Inconel 600 was satisfactory, but the creep data was inferior to Hastelloy X. Both the preliminary corrosion data and the creep data for Allegheny G-175 was unsatisfactory.

Table 12. CHEMICAL ANALYSES OF MODIFIED HASTELLOY X ALLOYS

Modified Alloy No.	Ni	Cr	Mo	Fe	C	Y	Nb
61*	45	21	10	20	0.1	0	--
62	"	"	"	19.5	0.1	0.5	--
63*	"	"	"	19.0	0.1	1.0	--
64	"	"	"	20.0	0.01	0	--
65*	"	"	"	19.5	0.01	0.5	--
66	"	"	"	19.0	0.01	1.0	--
67	"	"	"	18	0.1	0	2.0
68	"	"	"	17.5	"	0.5	2.0
69	"	"	"	17.0	"	1.0	2.0
70	55	"	"	10	"	0	--
71*	"	"	"	9.5	"	0.5	--
72	"	"	"	9.0	0.1	1.0	--
73	"	"	"	10	0.01	0	--
74*	"	"	"	8	0.1	0	2.0
75	45	25	"	15	0.1	--	--
76	"	"	"	14.5	0.1	0.5	--
77	"	"	"	14.0	0.1	1.0	--
78*	"	"	"	20.0	0.01	--	--
79	"	"	"	18	0.1	--	2.0

*Selected for further investigation.

Note: All modified alloys contained 1.0 wt%, maximum, of manganese and silicon; and 0.7 wt%, maximum, tungsten.

f. Evaluation of $BeO-UO_2$ Capsule for the BRR-GCR-2: A capsule of conventional, double wall design (with auxiliary heater) was used for irradiation of six specimens suspended in NaK. The specimens consisted of BeO/59 wt% UO_2 pellets clad in Hastelloy X, 0.030-in. thick. Each pellet was 0.158-in. OD by 0.177-in. long and achieved 97% of theoretical density. The specimen was fueled for about one inch, and the total length of the specimen was less than 1½-in. The specimen was designed to operate at $1750^{o} \pm 50^{o}F$ to a burn-up of about 3.0 atom% in the Battelle Research Reactor (BRR). Irradiation of the capsule began 11 January and was completed 12 March at a burn-up estimated to be 2.8 atom%. (Dosimeter evaluation later showed about 2.0 atom% U-235.) A typical temperature profile is shown in the table on the following page.

A TYPICAL TEMPERATURE PROFILE

Specimen Number	1	2	3 top	3 center	4	5	6
Specimen Surface Temp., °F	670*	1720	1640	1740	1730	1630	1440

*Thermocouple data considered erroneous.

Table 13. CHEMICAL ANALYSIS OF ALTERNATE ALLOYS

	Ni	Cr	Fe	Mn	Nb
Nichrome V	Balance	19/20	1.0 max	2.5 max	--
Nichrome V-Nb	Balance	19/20	2.0 max	1.0 max	2.0 max
Inconel 600	Balance	14/17	6/8	1.0 max	1.75/ 2.75

	Cr	Fe	Mn	Nb	Ti	Al	Zr
Martin DB-1	5.7	Balance	--	1.25	0.5	7	0.6
Martin DB-2	5.5	Balance	--	3.7	0.3	7	0.7
Martin DB-3	5.7	Balance	--	0.9	--	7	0.5
Allegheny G-157*	27 max	6 max	1.0 max	--	1.5	0.5	--

*Balance Ni. Also contains 2.0 max Mo, 1.5 W.

All alloys contain 0.1 carbon.

Table 14. GAS CORROSION SCREENING OF POSSIBLE ALTERNATE ALLOYS

	Maximum Corrosion Penetration, in.	Weight Change*, grams/cm^2
Nichrome V-Nb	0.0005	+ 0.00050
Inconel 600	0.0006	+ 0.00088
Nichrome V	0.0010	+ 0.00010
Type 310 Stainless Steel	0.0015	- 0.00091
Martin Nuclear Fe-Al-Cr	0.0021	+ 0.00167
Allegheny Ludlum G-157	0.0030	+ 0.00179

* Weight change in grams/cm^2 after 1000 hr in 300 psi 99.5 vol% N_2 plus 0.5 vol% O_2.

Hot cell evaluation started in mid-March and was almost complete by mid-April. Specimen removal was normal. Neither measurements nor macro-examinations revealed any obvious flaws or defects in the irradiated specimens. Specimens 3 and 6 (see table at top of page) were then punctured to draw off any fission gases. The BeO-UO_2 pellets in specimens 3 and 6 were removed from the cladding for macro- and micro-examination. Macroscopic examination failed to reveal any change in the pellets. Small changes in dimension were noticed (Table 15). Microscopic examination of both pellets and cladding failed to reveal any reaction. There was no observable change in the microstructure of the $BeO-UO_2$, or in the size or shape of the UO_2 that could be attributed to either irradiation or extended periods at high temperature.

Table 15. DIMENSIONAL EVALUATION OF $BeO-UO_2$ SPECIMENS

Specimen	Length, in. Pre	Post	Diff	Diameter, in. Pre	Post	Diff
3	.1802	.1788	-.0014	.1589	.1587	-.0002
	.1749	.1746	-.0003	.1587	.1587	N/C
	.1753	.1738	-.0015	.1587	.1585	-.0002
	.1812	.1807	-.0005	.1588	.1580	-.0008
6	.1768	.1768	N/C	.1587	.1590	+.0003
	.1791	.1791	N/C	.1586	.1590	+.0004
	.1764	.1761	-.0003	.1586	.1589	+.0003
	.1769	.1772	+.0003	.1590	.1590	N/C

Specimen	Weight, g Pre	Post	Diff	Density, g/cc Pre	Post
3	.2887	.2855	-.0032	5.038	5.10
	.2823	.2818	-.0005	5.033	4.99
	.2789	.2772	-.0017	5.035	5.02
	.2895	.2890	-.0005	5.027	4.96
6	.2822	.2819	-.0003	5.037	4.92
	.2842	.2840	-.0002	5.020	4.95
	.2817	.2820	+.0003	5.010	4.95
	.2835	.2779	-.0056	5.012	4.94

The release of fission product gas detected from Specimen 3 was 0.001% of all products predicted to be generated. The fission product release from Specimen 6 was lower than that detected from Specimen 3.

Isotopic burn-up analysis is being performed by Phillips Petroleum Co., Idaho Falls, Idaho, on pellets from both specimens.

g. Other Capsule Irradiation: Irradiation of two other capsules is planned: a capsule for the Materials Testing Reactor and an additional one for the BRR. The MTR/GCR-2 capsule will contain six pellets, 70 wt% $BeO-UO_2$, clad with Hastelloy X 0.030-in. thick. This capsule is scheduled to begin irradiation on 21 August and complete 105 days (about seven MTR cycles) on 1 February 1961. It is scheduled to receive about 9.2 atom% U-235 burn-up at $1750^{\circ}F$. This will provide irradiation of the ML-1 reference fuel to the equivalent burn-up of 10,000 hr of ML-1 operation.

The capsule for the BRR will contain six solid, highly-enriched UO_2 pellets clad with Hastelloy X 0.030-in. thick. Irradiation will start 1 August and be completed on 15 January through about 11 BRR cycles, about 124 days. It is planned to achieve about 2 atom% U-235 burn-up, at 1750°F, the equivalent of 10,000 hr of ML-1 operation. Specimen design and fabrication is almost complete at Aerojet, San Ramon.

h. Thermal Fatigue Tests: A machine was designed and is being fabricated to thermally cycle production Hastelloy X tubing to investigate the effects of thermal stresses. The machine will use resistance heating to heat a specimen 8-in. long to 2000°F in air and then cool the specimen by forced draft to 300 to 400°F at the rate of at least 40°F/sec. Tests conducted on incomplete equipment show that 1620°F could be reached in still air and a cooling rate of 31°F/sec was obtained. Heavier leads are being installed to make higher temperatures possible. Automatic timing controls and mufflers also are being installed.

i. Burnable and Permanent Poisons: A foil containing 0.4 grams of cadmium is considered necessary for burnable poison for each element in the IB-2L and ML-1 fuel elements. The availability, ductility and high melting point (1020°F) of a cadmium/copper (about 1 wt% cadmium) alloy made it the best material for the burnable poison. Most other alloying elements were discarded because of either high thermal-neutron cross-section, or low melting point (estimated hot spot temperature is 870°F). Cadmium/copper is commercially available and is being procured with the highest possible cadmium content per sheet. Foils received so far have varied between 0.76 and 1.02 wt% cadmium.

The alloy is difficult to melt because of the narrow temperature range at which cadmium exists as a liquid. The material also is difficult to roll because a brittle two-phase region forms under certain cooling conditions. Quantitative chemical analysis for cadmium proved difficult.

A permanent poison will be used in the IB-2L fuel element to reduce the active core length to that used in the ML-1 fuel elements. The poison concentrations required for the IB-2L fuel element are shown in the table below:

THICKNESS OF NATURAL CONCENTRATION OF ISOTOPES
NEEDED FOR PERMANENT POISON IN THE IB-2L FUEL ELEMENT

ELEMENT	THICKNESS (inches)
Boron	9.63×10^{-4}
Cadmium	11.7×10^{-4}
Europium	18.0×10^{-4}
Samarium	23.6×10^{-4}
Gadolinium	171.0×10^{-4}

An alloy of 35 wt% cadmium/silver was selected because of availability and relatively high melting point (1360°F solidus). The "blackness" of cadmium 0.012-in. thick reduced the importance of cross-section, permitting the use of silver. This alloy is commercially available and has been used in pressurized water reactors.

Cladding studies were performed on both cadmium/copper and cadmium/silver alloys. Little information is available in the literature on the corrosion resistance of these alloys at ML-1 conditions. Electroless nickel plating proved to be the most desirable cladding procedure. Production size specimens were roll-formed without cracks in the cladding, and a vendor produced a high-integrity coating. (Brazing appeared to be a promising method of cladding, but excessive numbers of wrinkles were found on production-size samples.)

Two basic corrosion tests were conducted on reference permanent and burnable poison materials. Tests were conducted in a flow of reference atmosphere (about 5 ft^3/hr) at 870°F for 500 hours. Galvanic tests were performed at room temperature in water with a full size element (without fuel pins) and with samples in contact in beakers of water. Samples of bare cadmium/copper, nickel-clad cadmium/copper, and bare cadmium/silver were exposed in the high-temperature tests. The bare cadmium/copper oxidized and spalled at a rate calculated to be about 0.001-in/500 hr. There was no apparent oxidation on the nickel-clad specimens after 892 hr. The cadmium/silver alloy exhibited a black adherent oxide after 967 hr.

j. Tubing Defects: Production Hastelloy X tubing is being inspected to determine the magnitude and mode of defects. These tubes were produced from sheet formed into tubing before welding and drawing it to the required dimensions. All except the last draw was followed by annealing at 2050°F for 15 minutes in an oxidizing atmosphere. The last draw was followed by annealing in hydrogen. Metallographic examination of the tubing revealed the following:

1) The cast structure of the weld zone was not obliterated by the drawing and heat treating operations.

2) Carburized zones exist in the tubing, especially in cracks found in welds. These cracks do not permit the escape of entrapped drawing compounds, producing brittle, carburized regions.

3) From 5 to 10% of production tubing contained small cracks about 0.001-in. deep on the inside surfaces of the welds.

4) Grain size was uniform throughout the pieces and between pieces, except in the weld zone.

A program was outlined for the evaluation of production tubing. The program incorporates chemical, physical and mechanical tests of seamless and weld-drawn tubing.

k. Design and Fabrication Support: A test was performed by a vendor to determine the thermal conductivity (k) parallel to the insulating fibers of the insulation for the IB-2L fuel element. (Normal usage and reported k values are for the direction perpendicular to the fibers.) These results indicate that k increases 45 to 55% over the values for use of the fibers perpendicular to the heat flow. The value of k (Btu/in.-ft^2-$^\circ$F) at 800°F mean temperature is 0.85 for parallel and 0.55 for perpendicular. At 1000°F, k is 0.96 for parallel and 0.66 for perpendicular to the heat flow.

Accomplishments - June:

a. Gas Corrosion Tests: Tests were completed on Hastelloy X, Nichrome V, and Martin Fe/Al/Cr alloys at 1850°F in 300 psi in the reference atmosphere.

Metallographic examination of Hastelloy X exposed for 1000 hr showed maximum penetration of 0.0013-in. Room temperature tensile tests produced the following data: ultimate tensile strength, 104,800 psi; 0.2% yield strength, 51,000 psi; and 28% elongation.

Hastelloy X is better than Nichrome V as a fuel element alloy due to superior creep strength.

Gas corrosion tests of the Martin alloys were terminated when metallographic examination showed severe oxidation.

Gas corrosion tests on tensile specimens of Hastelloy X, Inconel, and Inconel 702 were terminated after 5000 hr at 1750°F in 300 psi reference atmosphere. Tests of Nichrome V-Nb were terminated after 2500 hr at 1750°F in 300 psi reference atmosphere. Tests of Allegheny Ludlum G-157 were terminated after 1000 hr at 1750°F in 300 psi reference atmosphere.

Specimens of Hastelloy X, Inconel, and Inconel 702 were aged for 2500 hr at 1750°F in a capsule filled with high purity argon. The test was performed to determine the effects of aging without the influence of corrosion and nitrogen diffusion.

b. Creep Tests: Two 1000-hr creep screening tests at 1750°F at 1000 psi stress were completed on modified Hastelloy X and alternate alloys. Analysis of this and earlier data confirms two conclusions: the addition of yttrium to Hastelloy X decreases the creep strength of the alloy; and none of the alternate alloys is comparable in creep strength to Hastelloy X.

A creep rupture test at 1750°F and stresses of 3000, 4000 and 5000 psi was completed on commercial and low-cobalt Hastelloy X specimens. The commercial Hastelloy X proved slightly stronger than the low-cobalt Hastelloy X.

c. Tube Tests: Specimens were prepared for testing the collapse of Hastelloy X tubing around stacks of UO_2 fuel. In a similar test run for 70 hr, there was slight collapse of Hastelloy X tubing under ML-1 hot spot conditions (1750°F and 300 psi external gas pressure).

d. Fuel Oxidation Tests: UO_2 pellets are being exposed to high purity nitrogen (20 ppm of oxygen, maximum) at elevated temperatures. The test is to run for 1000 hr. The purpose of the test is to determine the physical changes in UO_2 pellets under such conditions.

Specimens were fabricated to simulate defective fuel pins. UO_2 and BeO-UO_2 pellets are encased in Hastelloy X tubing with a hole 0.004-in. in diameter at one end. Two configurations were prepared to simulate a leak at either the upper or the lower portion of the fuel pin.

e. Alloy Modification: Fifty-pound heats were prepared of each of the six favored modified Hastelloy X alloys at BMI, and rolled into strips. Initial examination was begun of specimens exposed to ML-1 reference gas for 1000, 2500 and 5000 hr. These examinations will provide data on the formation of oxide film, microstructural changes, and chemical changes. X-ray diffraction and fluorescence are being used in these studies.

f. BeO-UO_2 Capsule: No work was performed on this task during the period. Data on isotopic burn-up is not yet available.

g. Capsule Irradiation: Heat transfer calculations were completed at BMI for these two capsules. A nuclear mock-up of one capsule was operated in the BRR to obtain data on nuclear perturbation. Capsule fabrication was started.

Specimens of BeO/70 wt% UO_2, clad with Hastelloy X 0.030-in. thick, were fabricated at Aerojet, San Ramon, and shipped to BMI for irradiation in the MTR-GCR-2. Solid UO_2 specimens are being fabricated at Aerojet, San Ramon, for irradiation in BRR-GCR-3.

h. Thermal Fatigue Tests: Automatic timing controls are being installed on the machine for thermal fatigue testing.

i. Burnable and Permanent Poisons: Work under this task on burnable and permanent poisons was completed in May. Work performed in June on this subject is reported under Task 21-7XX, Fabrication Development.

j. Tubing Evaluation: A production tube was metallographically examined to determine the frequency and extent of defects not detected by the Radac eddy current machine. Sixty-five per cent of the areas examined in this tube contained defects 0.0005-in. deep or deeper, all on the inside surface of the weld. Sixty samples from 30 production tubes were mounted and will be examined for defects.

k. Design and Fabrication Support: Measurements of thermal conductivity of Thermoflex insulation (to be performed by the vendor) were delayed three weeks.

Anticipated Accomplishments - July:

a. Gas Corrosion Tests: Tensile tests will be performed at room temperature on samples of Hastelloy X and Inconel after 5000 hr exposure to 1750°F in the reference atmosphere, and on samples of the same alloys after aging 2500 hr at 1750°F in argon. These specimens will be metallographically examined for corrosion penetration and changes in microstructure.

The results of tests on three Martin Fe/Al/Cr alloys will be evaluated. The evaluation will conclude the work on these alloys.

b. Creep Tests: Creep tests will be completed to provide data on secondary creep rate for Hastelloy X under several stresses at 1750°F.

c. Tube Tests: A test to determine the mode and magnitude of collapse and corrosion effects will be started on reference Hastelloy X tubing fully loaded with natural UO_2. The samples will be exposed to 300 psi external pressure of reference gas at 1750°F for 200 hr.

d. Fuel Oxidation Tests: Tests will be started on simulated leaking fuel pins exposed to reference coolant gas and air. Data will be obtained on the rate of oxidation of the fuel stack and the resulting physical changes.

e. Alloy Modification: Specimens will be fabricated from six modified alloys and long term exposure begun in the reference gas.

Creep tests will begin on the six modified alloys, initially at 1750°F.

A statistical evaluation was completed on the 19 modified Hastelloy X alloys considered originally. The information from this study now will be correlated with planned corrosion experiments.

f. $BeO-UO_2$ Capsule: Isotopic burn-up data is expected from Phillips Petroleum Co. This data will be correlated with dosimeter data and heat balance calculations.

g. Capsule Irradiation: Fabrication of capsules will be completed at BMI, and the solid UO_2 capsule will be ready for irradiation. The $BeO-UO_2$ capsule will be ready for shipment to NRTS early in August.

Solid UO_2 specimens will be fabricated for the above capsule early in August.

h. Thermal Fatigue Tests: Equipment will be installed and tests started.

i. Burnable and Permanent Poisons: Work will begin on a rough draft of the final report summarizing the results of these tests.

Vendors of such materials will be evaluated to supply materials for use in the future.

j. Tubing Evaluation: Tests will continue on production tubing to obtain information on the size and frequency of defects. Liaison will continue with the inspection department to determine the accuracy and sensitivity of the Radac eddy current testing machine.

k. Design and Fabrication Support: Data will be available from tests of Thermoflex RF-600, -800, and -1200 at mean temperatures of 800 and 1000°F.

5. Fuel Design (Task 21-6XX)

Summary - January through May:

a. IB-2L Core: This core for the GCRE reactor is similar to the ML-1 first core except the end fittings are modified to fit the GCRE pressure vessel (Figure 60). The pin bundle proper in the IB-2L is similar to that in the ML-1 first core. The major differences are that the IB-2L core has welded tubing with an unfueled center pin (loaded with a Haynes-25 alloy rod) whereas the ML-1 has seamless tubing with the unfueled center pin loaded with ceramic.

Most of the drawings for this element were released before 1 January 1960. The burnable poison was being analyzed and developed during the period, and the drawings of this portion of the assembly were released during the period. At the beginning of the period, the theoretical study had determined the quantity and placement of the poison. The fabrication development study now is completed for the support of the poison foil and the protection of the foil from oxidation.

The characteristics of the IB-2L components were categorized to show the degree of importance of each inspection step in terms of critical, major or minor. The guide will be used by inspectors. The quantities of burnable poison material, the assay and content of fissionable material, and the means of sealing the fuel pellets completely in the pin tubing are the most important steps to ensure the element will have a long lifetime.

The stress analysis completed for the IB-2L fuel element revealed no major deviations from previous analyses. All components are designed to withstand elastic or shock stress at least four times more than predicted. The inner liner might be damaged in an accidental blowout of coolant gas; this weakness was eliminated by boring four holes, each 0.065-in. dia, in the liner.

Fabrication began on the IB-2L during the period. Extensive effort was directed toward developing fabrication techniques for the first core design.

b. IB-9R and IB-10R: The first two pin-type elements used in the GCRE before the IB-2L core is used will be the IB-9R and -10R. More extensive instrumentation will be used in these elements than in the IB-2L, including thermocouples to sense temperatures at the surfaces of the pins. These elements were detailed and the drawings released. (Additional information on these elements is reported in Task 21-9XX in this section.)

c. The ML-1 First Core: Fabrication drawings were released for the ML-1 first core (Figure 61). Basically the ML-1 fuel element assembly is a cylindrical tube, 32-in. long by 1.720-in. OD, that weighs about 10 lb. The active fuel length is 22-in. Each fuel element consists of a center pin containing a ceramic, such as BeO or MgO, six intermediate fuel pins loaded with fully-enriched UO_2 pellets, and 12 pins in the outer ring loaded with BeO-UO_2 pellets. The pins hang from an upper spider and are free to expand through a lower spider. Spiral wires run the length of the pin to serve as spacers. The pins are surrounded by an inner liner, a layer of insulation and an outer liner. The fuel pins are made of Hastelloy X tubes, 0.241-in. OD with 0.030-in. walls.

The fuel element retaining plate prevents upward movement of the fuel elements through the upper tube sheet. A seal is formed between the tube sheet and the fuel element to prevent escape of coolant gas. The coolant gas flows from the upper plenum down past the fuel pins. Thus gravity and coolant pressure tend to place the element structure and fuel pins in tension. The spider that supports the pins at the top of the element is designed to reduce pressure drop.

Lateral shift of the fuel pins is prevented by wires wrapped in a spiral four times around the full length of all but the center pin. The wire spacers, made of 0.040-in. Hastelloy X, are attached to the upper and lower pin lugs. These plugs are pressed into the ends of the fuel tube and Heli-arc welded into place. The lower ends of the pins are spaced by the lower spider. The lower spider prevents the pins from dropping into the lower plenum if the primary support of the pins fails. Each lower pin plug has a cylindrical section that slides freely through an aperture in the lower spider to accommodate differences in thermal expansion.

The power between pins is adjusted to equalize maximum metal temperatures. More uranium is placed in the intermediate pins than in the outer 12 to equalize wall temperatures among the pins because the thermal neutron flux is lower in the center of an element. The intermediate pins are filled with fully enriched UO_2 pellets (nominally 0.177-in. dia by 0.325-in. long) and the 12 outer pins are filled with BeO-UO_2 pellets about 40 vol% highly-enriched UO_2. The BeO-UO_2 pellets are nominally 0.176-in. dia by 0.22-in. long. All pellets are cold-pressed and sintered to about

1B-2L FUEL ELEMENT

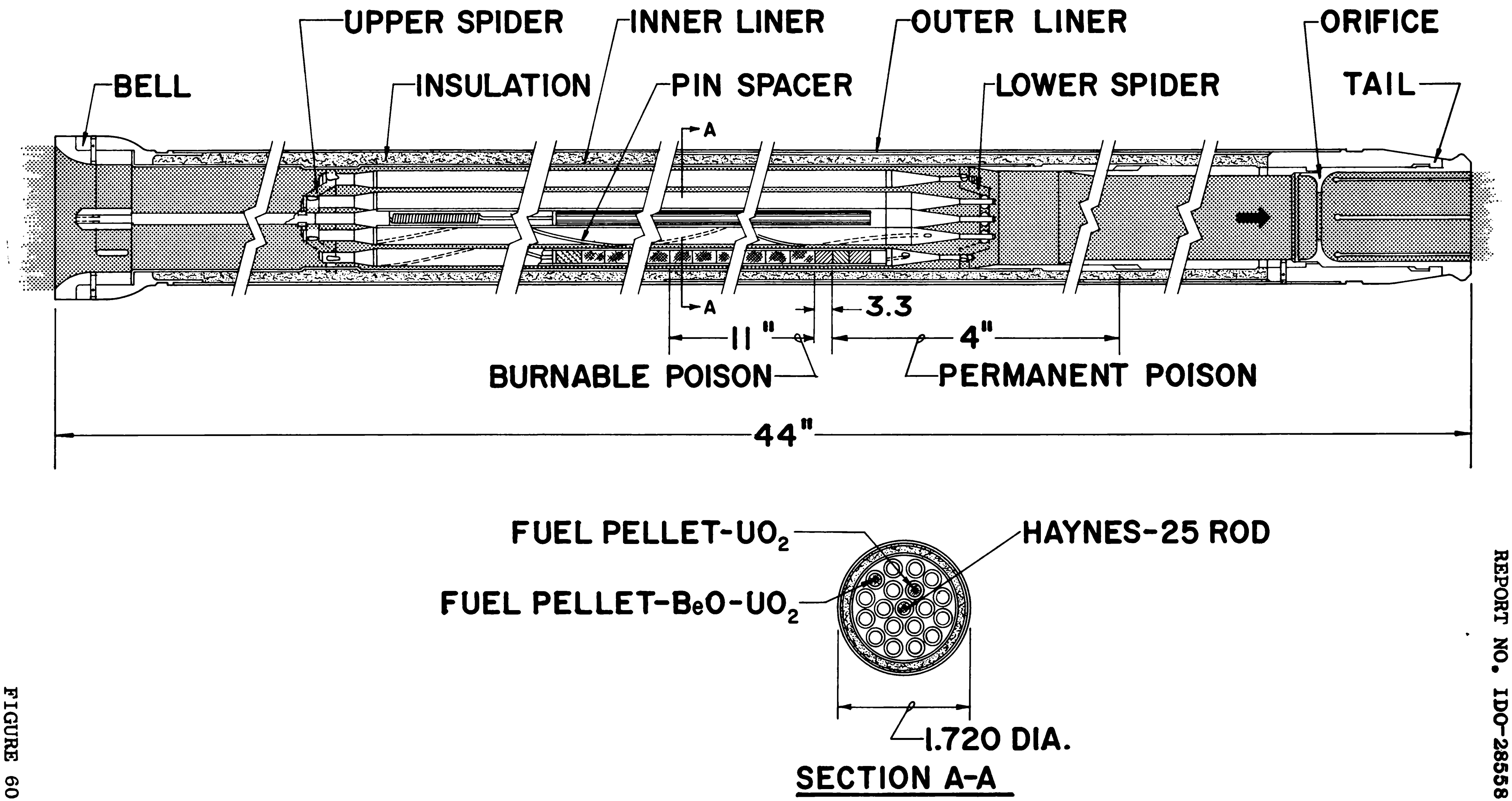


FIGURE 60

ML-1 FIRST CORE FUEL ELEMENT

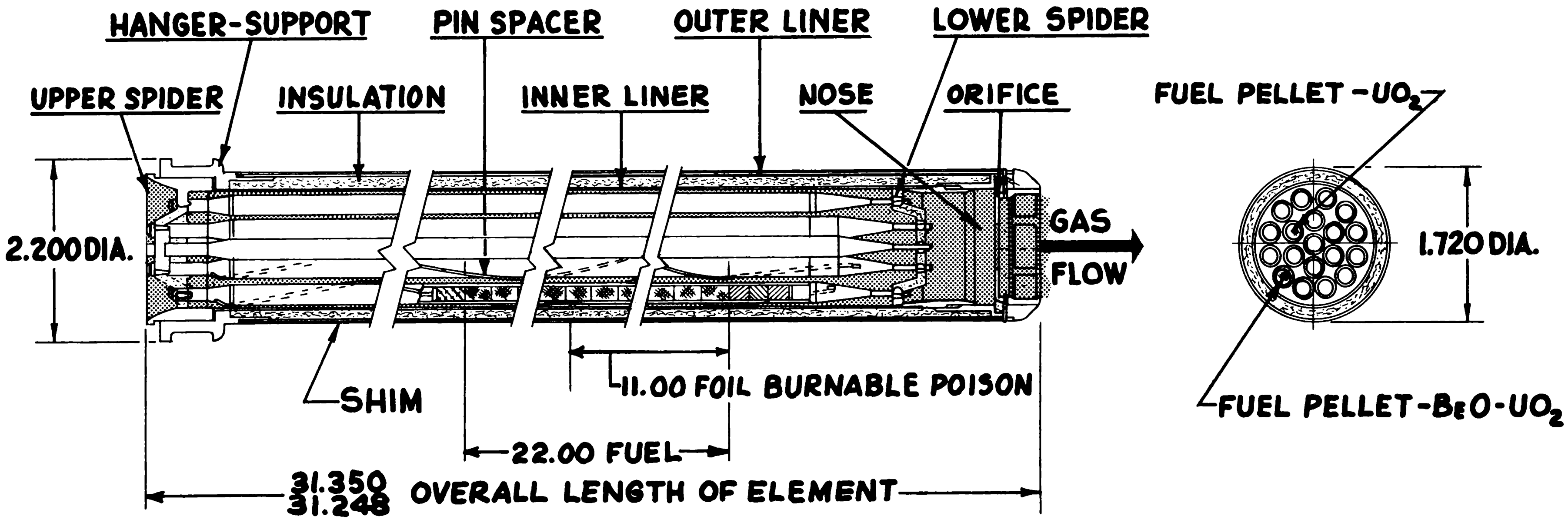


FIGURE 61

96% theoretical density.

Washers of Thermoflex insulation are stacked to occupy the space between the inner and outer liners. The inner liner is Hastelloy X, 1.426-in. ID with 0.010-in. wall. The outer liner is stainless steel tubing (0.012-in. wall) welded to the upper and lower closures of the fuel elements. The outer liner supports the fuel element bottom end closure, the "nose". The nose of the element may be orificed to allow control of minor variations in power distribution across the core by varying the coolant flow. All elements will run, ideally, at the same temperature. The burnable poison, formed of a cadmium alloy canned in stainless steel foil, is attached to the inside of the outer liner that surrounds the lower half of the fuel. The poison is used in this location to reduce the peak temperatures of the fuel pins during the first few thousand hours.

The fuel pins are assembled as follows: a lower plug is pressed into the fuel pin and Heli-arc welded. Then 0.75-in. of MgO pellets is placed in the fuel pin, followed by 22-in. of the appropriate fuel pellets for the outer or intermediate ring of pins. A BeO pellet is added and a spring spacer inserted on top of the stack to prevent movement of the pellets into the gas expansion chamber and to minimize the gaps between the ends of the pellets. The pin is evacuated and back-filled with helium. The top end plug is pressed into the pin and Heli-arc welded into place.

The MgO pellets are used to reduce the temperature at the weld that joins the lower plug to the tube. A BeO pellet is used at the top of the fuel stack to disperse the heat from the top fuel pellets, thus reducing the peak temperature gradient. at this point in the stack. The fuel is enclosed in Hastelloy X.

The fuel tubes are inspected with a Radac eddy current machine. The welds are inspected with a helium leak spectrometer and by X-rays. Each fuel pin assembly is checked with a gamma ray scintillation spectrometer to ensure that UO_2 pellets are not mixed with BeO-UO_2 pellets.

Specifications were written for pin and fuel element assembly.

Stress analysis is nearly completed for the ML-1 first core element. Tentative conclusions are that the assembly will withstand higher elastic and shock loads than the IB-2L except that severe coolant loss still could cause buckling of the inner liner. Thermal stresses continue to be reviewed without discovering any danger areas thus far: the strains resulting from thermal stresses are believed to relax themselves and the analysis is difficult. In-pile tests and capsule tests did not reveal any ill effects arising from steady or cyclic thermal stresses.

<u>Accomplishments - June:</u>

A conceptual design was completed for the cross section of the ML-1 second core. The conceptual design incorporates 19 fuel pins, each 0.275-in. OD, inside an inner liner 1.55-in. ID. These dimensional changes will lower fuel pin metal temperatures and provide more room for diluent.

These two factors will improve retention of fission gases, and improve dissipation of heat to the moderator water during shutdown or an accidental severe loss of coolant.

The design of the IB-9R fuel element was modified to incorporate the IB-2L fuel loading and thermocouple positions. The elements with these changes, called the IB-9R-2A and IB-9R-3A, will be used to determine shifts of axial power from burn-up and from changes in control blade position. Drawings of these element are being checked.

The drawings were released for the thermocouples for the IB-9R elements. The material for the water seal locking nut was changed by increasing its hardness to prevent galling.

Anticipated Accomplishments - July:

Drawings will be released for the IB-9R-2A and IB-9R-3A.

Stress calculations will be completed for the ML-1 first core element.

The burnable poison drawings will be released for the ML-1 first core fuel elements. This will complete the release of all drawings for the ML-1 first core fuel element.

6. Fabrication Development (Task 21-7XX)

(Note: The work under this task formerly was reported as a portion of Task 21-200, IB Fabrication Development.)

Summary - January through May:

a. Mechanical: Special tooling was supplied for fabricating the IB-2L and ML-1 cores. The tooling included welding and positioning fixtures, pellet inspection gages, and pellet assembly tools. Conceptual designs were made of a fixture to use in attaching poison foils to the outer liner at NRTS before the elements are inserted into the reactor.

Four mechanical tests were run during the period: liner ovality, de-pressurization, upper spider load, and thermocouple calibration tests. These tests confirmed the adequacy of the IB-2L and ML-1 designs. Parameters were established for shock and vibration tests of the ML-1 fuel element, and test specifications were written.

An ML-1 prototype fuel element was constructed and used in orifice calibration tests. Assembly of the prototype also confirmed the assembly procedure and the assembly tools. Fabrication began on three display models of the IB-2L fuel element.

Engineering support was provided in establishing an area for cleaning inert parts, putting pellet fabrication "on line" in the ceramic laboratory; and installing special hoods and vents to meet health and safety requirements. Special inspection tools and equipment were provided for quality control of core parts.

b. Process Development: Fabrication development work was concluded on welding fuel pin closures. The process uses tungsten inert gas welding in a semiautomatic, sequence-timed schedule. The fit-up of the weld joint must be carefully controlled to eliminate gas voids in the welds. Current data on the production of 500 fuel pins shows that the process is capable of producing 99.5% acceptable weld joints. A weld repair procedure was developed that permits one re-weld per joint.

An assembly procedure was developed for the wire spacers on the fuel pins, and tested by thermal cycling. The wires are spiral wrapped in an assembly fixture, the ends passed through holes drilled in the end plugs, and the wire spot welded into place with tungsten inert gas fusion welds. Several mock-up pins were thermal cycled 50 times from room temperature to 1750°F. Repeated cycling showed the spot welds were completely sound.

A braze joint was developed for fuel pin thermocouples and an induction brazing process was developed for instrumented IB fuel pins. Both joints were tested.

Schedules were developed for semiautomatic tungsten inert gas welding the end supports to the inner and outer liners of the fuel element.

The burnable and permanent poison foils must be clad or coated because of possible corrosion from reactor flooding. The feasibility and reliability of electroless nickel cladding was demonstrated by corrosion tests to be adequate. It is now the reference process for coating foils (see Task 21-4XX). Attempts to braze-clad the foils with stainless steel were unsuccessful.

The procedure was established for assembling poison foils. The burnable and permanent foils are assembled by enveloping the foils in stainless foil, resistance tack-welding the sub-assembly into position on an assembly mandrel (Figure 62). This sub-assembly is then positioned and tack-welded in position in the outer liner of the fuel element.

The process and test specifications and procedures were completed for the fabrication of the IB-2L and ML-1 cores.

A fabrication process was developed with the tubing vendor for the production of Hastelloy X inner liners. The schedule for drawing the rolled and welded tubing to the required final wall thickness (0.010-in.) requires seven individual cold reduction passes, each followed by process annealing at 2150°F for ten minutes. The feasibility of the process was demonstrated by cold drawing four trial tubes to final size.

Accomplishments - June:

a. Mechanical: Data from the de-pressurization test showed that the element is adequately designed to withstand pressure loss due to discharge of the relief valve, but that the design is of marginal strength in case there is a major rupture of the inlet and outlet pipe. It was recommended that additional holes should be drilled in the inner liner to equalize pressure.

Test parameters were established and a test specification written for shock and vibration tests for the ML-1 fuel element. The test fixture is being designed.

A test fixture was built to adapt the ML-1-type fuel pins to the thermal cycle loop. A thermal ratcheting test will be run with this equipment. Test parameters were established and a test specification written for the thermal ratcheting test. A fixture was designed for the upper spider fracture test, and test parameters were established.

Preliminary investigation began on the use of double-walled tubing for fuel pins to increase the reliability of containment.

The following tools were completed and checked for use in assembling IB-2L and ML-1 cores: pellet stack height fixture, pin plug press fixture, drill jig for fuel pins, and a lock box in which to store IB-4T fuel elements. A "go-gage" was designed to insure an adequate fit of the fuel element in the reactor tube sheet and is being checked. A flow calibration standard was designed, checked and approved for use with the Radac eddy current machine. The shim wrap problem is being investigated, and procedures and tooling are being developed.

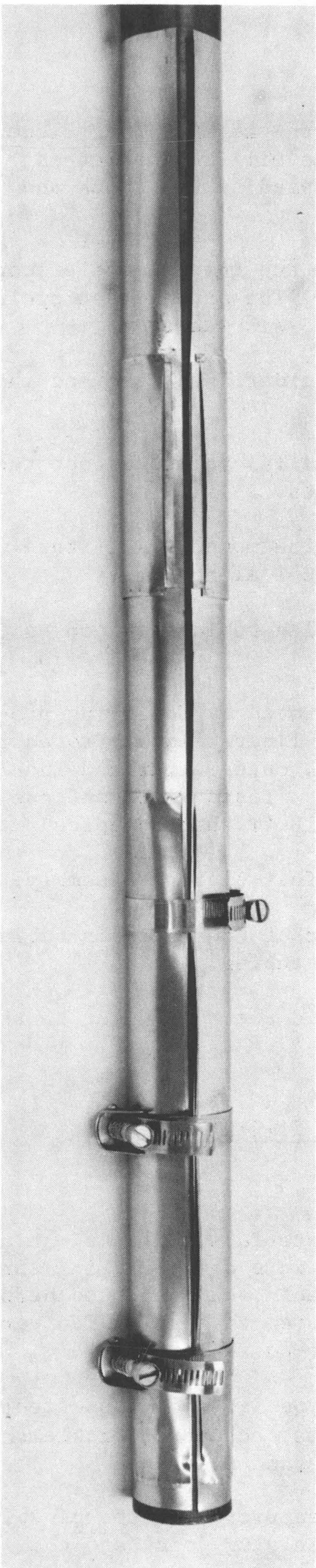
b. Process Development: Welding development is complete for the inner and outer liner of the IB-2L fuel element. A step-welding procedure is used, and the position of the electrode is adjusted to compensate for the fit-up of the joint. Metallographic examination of test welds shows full weld penetration without cracking. Process instruction sheets were completed.

Development work was completed for assembling the IB fuel element poison, the outer liner and the insulation. The thickness of the insulation ring was reduced to accommodate the thickness of the poison assembly. The IB fuel element drawings were revised to show the method of fastening the poison to the cladding; the dimensions of the cladding, poison and insulation; and the method of fastening the poison assembly to the outer liner of the fuel element.

Thermocouples were successfully spliced for the IB-10R and IB-9R-2. The service temperature is 800°F for these splices. Each thermocouple was spliced by oxyacetylene gas fusion welding the wires, potting the weld in cement(made by Continental Sensing Co.) and enclosing the potted splice in an Inconel can brazed to the thermocouple sheath.

Thermocouples for the IB-4T will be spliced by the above process. Corrosion tests show that, of the alloys tested, the American Welding Society BAg-30 corroded least at 1350°F. Improvements are being developed in the potting cement and in the fixture for holding the thermocouple during splicing. Corrosion and heat cycling tests will continue on brazed joints, potting cements and splices.

FOIL ASSEMBLY ON MANDREL READY FOR INSTALLATION



The left is the bottom of the cladding, next is the permanent poison envelope, and on the right is the burnable poison envelope.

FIGURE 62

Anticipated Accomplishments - July:

The shock and vibration tests will begin on the ML-1 fuel element during the last week of July. The test fixtures will be fabricated during the month so the fuel element can be adapted to the shock and vibration tables.

Dry runs will be started and completed on the thermal cycle loop in preparation for the thermal ratcheting test. The actual test cycle will begin. It is expected to take from four to six weeks.

The fixtures will be fabricated for the spider load test and the test runs made.

A test program will be initiated to thermally cycle and test thermocouples for use in the instrumented fuel elements.

The "go-gage" will be completed late in the month. A fixture will be designed for attaching poison foils to the ML-1 elements.

Test fabrication will begin on double-walled tubing as soon as quotations are received.

Welding schedules will be refined and improved by following production procedures for fabricating fuel element liner welds. Procedures for assembling fuel element poison foil, cladding, outer liner and insulation will be followed to improve fabricability. Tests will continue on materials and fabrication methods for splicing IB-4T thermocouples.

Process instructions will be written for fuel element assembly.

Liaison will be maintained with the vendor of the fuel pin tubing to improve the integrity and reliability of the tubing.

Development will begin on a process to weld the ML-1 liner to the end support.

7. IB-2L Core Production (Task 21-9XX)

Summary - January through May:

Procurement was initiated in January of materials for fabricating the IB-2L core. The initial 440 fuel pin tubes were delivered in February. These tubes were eddy-current tested, cleaned and inspected before machining.. The remaining 1500 tubes were delivered in April. Ten percent of the fuel pin tubes were rejected in the eddy-current test.

An additional order was placed for AISI Type 316 stainless steel for use as inner liners for the Hastelloy X tubes because of problems in forming the as-welded tubes to the required gage and tolerance.

Adequate control was attained in the concentricity of the pin plug between the bearing surfaces of the press-fit pin plug joint and the spider holes after a detailed review of the inspection methods.

The layer of poison foil was doubled during assembly to compensate for incorrect cadmium content.

Spring-type fuel spacers were substituted for the tube-type spacers.

Haynes-25 (low cobalt) alloy inserts were procured for the center pin after the decision to leave the center pin unfueled.

The precision of the drilling and inspecting fixtures was improved to correct poor location of pin locating holes in the support spider casting.

The intermediate fuel pins in this element will use fully-enriched UO_2 pellets. These pellets were procured from a vendor. The rejection rate was less than 1%. Fabrication was initiated in April on $BeO-UO_2$ (65 wt%) pellets and 1000 green pellets were made to establish procedures for mixing, blending, granulating and pressing. The hydrogen sintering furnace was installed in May and procedures were established for sintering and for controlling shrinkage. Experimental lots demonstrated the feasibility of controlling shrinkage to a diameter of 0.176- $\pm$ 0.002-in., thus eliminating the projected grinding process.

Production was initiated on 15 May with 3000 pellets, but the composition was revised to BeO-70.5 wt% UO_2 (cf Task 21-1XX), thus requiring readjustment of the procedures. Significant quantities of the 3000 pellets were produced on 4 June, using a mix with 3% CD 108 and 2% castor oil. The problem of inconsistent shrinkage requires adjustment of green density followed by test firing.

Assembly was planned in three stages. In the first, fuel pins were loaded with UO_2, the ends closed, and leak tests performed. The second stage was loading the outer pins with $BeO-UO_2$. The third was assembling the pins, liners, insulation and end fittings to the element. Assembly started on the UO_2 pins in May and was completed 15 June. Loading was initiated on $BeO-UO_2$ pins in June and is in process. Preliminary assembly also was started on 57 of the 70 elements planned. The center pins were modified to accommodate inserts of Haynes-25 alloy in place of fuel.

Accomplishments - June:

The procurement of tube plugs, lower spider castings and back-up AISI Type 316 stainless steel for the inner liner is compatible with the schedule. The most significant problem was the difficulty in machining pin plugs and lower spiders.

In fuel processing, 23,000 $BeO-UO_2$ pellets were completed in June. This is in addition to 6000 completed by the beginning of the month. About 32% of the pellets are now complete for this core. The most significant problem was the adjustment to control shrinkage.

Assembly of 347 intermediate pins (UO_2) was completed, and 375 pins were loaded with BeO-UO_2. Assembly started on 57 sub-assemblies of the inner pin spider. The most serious problem was to maintain a sufficient supply of plugs, spiders and BeO-UO_2 fuel pellets to maintain the assembly rate.

Anticipated Accomplishments - July:

Procurement will be completed.

Fuel pellet production will reach 78% (70,000) of the amount needed for the core by 1 August.

All of the UO_2 pins will be assembled, 58% of the BeO-UO_2 pins, and 30% (22) of the elements.

8. IB-1T Fabrication and In-pile Test (Task 24-1XX)

The effectiveness of the fins on the IB-1αT was evaluated on the basis of temperature profiles of the smooth and finned tubes.

Compensation was made for variations in power generation, in flow rate and in inlet temperature by adjusting the temperatures in the α element so these factors could be compared to the β element. Five steady state operating points showed 70°F variation in peak temperatures. In each case the smooth pins operated at higher temperatures. It is significant that the apparent peak temperatures fell at different values of X/L. The phenomenon is attributed to changes in core loadings. The α element reached a peak temperature at larger X/L than the β element.

The results of this work were written in rough draft form and will be published as "In-pile Tests of GCRE-IB Test Elements," IDO-28552.

The task was completed and no further report will be made.

9. IB-2T Fabrication and In-pile Test (Task 24-2XX)

Summary - January through May:

Fabrication was completed on three elements during the period: the IB-2T-1, the IB-2T-2 (power elements) and the IB-2Ø (a nuclear mock-up). The nuclear mock-up and the first power element, IB-2T-2, were irradiated. Irradiation of the IB-2T-1 was initiated.

Initially it was decided to insert an element instrumented only with inlet and outlet gas thermocouples. The HECTIC code and flux data from the IB-2Ø were used to calculate surface temperatures. The primary objective of this test was to obtain data on the effects of thermal cycles on the structural and mechanical integrity of the IB fuel elements. Irradiation began 9 March and was completed 2 May with a total operating time of 792 hr. A total of 1147 thermal cycles were accumulated during the run. The cycles were controlled between 1000 and 1600°F, based on calculated surface temperatures.

Test irradiation was started on the IB-2T-1 on 9 May.

Accomplishments - June:

Macroscopic examination was completed on the IB-2T-2 element on 20 June in the BMI hot cells. A special apparatus was constructed to disassemble the element without damaging the inner liner. The apparatus used an abrasive cut-off wheel mounted on a carriage riding on a monorail(Figure 63).

The inlet gas thermocouples were examined and photographed before the element was disassembled. The outer liner was removed and the liner thermocouples examined and photographed. The inner liner then was removed. After severing the top of the bell with a circumferential cut above the top spider, the outlet gas thermocouple remained with the piece cut off. The tips of the thermocouple were examined and photographed.

The pin bundle then was hung from the in-cell overhead crane. Photographs were taken at 90° intervals, using a ¼-in. grid as the background. (Figure 64). The bundle showed little evidence of distortion. The spacer wires separated from the fuel pins 1/16-in in several spots.

The fuel pins were separated and photographed. Each pins was photographed with the wire pitch points facing the camera and again with the pin rotated 90° clockwise. Several of the pins were bowed 1/8-in.

Irradiation of the IB-2T-1 element reached 809 hr of operation. The latest set of data is as follows:

Gas enthalpy increase	44.8 kw
Mass flow rate	828 lb/hr
Element inlet pressure	198 psig
Test section pressure drop	3.98 psi
Gas inlet temperature	560°F
Gas outlet temperature	1245°F (average)
Maximum pin surface temp.	1650°F

Anticipated Accomplishments - July:

Microscopic examination of the IB-2T-2 element will be completed at BMI.

Irradiation will continue on the IB-2T-1 element.

Preliminary reduction and evaluation will be completed on heat transfer data.

10. IB-3T Fabrication and In-pile Test (Task 24-3XX)

The drawbar to fit the BMI-16 in-pile tube was fabricated and all drawings completed. All efforts were stopped and the completed work transferred to Task 24-4XX, IB-4T Fabrication and In-pile Test in February because the IB-4T is closer to the ML-1 reference design, and a more useful test may be obtained by accelerating insertion of the IB-4T in the BMI-16 loop (the IB-3T and IB-4T are similar).

There will be no further report on this task.

11. IB-4T Fabrication and In-pile Test (Task 24-4XX)

This task was accelerated early in February by including all completed work from the IB-3T element. Calculations were completed incorporating the new flux values obtained in the BMI-16 facility. Detailing was completed for the test element and the drawings were released for fabrication. Inert part procurement was essentially complete. An engineering evaluation report was written and published.

Fabrication of this element was not started, as this work has been deferred.

There will be no further report on this task.

12. IB-9R, IB-10R Fabrication and In-pile Test (Task 24-9XX)

Summary - January through May:

This task provides for in-pile tests of IB-2L fuel elements. Four elements will be irradiated. The IB-9R-2 will be irradiated for 4000 hr to gather information on heat transfer. The IB-10R, a thermal shock test element, will run for 4000 hr. The IB-9R-4 and -6 will be inserted with the IB-2L core in October for additional heat transfer information.

The element for this task will be fabricated and instrumented by Task 21-6XX, IB-2L Fabrication, Fuel Design.

Accomplishments - June:

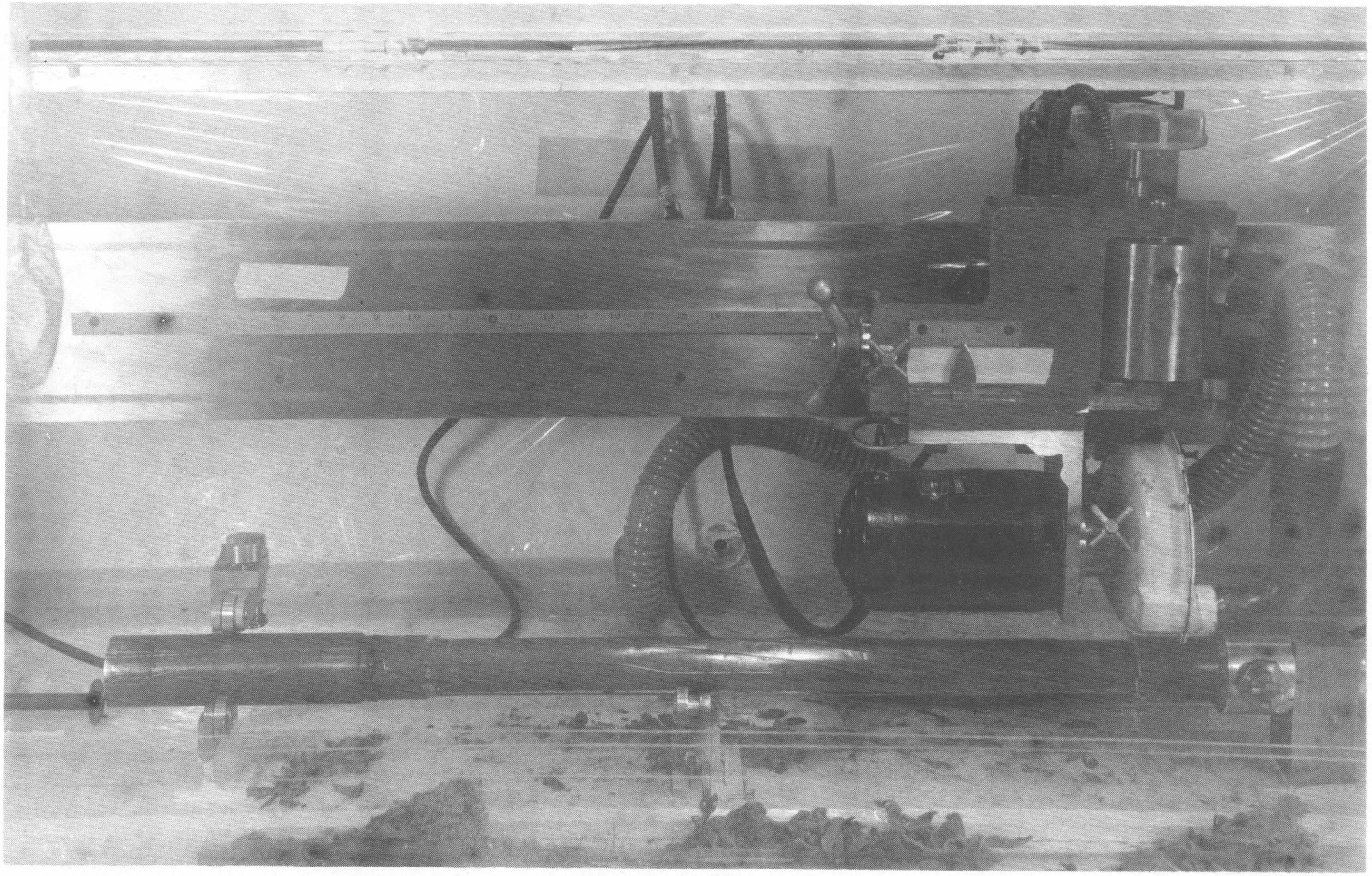
The IB-9R-2 and IB-10R test elements were completed and shipped to the GCRE-I site. Modification of the IB-2Ø for insertion in GCRE-I (the element re-labeled IB-9Ø) was completed and shipped. The flux run was completed and data reduction is in progress.

Anticipated Accomplishments - July:

The IB-9R-2 and IB-10R will be inserted in the in-pile loop.

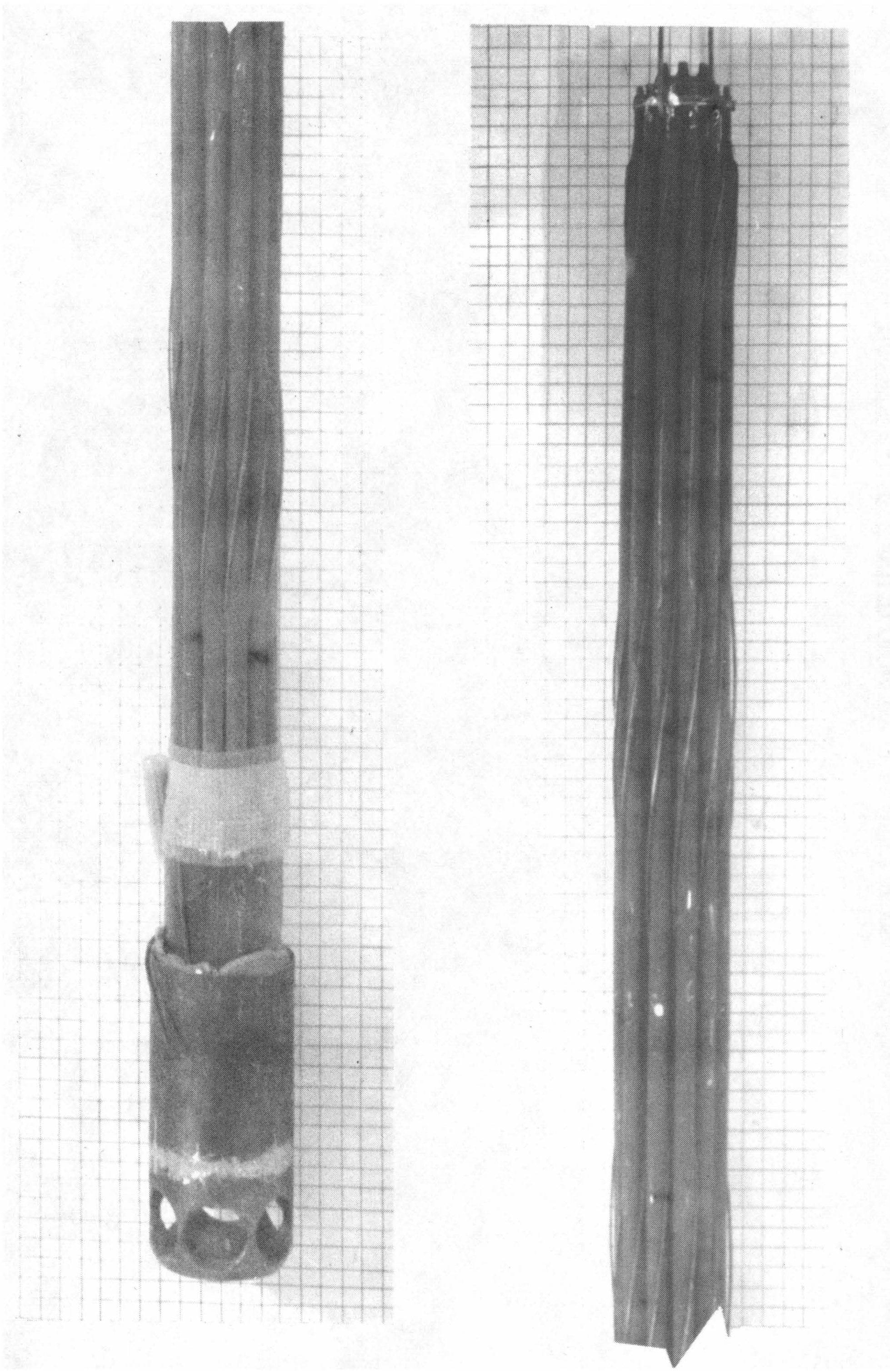
Fabrication will start on the IB-9R-4 and IB-9R-6 elements.

DISASSEMBLY APPARATUS FOR USE WITH THE 1B-2T-2 ELEMENT



THE IB-2T-2 ELEMENT IS PICTURED PARTIALLY DISASSEMBLED WITH THE CUT OFF-WHEEL IN POSITION.

FIGURE 63



PIN BUNDLE FROM THE 1B-2T-2

FIGURE 64

13. IB-7T Fabrication and In-pile Test (Task 25-1XX)

Summary - January through May:

A test was initiated to assess the effects of a pin-hole leak in a fuel pin on the ML-1 power plant. Several approaches were considered, and the concept of a dynamic capsule (i.e., one with self-contained circulator, heater and cooler) was selected. One approach was an in-pile loop with out-of-pile gas circulators, monitoring stations, a pre-heater and a cooler; but this was rejected on the basis of the cost of modifying the GETR loop and the danger of contaminating the plant. Another approach was the use of a capsule with natural convection, but the productivity of such a capsule would be severely limited. Hence the dynamic capsule was adopted as a compromise (Figure 65).

Test parameters were selected and specifications prepared. The test program will be implemented in seven steps: Design and procurement, tests of components, construction, out-of-pile tests, in-pile mechanical tests, and in-pile tests.

Accomplishments - June:

Components were designed, detailed and procured for the test. Fabrication was 75% completed by the end of the period.

Anticipated Accomplishments - July:

Tests will start on the components. [illegible]

Final design and detailing will be started for the capsule.

14. IB-8T Fabrication and In-pile Test (Task 25-2XX)

Summary - January through May:

The ORNL helium-cooled loop at GETR is being modified by an interim agreement with the General Electric Co. as approved by the San Francisco Operations Office of the AEC. The loop was operated on a preliminary [illegible] basis with nitrogen as the coolant to assess the modifications needed to satisfy the requirements of the AGCRSP. The compression ratio of the compressors and the pressure drop across the pre-coolers were found to be excessive. Slower speed motors will be installed to reduce the compression ratio. Aluminum windows and beryllium reflectors will be clamped to the in-pile facility tube to flatten the radial gradient of the neutron flux and thus possibly increase the fission heating capability of each tube.

Accomplishments - June:

Contract negotiations were started with the General Electric Co. through the AEC (SAN). The General Electric Co. performed the following: Achieved 40% completion of the detailed drawings for the in-pile facility tube; ordered all major items needed to modify the loop; completed the calculations necessary for the application to have the license amended; and dismantled the compressors for inspection by factory representatives.

Drawings were released to Aerojet for fabricating the test specimen for the IB-8T-1 and IB-8T-2. A data package was started for the IB-8Ø flux run.

Anticipated Accomplishments - July:

Fabrication will start on the test element.

Loop modifications will continue at the GETR.

The data package will be completed for the IB-8Ø flux run.

Fabrication will be initiated for the IB-8Ø flux element.

<u>CONCEPTUAL DRAWING OF THE 1B-7T TEST ELEMENT</u>

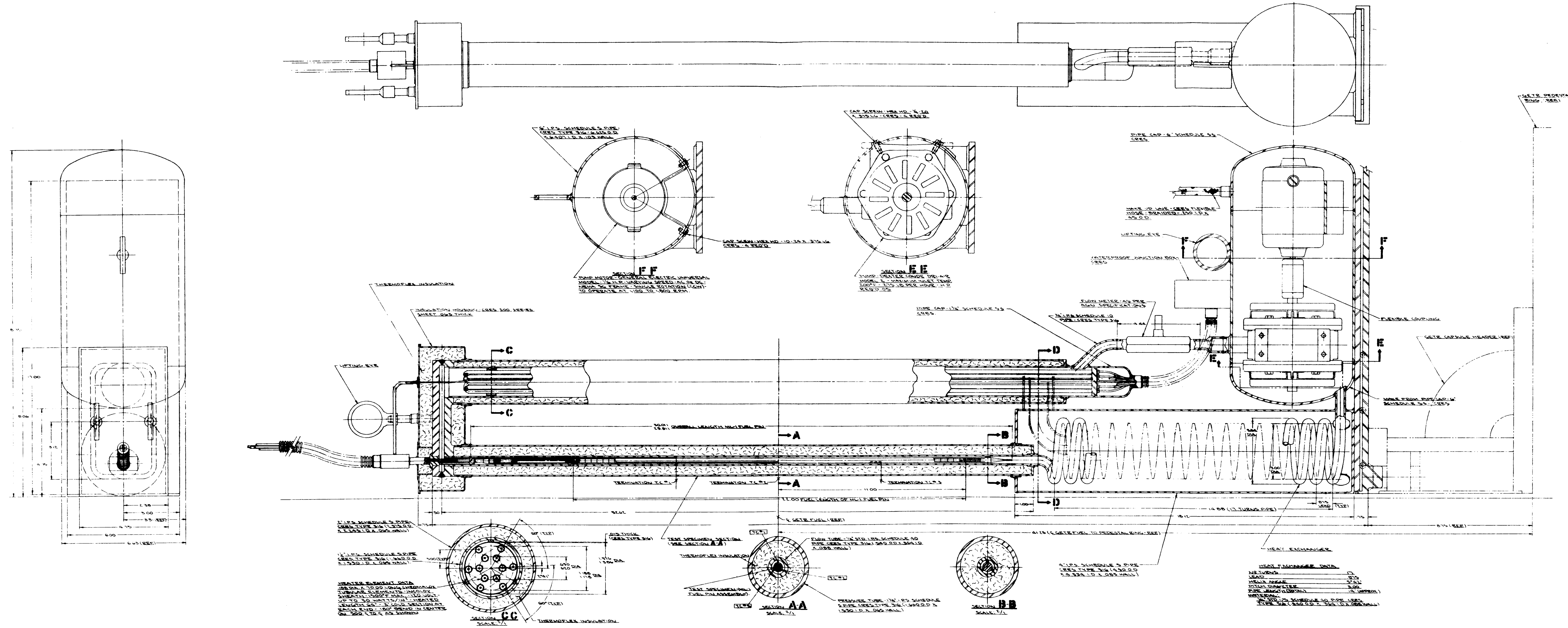


FIGURE 65

V. THE GAS TURBINE TEST FACILITY

(Note: The AGCRSP is concerned with GTTF insofar as work under Contract DA-44-009-3252 will affect the completion of the ML-1 and contribute to the design of power conversion equipment compatible with the ML-1 system. The complete report on the GTTF is made under the relevant contract.)

Summary - January through May:

Open cycle testing was continued on the turbine-compressor set during January. Tests were conducted up to the normal operating speed of the unit (18,000 rpm) and normal operating temperature (1150°F). Failure of a gearbox bearing and a damaged seal in the tec set made it necessary to terminate the test before self-sustaining operation was attained. The unit was returned to the vendor.

A summary of the open cycle test analysis and predictions for closed cycle self-run were published in March.

The facility was converted to closed cycle from open cycle operation by April, and pre-operation check-outs and tests were conducted. The t-c set seals were run in by performing more than 170 tests. A by-pass return line was added to the low pressure side of the loop because the leakage across the t-c set seals was greater than estimated.

A plan was completed in April for the 500-hr closed cycle test.

The initial closed cycle rotational tests were completed in May. Self-sustained operation was attained 12 May. The test was terminated after 10 minutes when lubricating oil leaked into the process gas system. Preliminary investigation indicated that the leaks occurred because the pressure in the compressor bearing seal cavity was higher than the pressure in the process gas system. Scavenger pumps were installed in the compressor bearing return line to maintain lower pressure in the bearing seal cavity. In the next test run, however, oil leaked into the gas system at 16,000 rpm. A separate oil sump was installed for the compressor bearing to prevent this condition in future tests.

Accomplishments - June:

Closed cycle tests were resumed on the t-c set. Testing was discontinued when a turbine inter-stage seal failed in the t-c set. The unit was returned to the vendor.

Anticipated Accomplishments - July:

Re-work will be completed on the t-c set, and the set returned to Fort Belvoir.

Testing is scheduled to be resumed in August.

SELECTED BIBLIOGRAPHY

REPORTS

Army Gas Cooled Reactor Systems Program, ML-1 Design Report, Aerojet-General Nucleonics, IDO-28550.

Army Gas Cooled Reactor Systems Program, Semiannual Progress Report July - Dec. 1959, Aerojet-General Nucleonics, IDO-28549.

Army Gas Cooled Reactor Systems Program, Transportability Studies, ML-1 Nuclear Power Plant, Aerojet-General Nucleonics, IDO-28555, April 1960.

Brazing for High Temperature Service, Battelle Memorial Institute, DMIC Memorandum 48, 29 March 1960.

Calculated Activities and Abundances of U-235 Fission Products, USNRDL-456.

Calculation of Armature Reactance of Synchronous Machines, AIEE Trans. Vol. 47, 1928.

Calculation of Synchronous Machine Constants, AIEE Trans. Vol. 50, Dec. 1931.

Carbon Dioxide Storage and Charging Systems, Henry J. Kaiser Co., IDO-24263, March 1958.

Contaminated Effluent Disposal, Henry J. Kaiser Co., IDO-24262, March 1958.

Contribution to the Theory of Oil Whip, Trans. of ASME Vol. 75, 1953.

Effective Cadmium Cutoff Energies, Oak Ridge National Laboratory, ORNL-2823

Effect of Temperature-Dependent Fluid Properties on Heat Transfer and Flow Friction For Gas Flow, Stanford University, 1957.

Elastomers for Use in the Radiation Fields, HAPO GE HW-5647.

Estimated Radiation Stability of Aircraft Components, APEX-357, Sept. 1956.

Examination of Flow and Pressure Losses in Blade Rows of Axial Flow Turbines, NGTE R&M Z891.

Fast Neutron Spectrum Code for the IBM, MUFT-4, WAPD-TM-72.

Fuel Element Conference, Technical Information Service, AEC, TID-7546, Nov. 1957.

Further Studies With the GCRE Critical Assembly, BMI-1306.

GCRE Critical Assembly Studies, BMI-1288.

GRACE I, An IBM 704, 709 Program Design for Computing Gamma Ray Attenuation & Heating in Reactor Shields, NAA-SR-3710, 1 April 1959.

Graphite Compatibility with Metals, BMI-1261, April 1958.

Graphite and Its Properties, General Electric Co., R 58 AGT 591, July 1958.

Heat Transfer and Friction Flow Characteristics of Cylindrical Parallel Rods with Transverse Cylindrical Spacers, AED-3975, 1954.

Heat Transfer from Paralled Rods in Axial Flow Reactor Heat Transfer Conference, BMI Part 1, Book 2, 1956.

Heat Transfer Source File Data, APEX 425, 1958.

Influence of Non-Uniform Heat Flux & the Convection Conductances in a Nuclear Reactor, Stanford University, Dept. of Mech. Engr., Tech. Report No. 23, 1957.

Lubrication in the Atomic Age, Standard Oil Co. of Calif., Tech. Release No. 877, 13 Feb. 1959.

Lubricating Oil, Hydraulic and Light Turbine, Noncorrosive, Military Specs ML-L-17672A, June 1954.

Means of Limiting Impurities in the GAS System of the PECPR, Nuclear Products, Erco Division, ACF Industries, Inc., IDO-24062, 19 Feb. 1959.

Measurements of Average Heat Transfer and Friction Coefficients for Sub-Sonic Flow in Air in Smooth Tubes at High Surface and Fluid Temperatures, NACA-1020, 1951.

Measurements of Heat Transfer and Friction Coefficients for Flow of Air in Noncircular Ducts at High Surface Temperatures, NACA-RM-E53j07, 1954.

ML-1A Studies with the GCRE Critical Assembly, BMI-1396.

MUFT-4 Fast Neutron Spectrum Code for the IBM-704, WAPD-TM-72.

Nbc Coating on Graphite, BMI-1296, Oct. 1958.

Nuclear Evaluation of Slab Type Control Rods, KAPL-M-RWD-17.

Nuclear Irradiation Effects on Ferro Magnetic Core Materials, U. S. Naval Ordnance Laboratory, NAVORD Report 6127.

Oxidation of Experimental Alloys, WADC-TR-58-164, June 1958.

Oxidation of Zirconium and Zirconium Alloys, Argonne National Laboratory, ANL-6046, Sept. 1959.

PDQ - AN IBM 704 Code to Solve the Two-Dimensional Few Group Neutron Diffusion Equations, WAPD-TM-70.

Pile Oscillator Measurements of Resonance Absorption Integrals, AERE R-20887.

Proceedings of 2nd Annual Symposium of High Temperature Technology, SRI, August 1958.

Progress Development of UC Fuels, BMI-1370.

Prototype PEGCPR Annual Helium Loss, Henry J. Kaiser Co., IDO-24336, 26 Feb. 1959.

Prototype PEGCPR Radiation Monitoring of Liquid Waste, Henry J. Kaiser Co., IDO-24312, 26 Feb. 1959.

PWR Fuel Element Specifications, WAPD, TID-5302, (Rev) 1957.

Radiation Damage to Elastomers Plastics and Organic Liquids,

Reactor Physics Constants, Argonne National Laboratory, ANL-5800, 1 July 1958.

Relative Effectiveness at Reactor Control Materials, General Electric Co., Vallecitos Atomic Laboratory, GEAP-3201.

Release of Fission Gases from UO_2, Bettis Atomic Power Division, WAPD 173.

Review of Methods Used in Control Rod Analysis for Reactor Design at Bettis Plant, WAPD-BT-4.

Shippingport MPWR Core 1 Fuel Component Fabrication Process and Equipment Manual, WAPD-NCM-PL-51, 1957.

Thermal Properties of Certain Metals, WADC-TR-56-423, August 1958.

Transient Response of Gas Turbine Plant Heat Exchangers - Regernators, Intercoolers Precoolers, and Ducting, Stanford University, Dept. of Mech. Engr., Tech. Report 38, 1958.

Turbine Compressor Set for ML-1, Clark Brothers Final Report No. UDR 94, March 1960.

Turbine Compressor Set for ML-1, Stratos Division Final Report, SRC104, March 1960.

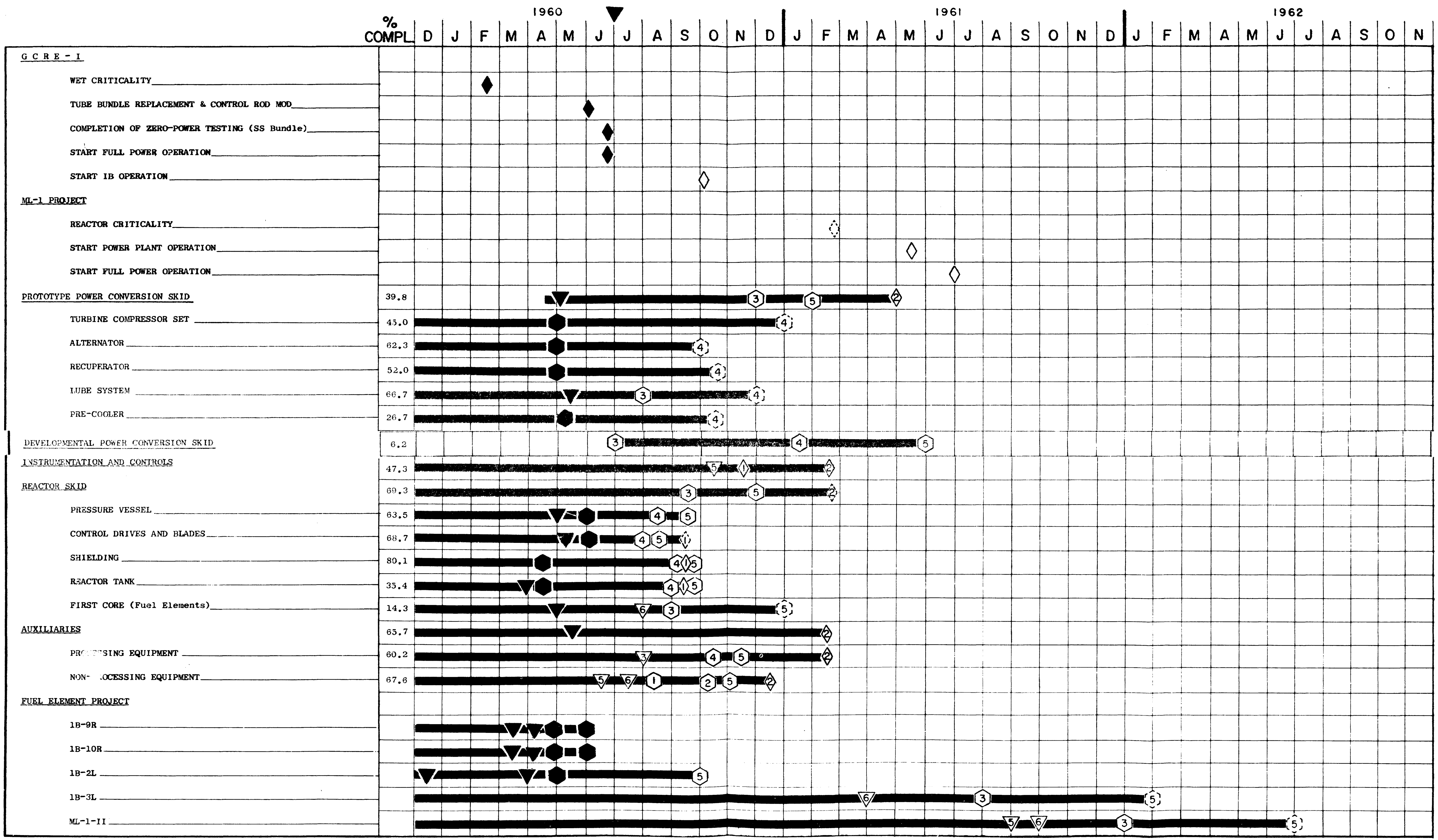
U-235 Fission Product Production as a Function of Thermal Neutron Flux, Irradiation Time and Decay Time, ORNL-2127.

WANDA a One Dimensional Few-Group Diffusion Equation Code for the IBM-704, WAPD TM-28.

Zirconium and Zirconium Alloys, Atomics International Division, North American Aviation, Inc., NAA-SR-3481, July 1959.

APPENDIXES

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

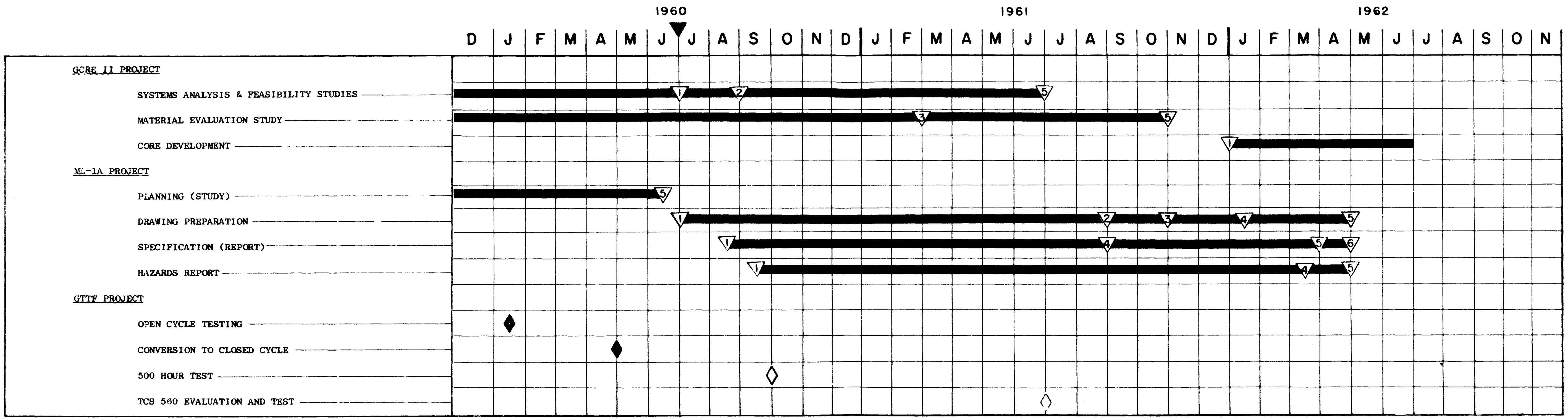
30 JUNE 1960

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
◆			MILESTONE ACHIEVED

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

APPENDIX B

ML-1 PLANT CHARACTERISTICS

(Note: Items marked * are revised since May report. Items marked ** are added.)

1. General (See Task 51-870)

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	279x113x93 in high

Overall plant weight and dimensions

	Weight	Dimensions (in.)
Reactor package	30,000 lb.	111x110x93 high (plus ion exchange column on end)
Power conversion package	30,000 lb.	168x113x93 high
Control cab	5,000 lb.	145x82x81 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. <u>Reactor Thermal Characteristics</u> (Task 21-1XX)

Power density	700 kw/ft^3
Maximum heat flux	137,500Btu/hr/ft^2*
Average heat flux	80,500Btu/hr/ft^2*
Heat transfer surface	126.5 ft^2*
Maximum-to-average heat flux ratio	1.71*
Maximum fuel center temperature	2150°F
Maximum moderator temperature	200°F
Maximum surface temperature of fuel cladding (nominal, average)	1460°F*
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1750°F

3. <u>Reactor Nuclear Characteristics</u>

Average thermal neutron flux (fuel)	1.9×10^{12} neut/cm^2-sec
Average fast neutron flux (fuel)	1.7×10^{13} neut/cm^2-sec
Maximum to 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	3.0 x 10^{-5} sec
K_{eff}, cold, clean core; no shims or burnable poison	1.102
K_{eff}, cold, clean core, with shims, no burnable poison	1.043
K_{eff}, cold, clean core, with shims and burnable poison	1.021
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.6% in 10,000 hr
Prompt temperature coefficient, $\Delta k/k/^{\circ}C$	$(-0.8\pm1)\times10^{-6}$ @ $0^{\circ}C$ $(-1.7\pm1)\times10^{-6}$ @ $90^{\circ}C$

4. Reactor Vessel

Materials

Tube sheets	Stainless steel, type 304, 3 inches thick
Pressure tubes	Stainless steel, type 321
Gas ducts, plenums and baffle	Stainless steels, types 304-L, 321 and 347
Outside diameter	30.968 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°F
Wall thicknesses	Tubes .020 in; plenum 1.25 in. min

5. Reflector

Composition, top	2 in. H_2O; 3 in. stainless steel; 3 in. W
bottom	3 in. stainless steel; 3 in. W

radial	1.8 in Pb; 2 in. W; 180° segment 4 in. Pb; 180° segment
Total heat generation	6×10^5 Btu/hr
Maximum power density	360 Btu/hr-in^3

6. <u>Biological Shielding</u>

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

7. <u>Core (excluding reflector)</u> (Task 21-1XX)

Diameter	22 in. equivalent
Height	22 in.
Number of fuel elements	61
Number of coolant passages	61
Number of coolant passes	1
Type and 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 7 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. <u>Fuel Element</u>

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	0.174 in. and 0.177 in.
Type burnable poison	Cadmium
Reactivity worth of burnable poison	2.2% at startup

9. Control Elements

Type	Tapered blades
Location	Moderator
Number:	
Shim-scram blades	5 pairs (5 actuators)
Regulating blades	1 pair (1 actuator)
Absorber material:	
Shim-scram blades	5 wt% Cadmium- 15 wt% Indium- 80 wt% Silver
Regulating blades	Stainless steel
Cladding material:	None
Dimensions	4.0 x 10.0 x 0.25 to 0.62 in. each blade
Reactivity worth of control elements:	
Shim-scram blades	0.050 $\Delta k/k$
Regulating blades	0.005 $\Delta k/k$
Total	0.055 $\Delta k/k$

Actuating Time:

Regulating blade actuator:

Drive: 13.3 sec for full stroke insertion or withdrawal.

Scram: 1.0 sec for full insertion

Shim-scram actuator:

Drive: 4.0 minutes for full stroke insertion or withdrawal.

Scram: 0.35 sec for full stroke insertion from scram signal

10. Moderator

Type	Water
Reactor inlet temperature	180°F
Reactor outlet temperature	190°F
Pressure	32.5 psi max
Flow rate	300 gpm
Type of flow circulation	Forced
Purity:	
Total solids	1 gpm
Resistivity	10^5 to 10^6 ohm-cm
Total heat removal rate	1.5×10^6 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 (Task 40-500)

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	18,000	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	2.29
Compressor stages	2	11
Compressor material	AL 355 T71	403 Stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compressor ratio	2.72	2.59
Case material	304 Stainless steel	Low carbon 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

	60 Cycle Operation	50 Cycle Operation
Output		
Rating	500 KVA	417 KVA
Voltage	2400/4160 V	2000/3467 V
Rotor shaft speed	3600 rpm	3000 rpm
Case		
Diameter	38 inches	
Length	34 inches	

	Weight	3600 lb
	Temperature, operating	250°F internal max (hot spot)
15.	<u>Recuperator</u>	
	Length (including insulation)	81 in.
	Outside diameter (including insulation)	49 in.
	Headers	
	High pressure inlet	8 in.
	High pressure outlet	8 in.
	Low pressure inlet	20 in.
	Low pressure outlet	14 in.
	Effectiveness	80.75%
	Pressure loss	
	High pressure $\Delta p/p$	1.61%
	Low pressure $\Delta p/p$	1.06%
	Type	Shell and tube regenerator
	Tubes	4 passes x 840 tubes
	Shell	1 pass
	Surface	External fins
	Materials	300 series stainless steel
16.	<u>Pre-cooler and Moderator cooler</u>	
	Dimensions:	
	Length, overall	168 in.
	Pre-cooler	128 in.
	Moderator cooler	27½ in.
	Oil cooler	12½ in.
	Width	113 in.
	Thickness, overall	32 in.
	Core	15 in.
	Fans and plunums	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	93%
Total Δ p/p	1.55%
Air flow	289,000 lb/hr
Type	Fin fan air-to-gas exchanger
Tubes	1131 tubes, single pass
Surface	Internal and external fins
Moderator cooler:	
Headers, inlet and outlet	4 in.
Total Δp	6.0 psi
Water temperature:	
In	190°F
Out	180°F
Airflow	78,600 lb/hr
Type	Fin fan air-to-water exchanger
Tubes	84 tubes, three passes
Surface	External fins
Oil cooler:	
Headers, inlet and outlet	1½ in.
Total Δ p	11.1 psi
Oil temperature	
In	180°F
Out	150°
Oil flow	19,380 lb/hr
Air flow	29,400 lb/hr
Type	Fin fan air-to-oil exchanger
Tubes	42 tubes, 2 passes
Surface	Internal and external fins

(30 JUNE 1960)