Report No. IDO-28617
Contract AT(10-1)-880

AGN

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

Quarterly Progress Report

1 July through 30 September 1963

15 November 1963

GENERAL TIRE

AEROJET-GENERAL NUCLEONICS
SAN RAMON, CALIFORNIA

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Supervising Representative
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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT

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Report No. IDO-28617

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT*

1 JULY THROUGH 30 SEPTEMBER 1963

ABSTRACT

This document summarizes the technical progress of the Army Gas-Cooled Reactor Systems Program (AGCRSP) under Contract AT(10-1)-880 between the USAEC and Aerojet-General Corporation. The purpose of the Program is to develop a mobile, low-power nuclear power plant capable of extended operation under military field conditions.

The ML-1 power plant did not operate during the report period. The repair of the leak in the pressure vessel and modification and reassembly of the reactor were completed.

The design of turbine blades for the CSN-1 was revised to prevent the cracking reported earlier and fabrication of replacement parts was initiated. The unit was reassembled with spare parts to permit the conduct of a bearing evaluation program. This program was interrupted shortly after inception by an explosion in the turbine end of the unit. The damage was confined to parts scheduled for modification in the CSN-1A rebuild; little schedule slippage is anticipated in this phase of the work although evaluation of the bearing will require additional time.

The TCS-670A turbine compressor set performed satisfactorily during open cycle test and was installed on the power conversion skid for closed cycle tests. Early in this test program, the unit seized when the turbine interstage seal failed. The disassembly and inspection of the unit was completed by the end of September.

Testing of the mock-up of the ML-1 pressure vessel was interrupted in mid-September after 2938 hours of operation by the failure of the bearings in the moderator circulating pump.

A hot cell examination of the IB-17R-1 (instrumented ML-1-II prototype test element) was initiated. No unanticipated conditions were observed. Irradiation of the IB-17R-2 and -3 test elements in the GETR loop continued without incident.

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

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT*

1 JULY THROUGH 30 SEPTEMBER 1963

I. SUMMARY OF PROGRESS TO 1 JULY 1963

The Army Gas-Cooled Reactor Systems Program evolved from studies conducted at ORSORT in 1954 and by Sanderson-Porter Co. in 1955 to evaluate the feasibility of the development of a mobile nuclear power plant for military purposes. These studies indicated that such a concept was feasible and established the basic objective of the Program. This objective was the development of specifications for a mobile, low-power nuclear power plant capable of extended operation under military field conditions. The development programs for the reactor and power conversion equipment started in late 1956 and Aerojet was selected as the systems contractor to integrate all activity in the Program in 1959. The following major projects have been undertaken:

1) The design and construction of a reactor test facility (GCRE) at NRTS, Idaho: This work began in early 1959 and was completed late in 1959.

2) The design and construction of a turbine-compressor test facility (GTTF) at Fort Belvoir, Virginia: This work was completed in 1959.

3) The design, fabrication and test operation of a test gas-cooled reactor (GCRE-I): This test reactor was provided in the program to investigate the operational and control characteristics of the reactor concept chosen for the power plant, to provide information on system transients for use in designing the plant, and to provide for developmental testing and life testing of fuel elements. The reactor was heterogeneous, water-moderated and nitrogen-cooled, and operated at a nominal thermal power of 2.2 Mw. The reactor was first taken to criticality in February 1960 with plate-type fuel elements and operation continued with these and with a replacement core of pin-type elements (prototype for the power plant) until April 1961 when the reactor was

*Published by Aerojet-General Nucleonics, San Ramon, California shut down after a failure in the reactor calandria. Investigation of the failure continued for the balance of 1961 and the decision was made early in 1962 to deactivate the GCRE-I reactor.

4) The design, fabrication and test operation of a developmental turbine compressor set (TCS-560): This unit was delivered late in 1959 and tests and modifications of the set continued from that date until May 1963. At that time, Aerojet was relieved of cognizance for the developmental program.

5) The design, development and fabrication of two core loadings for the reactor of the demonstration power plant (ML-1): The design, development and fabrication of the first core loading (ML-1-I) was completed early in 1961 and this core has been in operation in the ML-1 since that time. The design and development of the second core loading (ML-1-II) is in progress. Activity related to both cores is reported in this document (see Sections 2.4 and 3.4).

6) The design and fabrication of two turbine-compressor sets for the demonstration power plant:

a) TCS-670 (Stratos) - This set was delivered early in 1961. Preliminary testing revealed that the unit did not satisfy design specifications and a modification to improve performance and correct certain mechanical deficiencies was undertaken in 1963. In open cycle tests following the modification, the unit again failed because of insufficient internal clearances for thermal expansion. The modification program to correct these deficiencies was completed and the results of subsequent testing are discussed in Section 3.2b.

b) CSN-1 (Clark) - This set, delivered in March 1961, was installed on the power-conversion skid after preliminary testing and delivered to NRTS for testing with the demonstration power plant in June 1962. The unit performed acceptably during ML-1 testing in September 1962 and February 1963 (although the power output was less than the design value). The program of modification and repair following the February operation is discussed in Section 3.2a.

7) The design and construction of a test facility for the demonstration power plant at NRTS-Idaho was completed late in 1960.

8) The design, fabrication and test operation of a demonstration power plant (ML-1): The ML-1 control cab and reactor skid were delivered to NRTS in February 1961 and the reactor achieved initial criticality on 30 March of that year. Operational testing to verify predictions of control rod worth, reactivity temperature coefficients and shielding effectiveness, and to develop general core physics data occupied from April 1961 to June 1962. With the arrival of the power-conversion skid (see 6-a above), the final checkouts were completed and initial operation of the power plant was achieved in September 1962.

Following this operation, the plant was shut down for modification and maintenance. Test operations were resumed in January 1963. During these tests, the ability of the reactor to operate at 3.3 Mw(t) - full design power - was demonstrated and a shaft output power of 247 kw(e) was measured. Following this testing, evidence of a leak in the reactor pressure vessel was observed and, following confirmation of the leak, a program for partial disassembly of the reactor skid, repair of the leak and reassembly of the reactor skid was undertaken. This program is discussed in Section 2.1 of this report. The ML-1 plant characteristics are presented in Appendix A.

9) The development of performance specifications for a field-operable, gas-cooled nuclear power plant based on the ML-1 design (ML-1A): This work was completed on 30 June 1963.

10) The completion of a design study for a "second generation" gas-cooled mobile nuclear power plant (ML-2): Preliminary feasibility studies of advanced concepts were begun at a modest level of effort in 1961. The first phase of the work was completed in March 1962, at which time a more detailed evaluation was initiated. The goal of this evaluation was to define a 500 kw(e) power plant with minimum weight, maximum reliability and maintainability, minimum logistic support requirements, and minimum startup and relocation times. The report of the preliminary studies was published in September 1962 and the final report of the detailed study was published in October 1962. A limited evaluation of a reactor concept not fully considered in the earlier work was performed in May and June, 1963, at the direction of the USAEC.

11) The preparation of a preliminary design for a field-operable, gas-cooled nuclear power plant (ML-1A) based on the ML-1A performance specification (item 9 above): This work was initiated during the report period and is discussed in Section 4.0.

This work was conducted under several contracts. The principal contract at this time is Contract AT(10-1)-880 between the USAEC-ID and AGC. The repair of the CSN-1 t-c set is being performed under Contract DA-44-192-ENG-8 between USA-ERDL and AGC and is the only remaining activity under that contract.

This report is organized under three primary headings: Summary of Progress to 1 July 1963, ML-1 Project and ML-1A Project. Significant areas of activity are identified by numbers 1.0 through 4.0 (second order identification) and details are reported as decimals of the second order identification. The figures and tables are identified with the appropriate second order heading and are included in the text close to the point of reference. Two kinds of references are cited: Alphabetical designations refer to reports of general interest that are readily available; numerical designations refer to in-contract reports.

II. ML-1 PROJECT

1.0 ML-1 TEST OPERATIONS

The ML-1 power plant was not operated during the report period. At the end of June, the reactor skid had been relocated to the GCRE facility, the pressure vessel had been removed from the shield tank and the location of the pressure vessel leak had been established (Ref. a)*. The major activity during the current report period was the completion of the repair and reassembly of the reactor skid under the supervision of the Reactor and Auxiliaries Engineering Group. This program is described in Section 2.1.

When reassembly was complete, seven instrumented fuel elements were installed in the reactor and reactivity shims were installed in all core positions. The reactor skid was transported to the ML-1 test building at the end of September and components and instrumentation were being checked out in anticipation of refueling.

A reliability test of the Beckman Model 109 hydrocarbon analyzer, used to monitor the hydrocarbon concentration in the ML-1 main gas loop, was initiated early in July. The instrument was operated continuously for a period of approximately 750 hr. Performance was satisfactory throughout the test; the test was terminated by a short circuit in the combustion chamber as a result of buildup of aluminum oxide deposits. It appears that incorporation of a stainless steel chimney in the burner assembly would prevent this type of failure. A detailed report of this evaluation was published (Ref. 1).

The program to control the purity and pH of the GCRE pool water, to minimize corrosion of the ML-1 components stored in the pool, continued throughout the report period. The resistivity was maintained above 0.5 megohms and the pH was controlled between 6.2 and 6.7 during the entire period except for two days in early August. During this 48 hr period, the resistivity decreased briefly to 0.17 megohms as the result of premature exhaustion of the ion exchange resin (caused by ineffective regeneration) and simultaneous failure of the annunciator on the resistivity (conductivity) monitoring system.

*References are listed after the main body of text. Alphabetical designations refer to reports of general interest, and numerical designations to in-contract documents.

Work was begun in mid-September on several modifications to the ML-1 test building to improve the efficiency and testing capability of the facility. These modifications include the installation of the piping/cable trench, the construction of a separate small building to house shielding solution mixing equipment, and the installation of an exhaust fan, with associated ducting, to minimize air recirculation in the test building during power plant testing.

2.0 ML-1 OPERATIONS ENGINEERING SUPPORT

2.1 Reactor and Auxiliaries

a. Pressure Vessel Repair: The inspection of the pressure vessel after removal from the reactor skid, in progress at the end of June (Ref. a), was completed. All pressure tubes in the calandria* were plug gauged, borescopically examined, and air gaged to determine the inside diameters at various locations. No evidence of significant deterioration or non-standard conditions was observed.

Sections of the seal welds from shear pins 16, 17 and 18 were removed for metallographic examination. The seal weld from pin 18, the source of the pressure vessel leak, was found to be cracked as a result of improper welding technique; penetration on the plenum side of the joint was quite shallow and the weld fusion zone was less than 0.01 in. deep. The weld is shown in Figure 2-1 following removal from the reactor. Macro and micro photographs of the failed weld are shown in Figures 2-2 and 2-3.

The outside of the plenum wall was machined to accommodate the seal cup (see page 20 of Ref. a for complete description of the revised shear pin design) and passages were drilled to vent the space betwen the shear pins and the seal cups to the lower plenum. The seal cups were welded in place and inspected; no deficiencies were observed. A typical completed weld is shown in Figure 2-4.

Detailed plans and procedures were prepared to specify the work to be accomplished during reactor modification and reassembly (Ref. 2, 3). The modification program incorporated several changes made to simplify the reassembly operation and to improve the performance of the equipment. These are summarized below:

1) A flanged connection was provided in the reactor outlet gas duct between the two 90^{o} elbows (Figure 2-5). This closure was designed to satisfy the requirements of the ASME Pressure Vessel Code and a prototype was subjected to standard proof and leak tests as well as thermal cycling tests. Minor modifications were required in the lower end seal cone to accommodate the flanged closure.

*Calandria: A part of a vacuum evaporating system in which the liquid to be concentrated circulates through tubes surrounded by steam; in this case, the tubes enclose the fuel elements, and the moderator water surrounds the tubes.

FIGURE 2-1. SEAL WELD FROM PIN 18

Note the crack extending along the entire visible surface

11.2-63-3857

15X

FIGURE 2-2. PHOTOMACROGRAPH OF FAILED SEAL WELD - PIN 18

Note incomplete fusion of joint on the thicker lip (plenum side)

100X

FIGURE 2-3. PHOTOMICROGRAPH OF FAILED SEAL WELD - PIN 18

Note evidence of mechanical working of the fusion zone

11.2-63-3862

FIGURE 2-4. COMPLETED REPAIRED SHEAR PIN WELD

11.2-63-3860

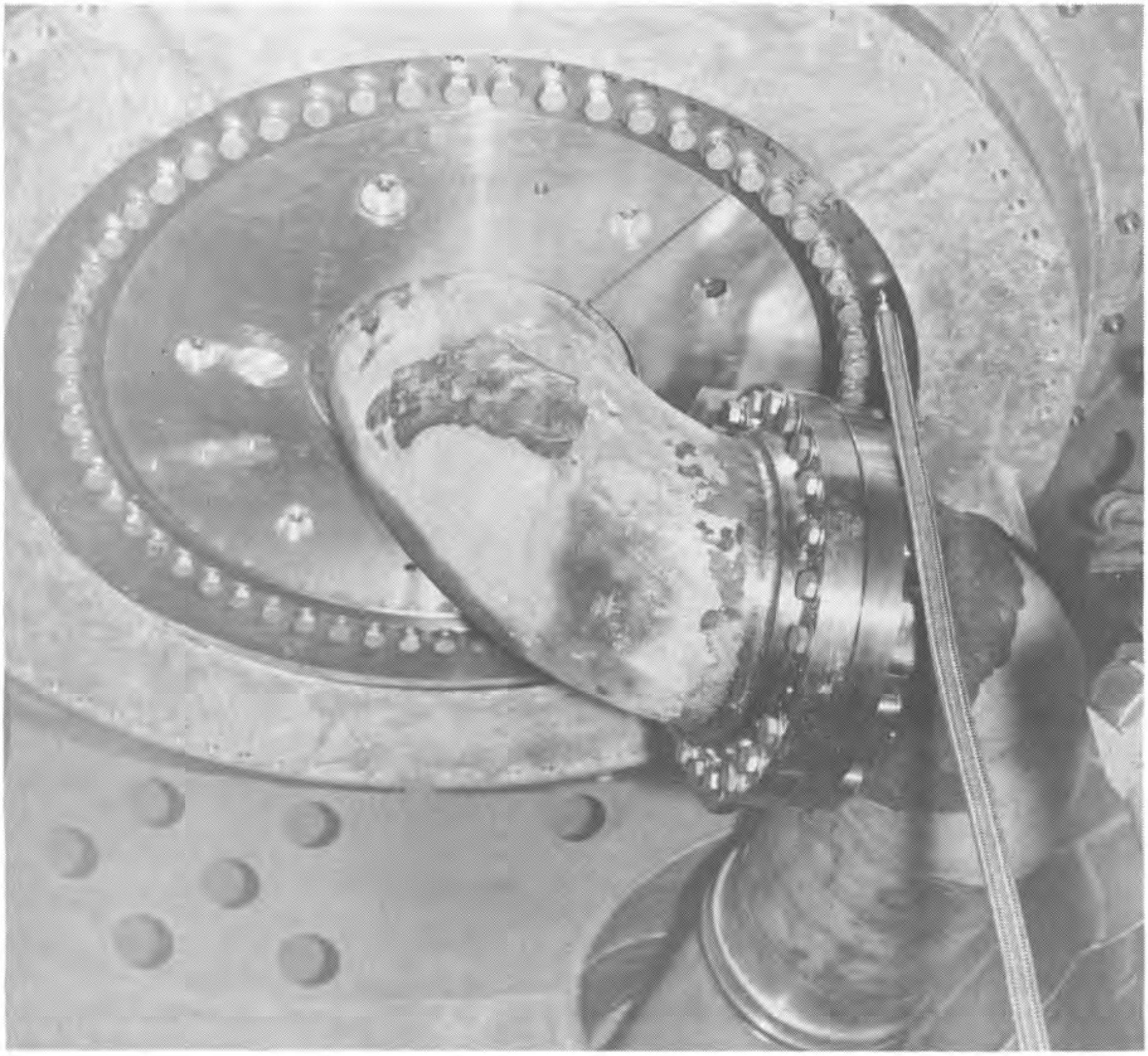


FIGURE 2-5. MODIFIED REACTOR OUTLET GAS DUCT

Note also the modified (bolted) lower moderator seal above

11.2-63-3859

2) An aluminum plug was installed in the recessed portion of the lower plenum cap to exclude trapped air at this location and, consequently, reduce thermal stress gradients in the cap (Figure 2-6 and 2-7). A report (Ref. 4) summarizing the effect of this modification and the anticipated stresses in the plenum cap was published.

3) The welded closures at the upper and lower moderator seals were replaced with bolted closures to facilitate reassembly and subsequent disassembly. The lower closure was sealed with a "K" seal and a rubber "O" ring, and the upper closure was sealed with aluminum foil formed into the gasket groove. Both of these closures were extensively evaluated in mock-ups prior to installation on the reactor.

4) A removable dished head was provided at the bottom of the shield water tank (Figure 2-7).

The reassembly operation was completed by the end of August. This program included the following significant steps:

1) The repaired pressure vessel was placed in the radial shield.

2) The upper and lower moderator seals were assembled and pressure tested.

3) The lower gas duct flange connection was fitted, aligned and installed.

4) The aluminum filler plug was installed in the recess in the lower plenum cap.

5) The modified lower end shielding cone was installed.

6) The shielding tank lower head was installed.

7) The control rods were installed.

8) Thermocouples were installed and routed to a junction box on the exterior surface of the shielding tank to monitor temperatures in the lower cap plug, shielding water and upper moderator seal holddown ring.

9) The pressure vessel was hydrostatically and pneumatically tested without evidence of leakage.

The reactor repair program was completed by the installation of the thermocouple leads from the instrumented fuel elements through the Grayloc seal ring at the upper plenum/reactor cap closure.

<u>b. Seven Tube Mock-Up Test:</u> The lifetime testing of a 7-tube mock-up of the ML-1 calandria in oxygenated water was resumed in July following a shutdown to evaluate the effects of a loss-of-flow which occurred in May (Ref. a). A detailed report of findings following the shutdown (Ref. 5) indicated that the test section had not been damaged by the incident.

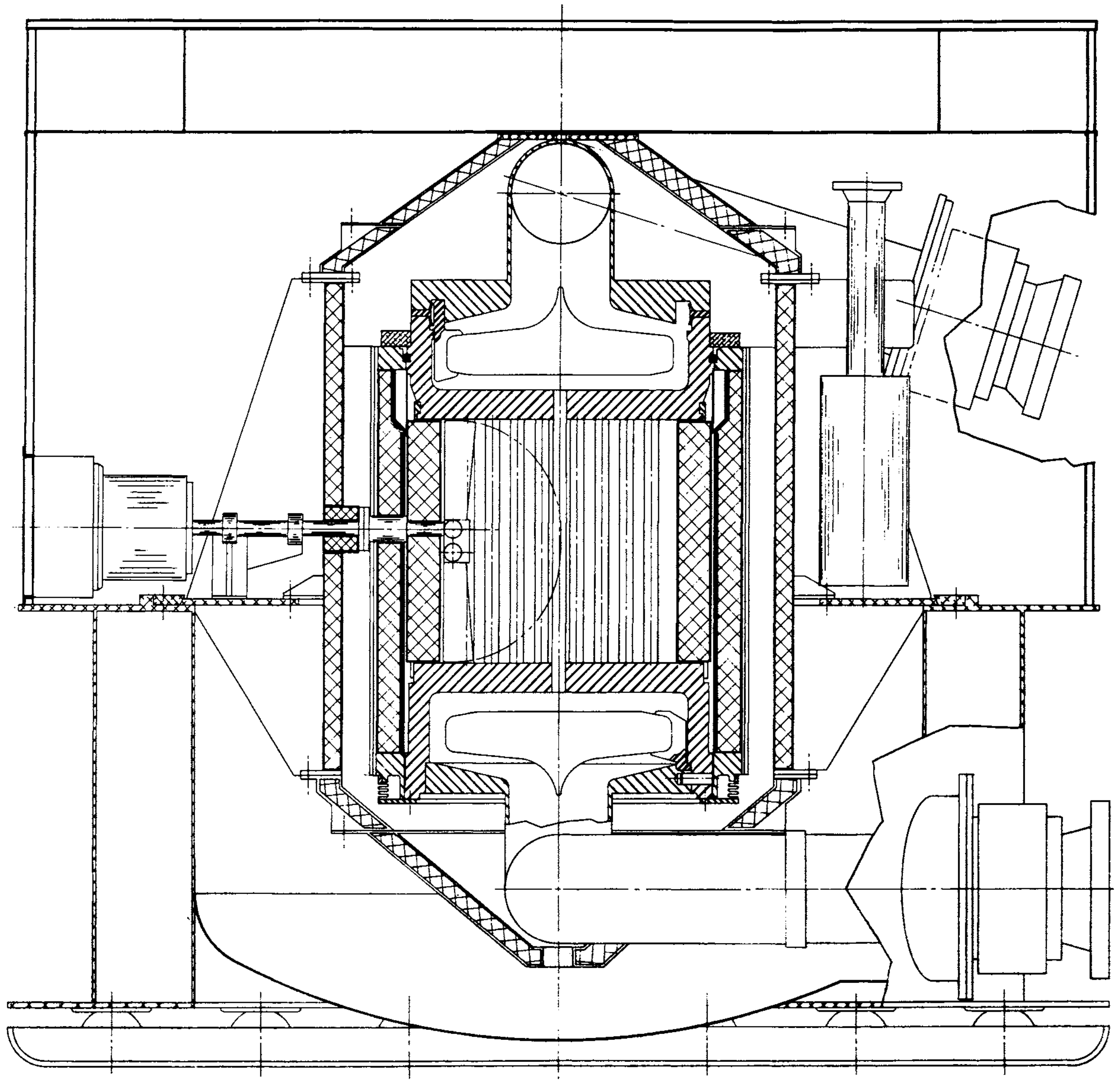


FIGURE 2-6. ML-1 REACTOR SKID BEFORE MODIFICATION

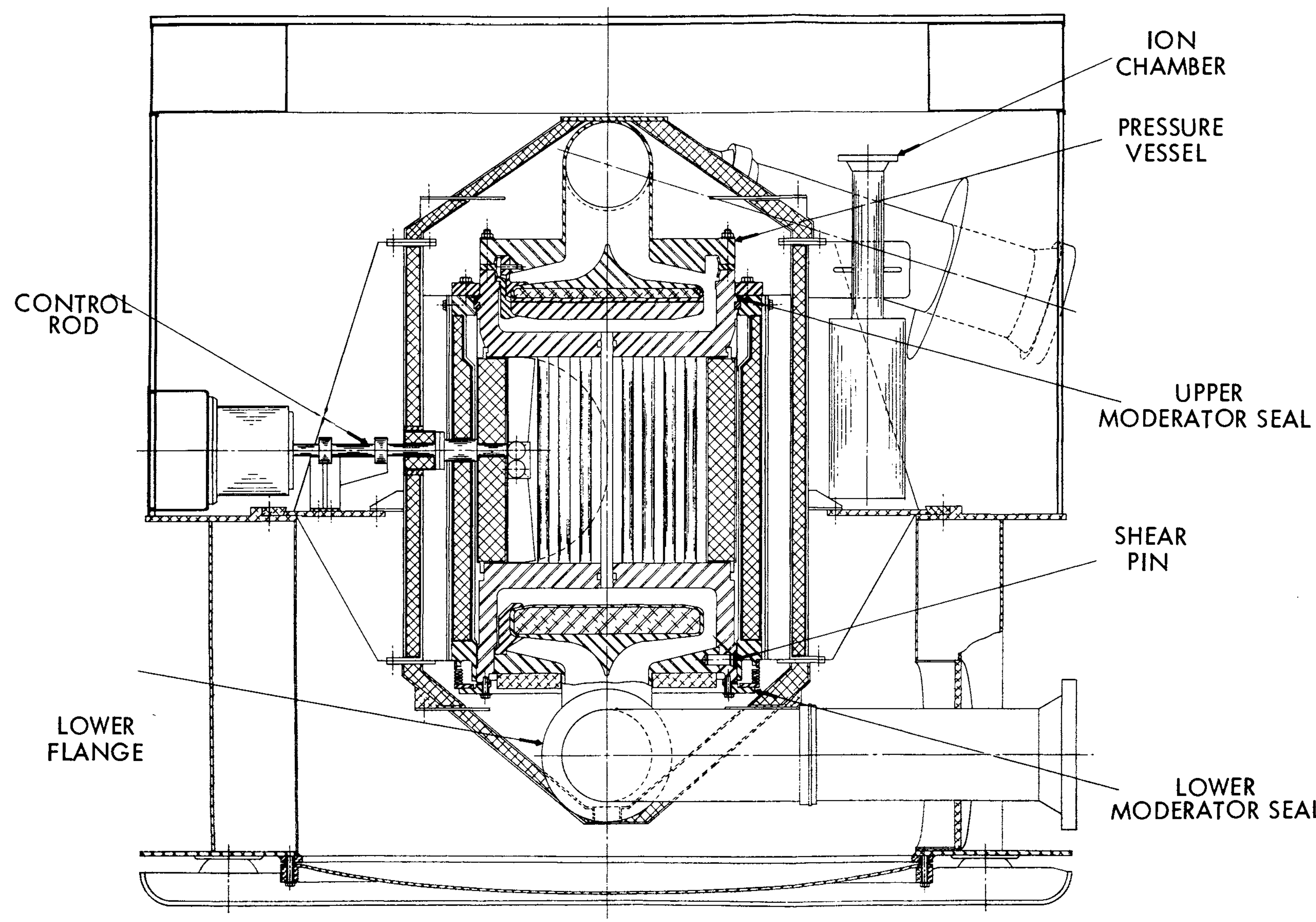


FIGURE 2-7. ML-1 REACTOR SKID AFTER MODIFICATION

11.2-63-3869

Testing continued without interruption until mid-September when the operation was shut down to replace bearings in the blower. Final preparations were being made at the end of September for the resumption of the test. The total testing time accumulated by the end of September was 2938 hr.

c. Aqueous Shield System: The design of permanent tanks and pumps for the mixing and transfer of the ML-1 aqueous shield solution was completed and procurement of all major components had been initiated by the end of September. This new system will prevent contamination of the ML-1 test building and power plant when mixing and handling the boric acid solution.

d. Deoxygenation System Heat Exchanger Modification: During full power reactor operation in connection with power plant testing in February, it was noted that the temperature of the water entering the deoxygenation column was undesirably high. This condition could rapidly degrade the deoxygenation resin and result in an unscheduled plant shutdown. A method for increasing the cooling capacity of the heat exchanger in the deoxygenation system was established. It was found that sufficient cooling could be accomplished by increasing the speed of rotation of the fan on the heat exchanger and by increasing the pitch of the fan blades. A larger drive motor and a new fan drive were ready for installation at the test site at the end of September.

e. ML-1 Lifting Sling: Several welds failed on the ML-1 lifting sling when handling the ML-1 reactor skid mock-up during the reactor repair program. The design and fabrication of the sling was reviewed and the joints were strengthened and stress distribution was improved by substituting round lifting eyes for the original pear-shaped eyes. The unit was ready for load testing at NRTS at the end of September.

f. Moderator Temperature Control: There was some difficulty in regulating the moderator water temperature during the operation of the ML-1 power plant in February. A review revealed that the louvers of the moderator cooler were not completely closing because of air loading from the moderator cooler fans. The design of balanced louvers with improved control linkages was completed during the quarter. It is anticipated that the new louvers will close completely and provide the necessary control of the moderator water temperature during subsequent operation.

2.2 Power Conversion

a. Refrigeration System Temperature Control: Investigation and testing during the previous report period (Ref. a) indicated the need to modify the refrigeration system temperature control. A new temperature controller, with the sensing bulb located in the gas line, was procured and installed on the Clark skid.

b. Lubricating Oil Temperature Control: Modifications were undertaken earlier (Ref. a) to improve the lubricating oil temperature control by installing a motor-operated bypass valve in the lubrication system. The engineering and fabrication required for installation of the bypass valve on the Clark skid was completed. At the end of September, on-site preparations were being made to install this equipment on the skid. In addition, a more accurate thermostat was procured for the lubricating oil sump. The oil sump was modified for installation of the thermostat and to provide for the sump equalizing compressor overflow (described below). The modified sump was hydrostatically tested to 400 psig, and leak checked at 250 psig; no detectable distortion or leakage was observed.

c. Sump Equalizing Compressor: The sump equalizing compressor was modified to incorporate a recirculating oil system so that oil need not be added to the compressor crankcase during plant operation. This modification included the installation of an overflow drain tube from the sump equalizing compressor crankcase to the lubricating oil sump. In addition, a continuous oil supply line was provided to meter a constant flow of oil to the sump equalizing compressor. All bleed ports in the compressor suction cavity were plugged.

d. Startup Compressor: Earlier testing indicated that operation of the start-up compressor at three-fourths speed was desirable (Ref. a). A test set-up to evaluate the performance of the compressor under these conditions was completed in the prior report period. In July, the startup compressor was tested at three-quarter speed, utilizing a special gearhead motor drive. The compressor output was 75% greater than during half-speed operation and operation of both the motor and compressor was satisfactory. The testing was conducted at normal system mass (60 psia) and low system mass (20 psia). A 30 psi differential was maintained across the compressor in both cases, and the unit operated satisfactorily without overloading the motor. The outlet temperature was 274°F, well below the 350°F allowable outlet temperature. At the end of September, a 100-hr three-quarter speed endurance run was in progress.

e. Oil Pump Evaluation: The main lubricating oil pump from the Clark skid was bench checked to determine output oil flow. The pump performed essentially as specified by the manufacturer. The auxiliary lubricating oil pump was also flow checked; performance of this unit was also satisfactory.

f. Gas Flow Measurement: A venturi-type flow meter was designed to provide a more accurate measurement of process gas flow rate with minimum loop pressure loss. The venturi will be installed in the straight pipe section between the reactor discharge and the turbine inlet. The assembly was being fabricated at the end of September.

g. Recuperator Insulation: Difficulties were experienced with the thin (0.005 in.) stainless steel thermal shield in the recuperator high pressure inlet line on the Stratos skid during closed-cycle testing (Section 3.2b). A decision was made to redesign this shield on both recuperators. A 0.030-in. thick Inconel insulation liner was designed and will be installed in place of the thin foil shield on both the Stratos and Clark skids.

2.3 Instruments and Controls

a. Control Cab Modification: Installation of the auxiliary electrical equipment panel and the auxiliary relay panel in the ML-1 control cab was completed. Lubrication system controls which were temporarily located on the upper process panel were relocated to the new auxiliary electrical equipment panel.

A final operational check of all systems operating from these panels was performed and all motor controls, lubrication system controls, interlocks, etc., functioned properly.

b. Liquid Level Indicating System: Installation of the electrical portion of the revised liquid level indicating system was completed. Final checkout of the system will be accomplished after the level probes have been installed on the moderator surge tank assembly. The revised system provides continuous indication of oil level in the lubricating oil sump and an adjustable low-level annunciation point. The moderator and shield level probes provide for annunciation at fixed predetermined levels only; a continuous indication of the level is not provided.

c. Reactor Outlet Temperature System: Temporary reactor outlet temperature circuitry was designed and fabricated to replace the original equipment which had failed. The new chassis provides circuitry for both the indicating and scram systems. The new circuitry provides for incorporation of the improved resistance element sensors when this development is completed.

d. SAM System: The original Site Area Monitoring (SAM) system proved to be unstable and unsuitable as an ML-1 prototype unit. A new system, using Tracerlab chambers (with demonstrated good stability and relative insensitivity to large changes in ambient temperature), was designed and tested in breadboard form. This prototype system was in final design at the end of September.

2.4 Fuel Elements

a. Thermal and Neutronic Analysis: The DEPI Code (a technique for solving problems on a digital computer which normally require an analog computer) was revised to be compatible with the IBM-7094. The changes minimized the read-in time and reduced the overall running time by a factor of two. The new code, ANASIM (DEPI with improved input and output), was successfully checked out and run. The checkout problem simulated ML-1 fuel element transient temperatures during a coolant loss accident. Instabilities, associated with the Runge-Kutta integration method, were encountered when the chosen time increment was large, but presented no problems with time increments of less than five seconds.

Calculations were performed to estimate the helium production in ML-1 UO_2-BeO fuel pellets (Ref. 6). This work indicated that the complete release of the helium produced in a 10,000-hr, maximum power, ML-1 fuel pin would increase the internal gas pressure by 160 psi (complete release of gaseous fission products would raise the internal pressure by an additional 920 psi). Puncture data from the IB-8T-2 (10,000 hr test element) indicates that 10 to 20% of the helium is released from the pellets although these results are quite uncertain and subject to large error. The most probable total pressure in the fuel pin after 10,000 hr of operation was calculated to be 67 psi (40 psi from initial charging during fabrication, 17 psi from 10% helium release and 10 psi from 1% fission product release).

Evaluation of the requirement for operation of the moderator water circulation pump after a reactor shutdown was undertaken. It was concluded that

ML-1 peak fuel pin temperatures following a normal shutdown are less than maximum steady-state operating temperatures provided the standby moderator pump is operated for at least 45 minutes.

An analysis of the criticality of ML-1 elements in the GCRE pool was completed. It was determined that seven elements could not be placed in a critical configuration unless the physical characteristics of the elements were altered.

b. IB-8T-1 In-Pile Test: Evaluation of the IB-8T-1 in-pile test element continued in an effort to better understand the metallurgical mechanisms involved in the formation of the pi-phase observed in the cladding of some fuel pins. The brittle intermetallic phases in the Fe-Cr-Ni-Mo system was investigated to determine the mechanism of formation. Pellets were prepared by blending elemental powders in the proportions indicated by analysis of pi-phase particles, and sintering the mixture. The pellets were aged at appropriate temperatures and X-ray diffraction analyses were performed. The pi-phase structure could not be identified. Some of the pellets were then heat-treated in high purity nitrogen for 24 hours at 1750^{o}F to attempt to produce the pi-phase structure. Similarly, a pellet of pi-phase composition was exposed to methane for 24 hours at 1750^{o}F to evaluate the possibility of carbon acting to promote the formation of the pi-phase. The pellets were examined metallographically after exposure and it was observed that pronounced structural changes had occurred in several of the pellets. However, X-ray diffraction analysis did not definitely identify any pi-phase structure. It was concluded that this method of "synthesizing" the pi-phase in Hastelloy X was unsuccessful. No further work in this area will be undertaken under the AGCRSP.

Investigation of IB-8T-1 metallographic samples commenced in the ACN hot cell. Emphasis is being placed on samples from pin 10 to examine 6400 hr exposure data on a cladding specimen which does not contain pi-phase. The major effort in the past has been the study of fuel pin cladding which contained the pi-phase.

A quantity of pi-phase particles was removed from specimens of pins 1, 13 and 18 to definitely establish the presence of nitrogen in the particles. The techniques used to remove the particles involved electrolytic dissolution of the metallic matrix in a 10% HCl-90% methyl alcohol solution under a 1 amp direct current. The chemical analysis of one sample taken from pin 13 was available at the end of September; this analysis is shown in Table 2-1.

TABLE 2-1 - NITROGEN AND OXYGEN ANALYSIS OF PARTICLES FROM IB-8T-1 FUEL PIN TUBING

(Performed by Battelle Memorial Institute)

Kjehldahl Analysis, % N_2	Vacuum Fusion Analysis	
2.63	% N_2	0.88
	% O_2	1.12

The oxygen detected may be in the form of oxide particles existing in the matrix or oxides contributed by the oxide film from the original tubing specimen. The nitrogen values, when compared with those determined from Hastelloy X not containing the pi-phase (normally about 0.037 by Kjehldahl, or 0.014 by vacuum fusion), indicate clearly that the nitrogen is bound in the precipitate matrix and not in the parent Hastelloy X matrix.

X-ray diffraction and fluorescence analyses were performed on the samples prior to chemical analysis. Results of the fluorescence analysis are compared in Table 2-2 with data from an earlier analysis performed on particles of Hastelloy X that had been annealed in high purity nitrogen.

TABLE 2-2 - ANALYSIS OF IB-8T-1 PRECIPITATE PARTICLES

Specimen Identity	Element % Ni	Mo	Fe	Cr	Other
IB-8T-1 pi-phase particles	25	25	4	46	0
Nitrogen-annealed Hastelloy X particles	35	12.2	35	17	0.8

These data do not agree with the IB-8T-1 microprobe analysis; the reason for the anomaly is not known at this time. No further work will be performed in this area; such activity is not considered warranted under the AGCRSP. An X-ray diffraction analysis of the particles indicated that the composition consisted of M_6C and pi-phase in equal volumes. No significant quantities of other phases could be detected.

c. IB-8T-2 In-Pile Test: Twelve irradiated tubing specimens were prepared at Battelle Memorial Institute (BMI) for tensile testing. The irradiated fuel was removed by chemical dissolution, and plugs were inserted in the ends to prevent tube collapse and to prevent sample elongation in the area of the grips. The general condition and size of specimens sent to BMI for testing is shown in Table 2-3. Eight specimens were tested at room temperature. Two specimens (T-2 and T-5) will be tested at 1200°F and two (T-4 and T-8) at 1400°F. The results of tensile testing at room temperature are shown in Table 2-4.

A wide scatter in the ultimate tensile strength data is apparent; the yield strength data is less scattered. A definite reduction in both properties can be observed, although the yield strength data shows more reproducible values. Based on available data, the elongation of the IB-8T-2 material appears to be greater than that determined for IB-8T-1 tubing. This may be attributed to a number of factors, although the longer time at operating temperature for the IB-8T-2 material appears most significant. Elevated temperature tensile tests are scheduled for completion early in the next quarter.

Metallographic evaluation in the M-E-ATR* hot cells of IB-8T-2 inner liner sections, the weld between the fuel pin cladding and the lower plug, and the chromium-plated fuel pin tip disclosed the following:

*M-E-ATR identifies the hot cells (previously referred to as the MTR hot cell) associated with the MTR (Materials Test Reactor) - ETR (Engineering Test Reactor) - ATR (Advanced Test Reactor), reactor complex at NRTS.

TABLE 2-3 - CONDITION AND LENGTH OF IB-8T-2 TENSILE TEST TUBING SPECIMENS

Specimen No.	Tube No.	Fuel Type	Specimen Length (in.)	Visual Condition
T-1	1	$BeO-UO_2$	7.2	Bent at one end
T-2	6	"	4.8	Straight
T-3	12	"	5.0	Severely S-shaped
T-4	18	UO_2	6.0	Straight
T-5	7	$BeO-UO_2$	6.0	"
T-6	7	"	6.0	"
T-7	12	"	4.8	Slightly S-shaped
T-8	13	UO_2	4.9	Slight bend
T-9	15	"	6.0	Straight
T-10	16	"	6.0	"
T-11	16	"	6.0	"
T-12	18	"	6.0	"

TABLE 2-4 - RESULTS OF ROOM TEMPERATURE TENSILE TESTS OF IB-8T-2 CLADDING SPECIMENS

Specimen No.	Ultimate Tensile (psi)	0.2% Yield Strength (psi)	Modulus of Rupture 10^6 psi	Elongation %
T-1	67,000	41,900	26.2	8.3
T-3	86,300	48,800	21.2	*
T-6	116,300	59,400	34.3	15.4
T-7	98,400	53,600	22.6	9.1
T-9	95,070	46,700	33.4	17.8
T-10	101,000	46,100	29.5	28.8
T-11	107,700	49,760	27.7	17.4
T-12	94,490	44,400	30.5	15.5
Control	114,800	67,000	28.19	37.5

*Specimen slipped in grips, elongation data invalid.

1) The IB-8T-2 Hastelloy X inner liner samples all showed the characteristic gray band on the metal surface closely resembling the initiation of the second-phase structure observed in some of the IB-8T-1 fuel pin claddings. (A cross section of the liner near the bottom is shown in Figure 2-8.) A very heavy oxide scale was also present on the surface of another section (not shown) taken 2-1/2 in. from the lower end of the liner.

2) The chromium plating on the lower tip of IB-8T-2 fuel pin 12 was functional after 10,000 hr of testing. Minor oxidation and cracking of the plating occurred but the plating remained adherent and the cracks did not propagate into the Hastelloy X lower plug. (A chromium-plated area after 10,000 hr operation is shown in Figure 2-9.)

3) The weld area between the Hastelloy X fuel pin cladding and the lower plug was in excellent condition. The weld appeared sound and no preferential oxidation of the weld deposit could be detected.

d. <u>Metallurgical Support of the ML-1-I Air Cycle Operation:</u> Low-cobalt Hastelloy X tubing (identical with that used in the ML-1-I fuel elements) is being exposed to high temperature air to determine the amount of oxidation and the corrosion product loss to be expected by conversion of the ML-1 reactor to an air cycle. Two investigations were started in the report period: 1) A determination of the extent of oxide penetration at various time intervals at 1750°F in air; and, 2) A continuous measurement of the weight change due to oxide film growth or loss in air at 1750°F.

During the report period, duplicate samples which had operated at 1800°, 1750°, 1600°, 1450°, and 1300°F in air for 1000 hr were examined. The oxide scale on the tubing surface was 0.0012 in. thick, maximum; oxide penetrations below the tubing surface reached 0.002 in., maximum. The low-cobalt tubing samples appeared more heavily oxidized than high cobalt sheet samples exposed in earlier studies at 1750°F for equivalent times and in similar atmospheres. Figure 2-10 shows the appearance of the tubing samples after 1000 hr of exposure in air.

Microhardness measurements obtained from these specimens showed some variation of hardness with temperature of exposure as indicated in Table 2-5. The variation in hardness is attributed to formation of carbide precipitates in the structure (Figure 2-10). At low temperatures, the precipitate formed is very fine, producing maximum hardness. At high temperatures, the precipitate is agglomerated, thus reducing the hardness of the material.

Pre-test vacuum fusion and Kjehldahl analyses were performed at AGN on similar tubing for comparison with data to be obtained when testing is completed. These data will also be useful in analyzing data from the IB-8T experiments which used the same material. The results of these analyses are shown in Table 2-6.

The second investigation, evaluation of the rate of oxide growth and spalling on Hastelloy X in air at 1750°F, was started during the report period. An apparatus was designed to determine continuously the weight change of a single sample. Feasibility of the concept was demonstrated in a short

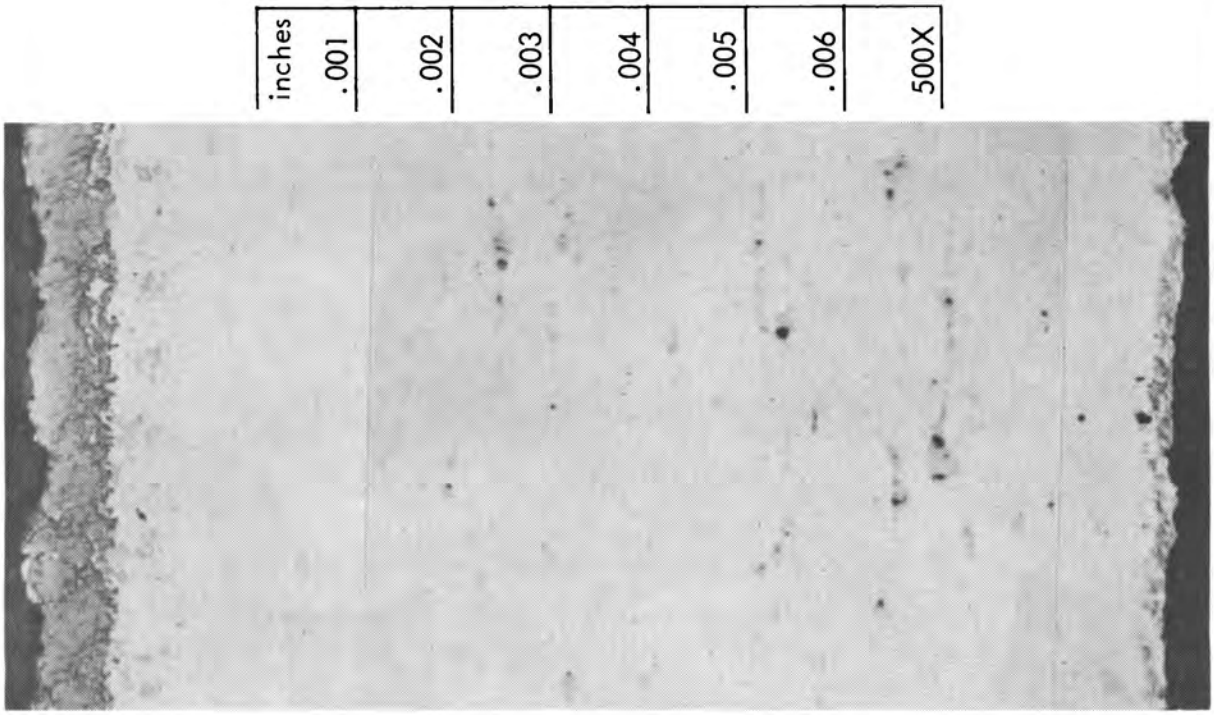


FIGURE 2-8. CROSS SECTION OF IB-8T-2 INNER LINER 2 1/2 in. BOTTOM SHOWING GREY BAND ON OD

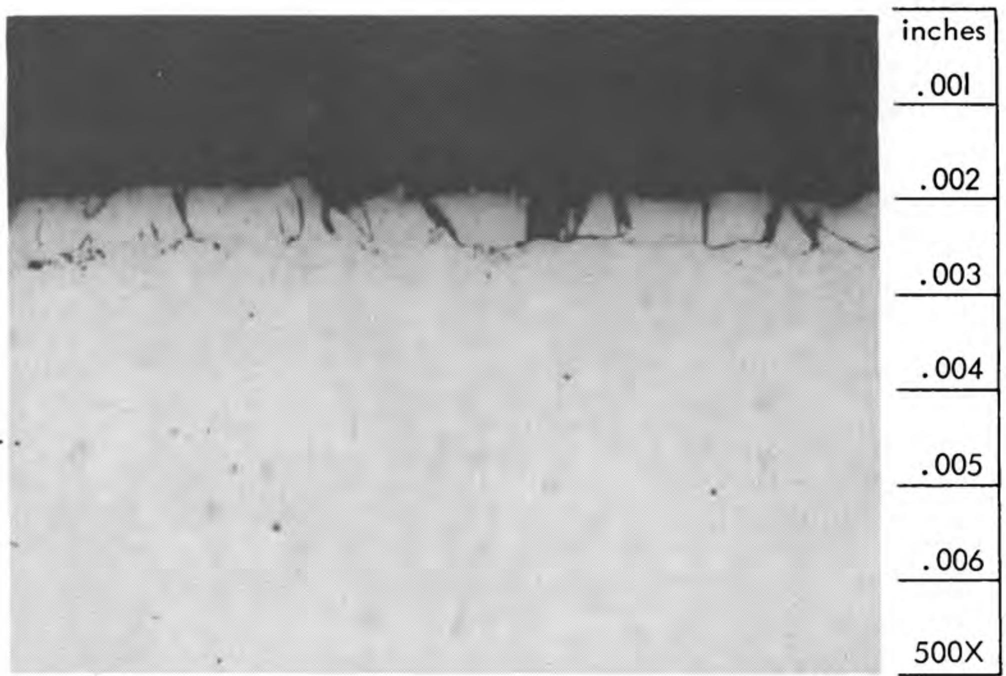


FIGURE 2-9. CHROMIUM PLATING ON TIP OF IB-8T-2 PIN 12

11-2-63-3863

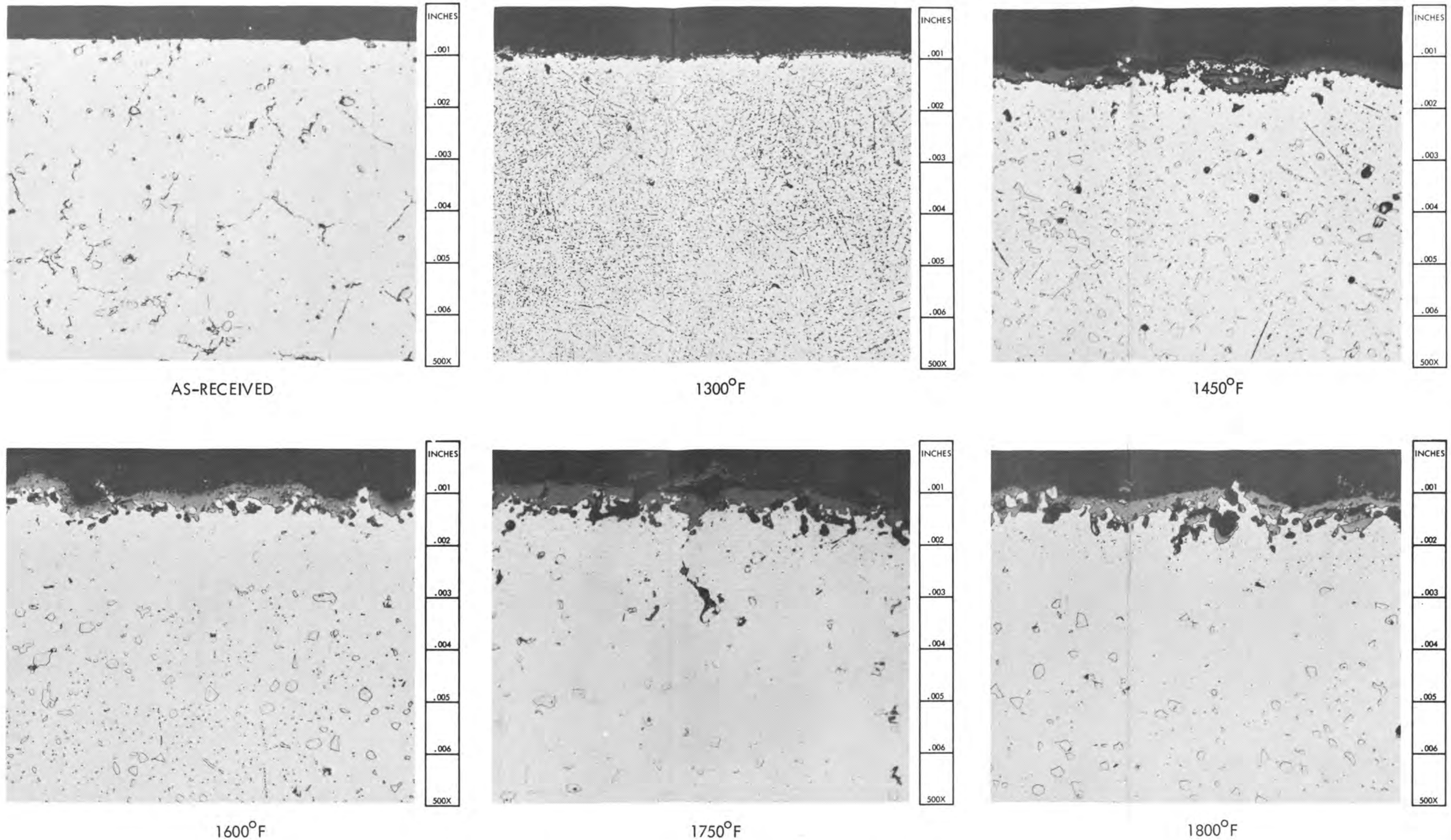


FIGURE 2-10. ML-1-I HASTELLOY X TUBING EXPOSED TO AIR FOR 1000 HOURS OUT-OF-PILE

11.2-63-3868

TABLE 2-5 - AVERAGE* MICROHARDNESS OF ML-1-I TUBING EXPOSED 1000 HR IN AIR

Exposure Temperature (^{o}F)	Average Microhardness, Knoop
Unexposed	240
1300	270
1450	256
1600	244
1750	229
1800	232

*Average of 4 samples except for unexposed and 1800^{o}F levels which are the average of 2 samples.

TABLE 2-6 - VACUUM FUSION AND KJEHLDAHL ANALYSIS ML-1-I TUBING

Tube No.	% Oxygen (Vacuum Fusion)	% Nitrogen (Vacuum Fusion)	% Nitrogen (Kjehldahl)
A1698	0.0043	0.0175	0.038
A2288	0.0050	0.0165	0.028
A2348	0.0050	0.0260	0.037
A2407	0.0040	0.0190	0.038

test with this equipment and a design was prepared for modification of the continuous weighing balance to accommodate multiple samples. Components for this modification had been received at the end of September; the test will be initiated following the equipment modification.

e. Storage of the ML-1-I Fuel Elements: The IB-2L-17 (GCRE) fuel element, which was stored under water following irradiation in the reactor, was macroscopically examined in the ARA hot cell. The purpose of this examination was to determine whether the ML-1-I fuel elements could be stored for extended periods in water without deterioration. This inspection did not reveal any deleterious effects of the 18-month immersion in water. Metallographic examination of sections obtained from the IB-2L-17 was performed during July. In general, the metallographic findings showed no evidence of water-caused deterioration, corrosion, or cracking. Points of interest are listed below:

1) The Kanigen nickel-plated 99% Cu-1% Cd burnable poison foil showed no evidence of galvanic corrosion or surface or internal oxidation. Only a few minor cracks extended through the plating.

2) Weld zones between the expansion joint, inner liner, outer liner, and nose piece were free of corrosion and stress corrosion cracking.

3) The inner liner (Type 316 stainless steel) was found to have intergranular separations and pits extending halfway through the liner. This was not the result of water storage; a similar condition was observed during previous metallurgical evaluation of the GCRE IB-2L-2 fuel element inner liner. This condition was attributed to mechanical stresses causing intergranular separations because of sigma phase formation in the stainless steel and is the reason for fabricating the inner liners of the ML-1 fuel elements from Hastelloy X.

4) The fuel pin surfaces and chromium-plated tips appeared to be unaffected by water storage.

5) The lower spider and the weld nugget between the upper spider and upper fuel pin plug did not show serious water corrosion damage, although a minor amount of corrosion product was observed on the surface. A report of this investigation was published (Ref. 7).

f. Reactivity Shims: During the ML-1 reactor defueling in April 1963, it was noted that about 40% of the reactivity shims were difficult to remove from the pressure tubes. The force required to pull the most difficult shims was estimated at 60 lb. In addition to the problems encountered in removing the shims, there appeared to be a loss of silver from the silver-plated shims as evidenced by white flakes observed on some pressure tubes which had been in contact with the silvered shims during reactor operation.

The reactivity shims are split cylinders rolled from Type 304 stainless steel sheet 0.010 in. thick. The pre-formed width is 5.400/5.500 in.; the nominal length is 28.25 in. The shims are located between the fuel element and the pressure tubes in the reactor. A total of 61 shims are used; 25 shims are plated with 67.8 gm of silver, 3 are plated with 23.7 gm of silver, and 33 are unplated.

A program of thermal and mechanical testing and chemical analysis of the silver content of shims in the as-built condition was undertaken. Simultaneously a hot cell examination of nine shims selected from those removed from the reactor during April 1963 was performed. The hot cell examination included both dimensional inspection and chemical analysis. The irradiated shims were selected to permit an evaluation of the effect of various exposure times and to represent the range of forces required to remove the shims from the pressure tubes. In addition, a few shims were selected from reactor locations where the small white flakes were observed.

It was determined from the examination that the major reason for removal difficulty was the amount of "bow"* existing in the as-built shims. The bow in the majority of the shims was more than 0.055 in. This bow increased the effective diameter of the shims sufficiently to result in an interference fit between the shim and the pressure tube and caused high frictional forces during removal. Calculations showed that the frictional forces resulting from the bowing were similar to those observed during shim removal.

A definite loss of silver was observed on the shims analyzed. The silver loss was found to be proportional to the thickness of silver plating and not to

*Bow: Deviation from straightness, that is curved.

exposure of the shim. It was concluded, therefore, that silver loss was due to mechanical abrasion and galling during shim handling and not to the dissolution of the silver. The total silver loss varied from 4.0 to 9.9% of the design silver weight on the four shims which were analyzed.

On the basis of these findings, a decision was made to alter the design and to procure a new set of reactivity shims for installation in the ML-1. The specifications for the replacement reactivity shims stipulated a maximum bow of 0.060 in. In addition, the pre-formed width of the shims was reduced to 5.27/5.28 in. This reduces the overall formed size of the shim and minimizes the effect of bow on binding. The silver plating was applied on the inside surface only. A new set of shims was fabricated with the above design changes and the core was reshimmed in August 1963. Only shims having bows of less than 0.040 in. were installed in the reactor. All shims were inserted with less than 20 lb of force.

g. Replacement Instrumented Fuel Elements: Seven spare ML-1 fuel elements were modified by inserting thermocouples in the unfueled center pins to provide the ML-1 core with instrumented fuel elements. The details of this work were published (Ref. 8).

h. Fuel Element Inspection: During the last week of September 1963, a detailed inspection of the 61 ML-1-I fuel elements stored in the GCRE pool was completed. Five fuel elements were found to have badly deformed and/or broken lower spiders. Except for these failures, the fuel elements appeared to be in good condition. The cause of the lower spider damage is not known at this time; investigation of the failure, including hot cell examination of one of the elements, was initiated at the end of September.

2.5 System Performance Evaluation

Evaluation of the performance of the ML-1 power plant during the limited endurance run (ANSOP 16625) was completed and a final report issued (Ref. b).

A preliminary review of the proposed design of the power conversion test facility at San Ramon was completed, and it was concluded that the various components of the test loop were adequately arranged and instrumented.

A study of the radioactive contamination of the ML-1 system was completed. A report summarizing the contamination experience to date and the future test objectives to predict the performance of a field plant was being prepared at the end of September.

An overall review of the reference ML-1 system analysis was initiated in September.

3.0 ML-1 DEVELOPMENT AND IMPROVEMENT

3.1 Reactor and Auxiliaries

This task was inactive during the period.

3.2 Power Conversion

a. Clark Turbine-Compressor Set (CSN-1): The program for the repair and modification of the CSN-1 was initiated. The t-c set was reassembled using the spare turbine blades (procured earlier in the program) and the type of bearings which failed at NRTS. Following this reassembly, the unit was installed in the open-cycle test facility at Clark Brothers and initial runs were conducted to checkout the facility and instrumentation. The instrumentation included four shaft position probes installed in the bearing cavities to monitor the frequency and amplitude of shaft movement and thus assist in the evaluation of the cause of bearing failure. Additional instrumentation was added to the t-c set to measure more accurately the pressure and temperature of the process gas at compressor inlet and discharge and turbine inlet and discharge.

Following the checkout of the facility and determination of reference shaft movement data, the "NRTS-type" bearings were removed and bearings of a modified design were installed. These bearings were of a three-scallop, sharp-edge design which was purported to reduce the half-frequency whirl tendency of the rotor/bearing system. Tests revealed that rotor/bearing instability with this bearing could be induced by cooling the lubricating oil. Although the temperature of the oil during instability (in the range of 100^{o}-120^{o}F) was lower than normally used (150^{o} to 180^{o}F) during ML-1 operation, it was near the minimum specified (130^{o}F).

Following these tests, the three-scallop bearings were modified by machining an annular groove 0.40 in. wide by 0.40 in. deep around each bearing. Testing this configuration for seven hours did not produce any evidence of instability. However, subsequent evaluation indicated that this design is unsatisfactory; the remaining bearing surface is insufficient to accommodate the load.

During the last test sequence,oil sprayed into the compressor inlet from an internal oil leak in the t-c set. This oil subsequently burned in the turbine inlet pipe. The additional energy from the burning oil resulted in a violent speed excursion (to approximately 125% rated speed) followed by compressor surge and an internal explosion. The turbine blades failed and substantial damage occurred in the turbine end of the machine.

Disassembly and inspection revealed the major damage was confined to those turbine end components which were to be replaced during modification to the CSN-1A configuration. The inspection also revealed the compressor blades had rubbed the case and, although no damage was evident, these blades will be replaced with existing spares.

The t-c set failure made it necessary to completely re-evaluate and redirect the CSN-1A repair and modification effort. The program outlined below was formulated:

1) An AGN technical representative was assigned full-time at the Clark Brothers plant to provide on-site liaison and technical direction.

2) A bearing consultant was retained by AGN to evaluate the CSN-1 bearing problem and to develop a technically sound bearing design as backup for the Clark-developed design.

3) Clark was authorized to develop a reference bearing design.

4) Clark will assemble the CSN-1A with modified and repaired parts and bearings of a revised design mutually acceptable to Clark and AGN.

5) Clark will conduct open-cycle tests with the CSN-1A to evaluate the aerodynamic and bearing performance under a detailed program to be developed at a future date.

6) Clark will disassemble, inspect, and reassemble the CSN-1A and ship the unit to NRTS.

b. <u>Stratos Turbine-Compressor Set (TCS-670A):</u> The TCS-670A was successfully open-cycle tested; a total of 20 hr and 35 min of operating time was accumulated. As expected, some difficulty was experienced during the wear-in of the seals because of high breakaway torques. However, by the completion of the open-cycle tests, breakaway torque values indicated that seal wear-in had been accomplished. The lubrication system functioned satisfactorily throughout the open-cycle test program; all oil flows and bearing temperatures remained well within allowable operating limits. The thermodynamic performance of the unit was exceptionally good; self-sustaining operation was possible during two tests with compressor inlet temperatures of 86^{o} and 95^{o}F. A final report of the test was published (Ref. 9).

The TCS-670A was removed from the open-cycle test facility following seal run-in and installed on the Stratos skid. Closed-cycle cold rotational tests were satisfactorily completed (see Section 3-2d). During the subsequent closed-cycle, hot rotational testing, while the unit was being shut down from a test run, a sudden increase in torque overloaded the start motor and resulted in a hot shutdown. Post-shutdown examination revealed that the t-c set had seized.

The gearbox adapter plate was removed for visual inspection of the gearbox. This inspection revealed no indication of the reason for the malfunction. The main lubricating oil pump was also removed from the gearbox (to check for seizure) and was found to be operable. The unit was then removed from the power conversion skid.

The TCS-670A was completely disassembled and inspected. This inspection revealed that the cause of the seizure was a failure of the turbine interstage seal and interference between the downstream side of the stator plate assembly and the upstream side of the second stage turbine wheel. Other items noted during this inspection were:

1) The entire stator plate assembly had deflected and moved the interstage seal downstream into the forward (upstream) face of the second stage turbine wheel. This caused severe rubbing which led to a complete failure and melting of the interstage seal.

2) The bearings, both journals and thrust, were in good condition, and could be reused.

3) The oil pump drive shaft bearings in the main gearbox were slightly damaged. This damage, although not severe, is sufficient to warrant replacement.

4) The compressor end seal, and the second stage compressor inlet seal, both showed slight signs of overheating. The general condition of these seals is acceptable, however, as is the condition of the rest of the t-c set seals (except the turbine interstage).

5) The inlet cone baffle to the first stage compressor wheel was cracked in a general radial direction from the inner diameter for a length of approximately one inch.

6) The trailing edge of one second stage compressor diffuser blade was broken off. This was in addition to those trailing edges that had been broken off previously.

7) The entire t-c set showed very slight signs of small particles of foreign material having been entrained in the gas stream. Subsequent investigation revealed that the stainless steel foil thermal shield in the recuperator high pressure inlet line had been blown loose, fragmented, and passed around the loop. A 0.030 in. thick Inconel insulation liner was designed, and will be installed in place of the thin foil on both the Clark and Stratos skids.

Stratos personnel assisted in the disassembly and inspection. Stratos was requested to submit a report of the preliminary t-c set failure analysis and a proposal for the design and completion of the required modifications and repair.

c. Alternator Development: Alternator tests were conducted during the quarter to determine the source of parasitic losses in the machine. In the first tests, the alternator was assembled without the stator. The unit was operated at rated speed with and without field coil excitation. The input power to the electric motor driving the machine was 30 kw greater when the rotor was excited to rated current than without rotor excitation. Most of this loss was attributed to eddy current formation in the metallic case.

A special fixture was fabricated to permit testing the alternator without a case to determine the effect of the case on the eddy current losses. Only limited data was obtained; the "caseless" fixture was too flexible to withstand the high magnetic forces between the rotor and the drive-end housing. This flexibility allowed the fixture to deflect, misaligning the bearings which, in turn, caused bearing overheating. The data obtained, however, indicated that approximately 15 kw of the previously determined losses (30 kw) were attributable to the interaction between rotor flux unbalance and the metallic case. Based on these data, and previous data which indicated 6 kw loss between the stator and thecase, it appears that the use of a structural plastic case will significantly reduce eddy current losses.

At the end of September, a canned stator section (to permit oil cooling of the stator) and the plastic case were being designed. It is planned that the caseless fixture will be strengthened to eliminate flexibility, and that further testing will be conducted in the next quarter to obtain more detailed data on eddy current losses in the case while the revised stator and case are being fabricated.

d. Stratos Power Conversion Skid Testing: During the prerotational checks of the Stratos power conversion skid, the t-c set was removed from the skid for replacement of a section of the compressor bearing lubricating oil supply line in the t-c set gearbox. This line had been damaged during installation of a flow orifice in the supply line.

The unit was reinstalled on the skid and closed-cycle cold rotational tests were satisfactorily completed. A maximum t-c set speed of 23% of rated speed was attained and a total of 4 hr and 35 min of operation was accumulated during these tests.

Prior to hot rotational testing, a 5.450 in. orifice was installed in the heater inlet line to simulate the reactor $\Delta P/P$ of 8.5%. During the initial hot rotational test, oil-nitrogen separator level control problems were encountered at t-c set speeds above 45% of rated speed. Under these conditions, the separator tended to overfill with oil. The problems were attributed to the high lubricating oil flow required by the Stratos t-c set. Two manually controlled bypass lines (3/8 in. and 1/2 in.) were installed around the separator level control valve to reduce the amount of oil controlled by this valve. In addition, springs were installed under the high and overflow floats in the separator in accordance with a recommendation by the vendor. These springs insure positive float action and prevent the floats from sticking on the shaft.

Self-sustained operation was attained during Test 12 at the following conditions:

Turbine inlet temperature,	1000^{o}F
Compressor inlet pressure,	60 psia
T-C set speed,	60% of rated

The maximum power developed during Test 12 was 144 kw under the following conditions:

Turbine inlet temperature,	1140^{o}F
Compressor inlet pressure,	110 psia
Compressor inlet temperature,	120^{o}F
T-C set speed	18,300 rpm

During the shutdown following Test 12 (21 August 1963) when the unit was at 60% of rated speed and at a turbine inlet temperature of approximately 800^{o}F, a sudden increase in torque reduced the speed of the start motor (and increased the current to this unit) sufficiently to trip the over-current devices on the emergency power unit. Attempts to restart the start motor from the commercial power failed and a hot shutdown of the t-c set resulted. The coastdown time from 60% of rated speed was approximately 2 minutes. Manual rotation of the t-c set after shutdown was impossible, indicating that a seizure had occurred within the machine. Maximum emergency seal gas supply and auxiliary lubricating oil flow was maintained during the entire shutdown to remove the residual heat from the seals and bearings. All seals maintained a positive pressure differential, indicating that oil had not escaped into the loop during this shutdown.

TCS-670A operating times and operating conditions during the closed-cycle series of runs are shown in Table 3-1.

TABLE 3-1 - SUMMARY OF TCS-670A CLOSED CYCLE TESTS

Test Condition	Turbine Inlet Temperature, ^{o}F	% of Rated Speed	Operating Time, hr
Cold	Ambient	0-40	4.6
		40-95	0
		95-100	0
		TOTAL	4.6
Hot	600-1000	0-40	4.5
		40-95	3.2
		95-100	0
	1000-1150	0-40	0
		40-95	3.5
		95-100	4.0
	1150-1200	-	0
		TOTAL	15.2

e. Power Conversion Improvement:

1) Improved Precooler Design and Development: An expanded-type tube-to-tube sheet joint for the improved precooler was tested. The test specimen, consisting of 4 5/8 in. diameter tubes rolled into 5/8 in. thick plate, was subjected to 29 thermal cycles (-65° to $+500^{\circ}F$) under an internal pressure reaching 120 psia. After nine cycles, minor leakage was detected at one rolled joint. Investigation revealed that the leakage resulted from insufficient rolling and the tube was re-rolled and testing continued. A helium leak check of the four tube joints revealed no evidence of leakage after 2½ hr at 140 psig internal pressure.

Analysis of the data from the pressure test of a mock-up section of the curved tube sheet/header (reference) design revealed only a slight advantage for the curved tube sheet over a flat tube sheet. The performance of curved tube sheet did not approach that predicted for a section of a cylinder and, as a consequence, its use in the improved precooler design is not warranted. The improved precooler design was reoriented to flat tube sheet construction, utilizing the ASME Unfired Pressure Vessel Code, Section VIII, 1962 Edition. Tie bars will be specified at the longitudinal centerline of the header, tying the tube sheet to the cover. This will permit the use of a 5/8 in. thick tube sheet.

The bids for the finned tubes for the improved precooler were received at the end of September. Work continued on the fabrication drawings; completion of this work is scheduled in October. The draft of the final design report on the improved precooler was completed.

2) Improvement for Air Cycle Operation: The seal and bearing development test continued throughout the quarter. As a result of the failure of the Type 440 stainless steel running face during the last quarter (Ref. a), it was decided to test other seals with harder surface finishes. While these running faces were being fabricated, the test fixture was modified to permit testing the journal bearings identical to those used in the CSN-1. The bearings were tested at full speed (22,000 rpm) for 25 hr, during which time the oil temperatures, flow and pressure were closely monitored. The bearing pressure differential was reduced to 20 psi (56 psi is normal) during the last half of the test and bearing oil return temperatures remained below $185^{\circ}F$.

Throughout the test, one journal bearing had a flow rate approximately twice the other. It was decided to disassemble and inspect the bearings to find an explanation for this difference. The inspection revealed that considerable scoring of the bearings had taken place although there was no measurable wear. Both bearings had the same clearance. The thrust bearing (utilized to balance end loads in the absence of the face seals) was severely worn. It is believed the material from the thrust bearing damaged the journal bearings. Lubricating oil flow tests of the fixture, without the shaft in position, indicated the total oil supply pressure drop was satisfactory at the operating flow rates.

Following the bearing tests, the fixture was reassembled for seal testing. A Colmonoy No. 6 running face was installed with a silver-impregnated carbon-graphite seal and testing was resumed. After approximately one-half hour of operation, the Colmonoy running face was grooved, although the seal face remained in satisfactory condition. A superficial metallurgical examination indicated the Colmonoy had not been applied properly, but the short life of the specimen indicated that the seal would have been unsatisfactory even with correctly applied face material.

The design of a hydrostatic face seal was completed. This seal operates on a principle similar to a hydrostatic thrust bearing in that it employs a pressure force balance between the process gas pressure and the seal buffer gas to hold the seal slightly off of the running face, while allowing a very small continuous leakage. A prototype of this seal was fabricated and tested. The seal failed after one-half hour of successful operation but the data indicated that it would be satisfactory if the pressure balance were adjusted to permit slightly more leakage flow.

Based on the results of the tests conducted and on information from other agencies developing face seals, the decision was made in mid-September to discontinue further development of dry, uncooled, contact face seals. Future seal work will be based on testing of the hydrostatic seal and a Borg-Warner gas-cooled seal being designed specifically for ML-1 application.

A commercially available air cycle dehumidification unit which would meet the system requirements (dewpoint - 37°F) was selected from 12 bids. This air drying system has a capacity of 7-1/2 scfm, and weighs 7 lb. While the capacity is only one-fourth of the 30 scfm output of the make-up gas compressor, four of these units can be used, or the vendor may be able to build a 30 scfm unit to meet ML-1 requirements. The dryer uses purge air to generate the molecular sieve desiccant material and operates on a 30-second use/regeneration cycle.

The Cardair air make-up compressor was ordered, received and inspected. At the end of September, preparations were being made for acceptance tests of the compressor. This unit delivers 30 scfm, the reference air make-up flow rate for an optimum air cycle system.

3.3 Instruments and Controls Improvements

Spare drawers for the scram logic and intermediate range nuclear drawers were completed and checked out. Fabrication of the spare source range and power range drawers was initiated and fabrication of the spare nuclear drawer test jig, designed to test and store the drawers in operating condition, was completed. The test jig is scheduled for checkout in October.

The improved ML-1 pressure monitor chassis was fabricated, tested, installed and checked out in the ML-1. This single chassis (with a six channel capability) replaced equipment which was unstable, heavy, power consuming and generally unsatisfactory as prototype equipment. An additional meter was installed in the control cab to indicate compressor inlet pressure.

Final design of the improved process temperature monitor was delayed to permit additional environmental testing of the breadboard circuitry. At the end of September, a design had been specified and final design was in progress.

The preliminary design of the improved ML-1 speed and temperature controller was prepared and submitted to the USAEC for approval (Ref. 10). No further work will be undertaken until this approval is received.

3.4 Fuel Elements

a. Mechanical Development: The Refrasil insulation on the IB-17R-1 test element, which had been irradiated in GETR loop for 1179 hr, was evaluated in ARA hot cell (see Section e below). Disassembly of the element revealed ten areas where the Refrasil had been rubbed or torn; holes from 1/4 to 1/2 in. in diameter were observed in one or more layers of the insulation. The Refrasil was not brittle in these areas, indicating that the insulation had experienced temperatures below 1600° to $1700^{\circ}F$.

It was postulated that some of the holes in the outer layer of insulation were the result of the techniques used during fuel element fabrication and that the inner layer holes resulted from Refrasil shrinkage (during first heatup) concurrent with the radial expansion of the inner liner. Tears in the inner layer can be avoided by a looser wrap and the assembly techniques can be modified to provide better protection for the outer wrap.

The effect of small tears in the insulation on fuel element operation was found to be negligible. The insulation package was designed to serve two functions: 1) to allow the inner liner to operate at temperatures of 800° to $1200^{\circ}F$ while the outer liner operates at about $180^{\circ}F$; and, 2) to serve as an internal radial support for the outer liner. Inspection, after 1179 hr of irradiation, indicated that both functions were accomplished. Post-irradiation disassembly of the 6000 hr IB-17R-2 and the 10,000 hr IB-17R-3 fuel elements will yield additional information on the suitability of Refrasil as insulating material for the ML-1-II fuel elements.

b. ML-1-II Burnable Poison Development: The development of europium-bearing burnable poison foils for use in the second core of the ML-1 was initiated. Europium was chosen because of favorable neutronics characteristics when compared to other poison materials. The objective is to prepare specifications for final fabrication of production quantities of poison foils. Trial order quantities of foil will be evaluated to determine neutronic, corrosion and compatibility characteristics to support the preparation of final specification.

The program was initiated with a survey of the literature and discussions with various researchers in the field to review the problems associated with the fabrication of europium-bearing alloys and dispersions. The survey showed that europium metal alloy was impractical; all attempts to produce europium-stainless steel alloys of a given composition, especially in the low (1 wt%) europium content range, have been unsuccessful. The adopted approach incorporates a europia dispersion (using the oxide of europium (Eu_2O_3) stabilized with titania (TiO_2) for added stability and resistance to reactions with water and silicon) in stainless steel powder. The cermet will be clad with 304L stainless steel and fabricated by the "picture frame" hot-cold rolling technique.

Preliminary specifications were written and a request for quotations for a trial order of the foils was submitted to prospective suppliers of these materials. A purchase order was issued to the low bidder for a trial order of 12 foils, and permission to purchase a backup order from the second low bidder was requested from the USAEC. The foils will be evaluated for resistance to several corrosive media (including water and reference gas) and uniformity of europium distribution. A complete test program for evaluating the foils was developed and the selection of a test technique for europium distribution determination undertaken. By the end of September, it had been established that a chemical (gravimetric) method of europium analysis was not feasible because of the large limits of error of such a process (about $\pm$ 30%). A neutron activation method of analysis had been shown to be feasible; the limits of error are $< \pm$ 1%. However, this method requires destruction of the foil. As a consequence, a tentative decision was made to use this technique as a "standard" for comparison with a non-destructive neutron capture-gamma release method. Evaluation of this concept is planned for early in the next quarter.

c. Out-of-Pile Testing: The thermal shock testing of the ML-1-II fuel element was completed and final reports were published (Ref. 11, 12). The testing was divided into two phases: Phase I simulated the shocks that an element would experience in the ML-1 during a scram at full power with coolant flow continuing for 30 seconds. This condition results in a temperature rate change of $-4F^o$/sec at the inlet to the element and $-20F^o$/sec at the outlet. Phase II simulated the shocks an element would experience in the in-pile loop in GETR. In this case, it was estimated that the temperature at the bottom of the element would change at a rate of $-80F^o$/sec during a normal scram.

The variation of temperatures within the element during a thermal shock cycle in Phase I is shown in Figure 3-1. The shapes of the curves were similar for all runs; the values of the slopes varied with adjustments of the flow rates. Figure 3-2 shows the data for a typical Phase II test. In both cases, the temperature of the fuel pin at the bottom of the element is estimated to be in equilibrium with the inlet gas temperature so that the rate of temperature change for the pin is estimated from the curve of the inlet gas temperature.

No major damage was found when the element was removed from the loop and inspected after the first 285 cycles. The element could be disassembled (fuel pin bundle removed from the insulation liner assembly) and reassembled easily. The outside of the outer liner was discolored in bands of orange and blue. The fuel pins were covered with a black coating, probably oil from the blower. Spacer wire vibration was evident on several pins but the rubbed spot was significantly large (0.19 inch by 0.75 inch) on only one pin. There was less evidence of wire vibration in the finned region than in the smooth surface region of the pins. Evidence of expansion of the pins through the lower spider guides could be seen. There was no evidence of galling in this area. The expansion joint at the top of the element appeared to be in the original condition, although a strand or two of Refrasil insulation was visible. In the finned region of the pins, many small flakes of the black coating, 0.010 in. diameter and smaller, had chipped out.

After inspection, the element was reinstalled in the loop for Phase II testing. The element was removed from the loop after 10 cycles and disassembled.

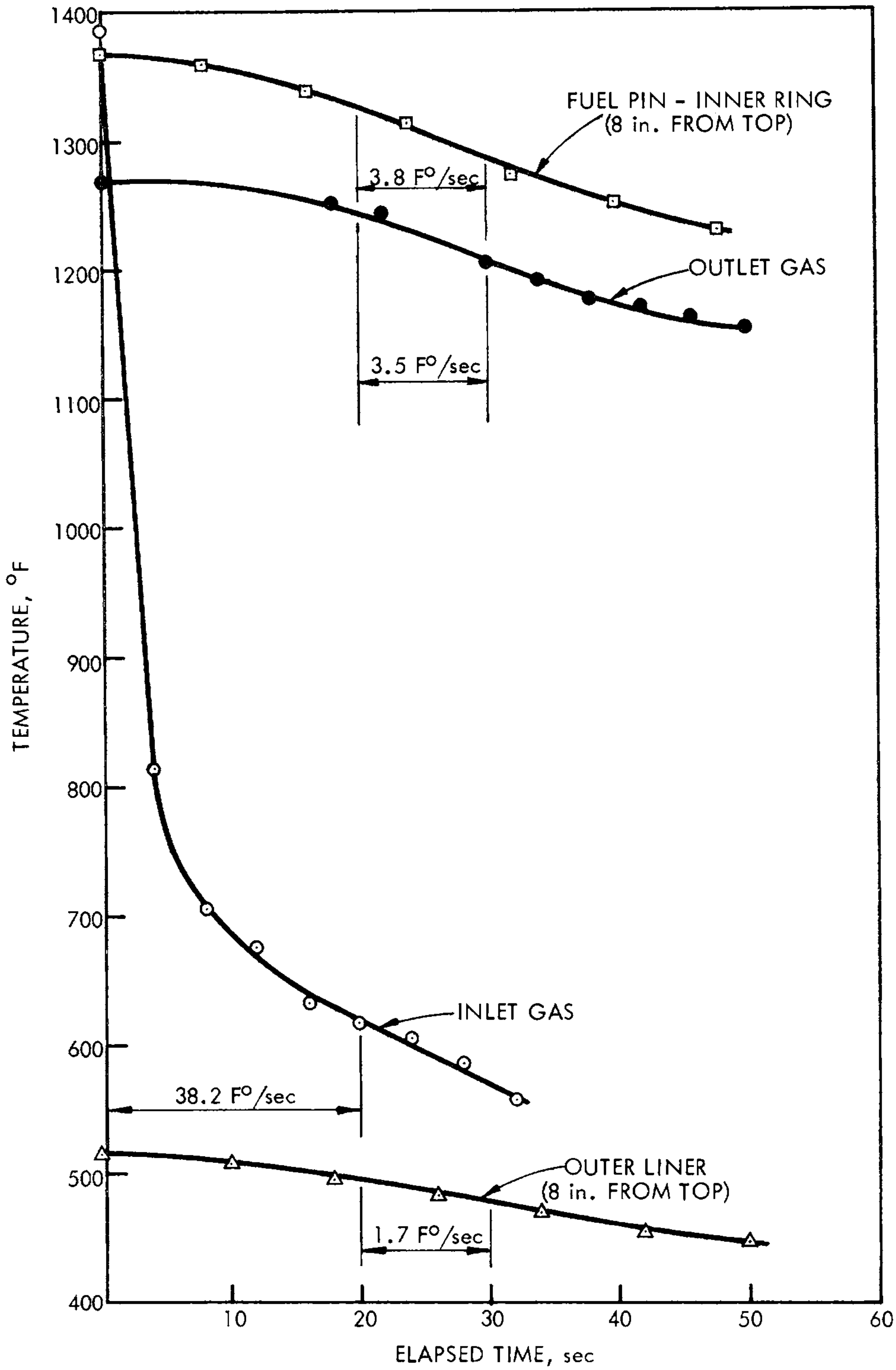


FIGURE 3-1. THERMAL SHOCK TEST OF THE ML-1-II FUEL ELEMENT
(Temperature Versus Time)
PHASE I

11.2-63-3867

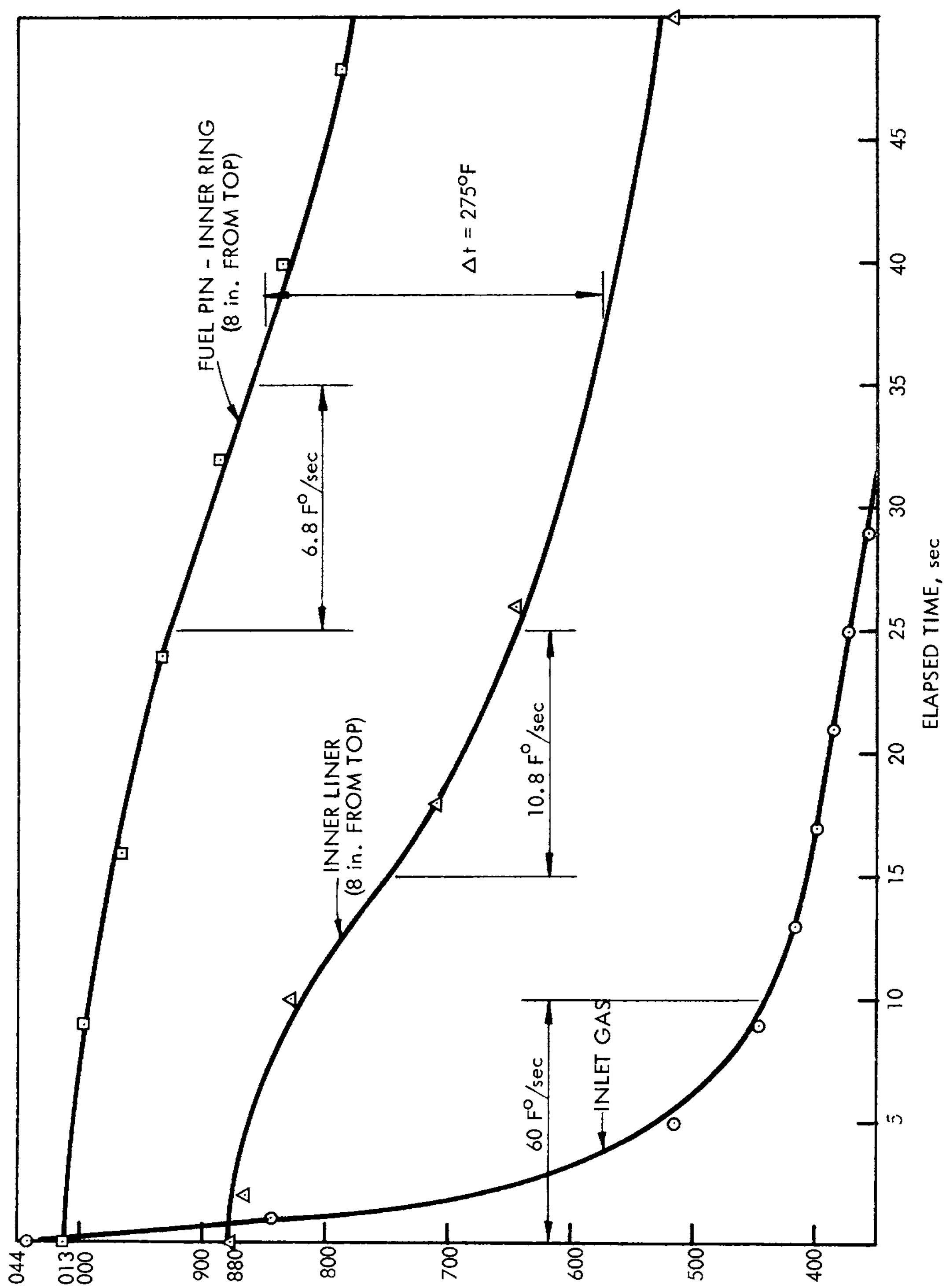


FIGURE 3-2. THERMAL SHOCK TEST OF THE ML-1-II FUEL ELEMENT
(Temperature Versus Time)
PHASE II

No damage to the element was apparent and no further discoloration or gross distortion had occurred. However, detailed inspection and measurement indicated that the pins in the outer ring had become permanently bowed. This bowing can be prevented by fabricating the spiral of the spacer wires on the inner ring of pins 60^{o} out of phase with the spiral of the wires on the outer ring of pins.

d. IB-14R In-Pile Test: The IB-14R test element operated with air coolant for 3735 hr at an average power of 45.2 kw. The fuel pellets were 65 wt% UO_2-BeO. Fuel pin 1 (closest to the GETR core) had an average burnup of 1.46 x 10^{20} fissions/cc (or 20,700 MwD/Metric Ton U-235).

The thermocouple junction region in the fuel pins of the IB-14R test element was examined in detail to evaluate the effect of the physical condition of the thermocouple on the indicated operating temperatures. The zirconium dioxide discs used as insulators in the clad temperature thermocouple terminations were severely cracked, but the fragments remained in place. Figure 3-3 shows the longitudinal section of a thermocouple. In Figure 3-4, the progression of polished surfaces through thermocouple 11 is shown. The numbers 0.094-0.101 designate the distance below the original cut surface in inches. When the Inconel disc was removed (lower left photo) fragments of ZrO_2 were visible. All pieces were very likely in place before polishing, but were disrupted when the specimen was held upside down during grinding. It was concluded that the discs performed their mechanical function of separating the thermocouple functions from the hot fuel. The details of this investigation were published (Ref. 13).

The gas extracted from the IB-14R test element fuel pins was predominantly helium, the filler gas added to the fuel pins during fabrication. All samples contained the fission gases krypton and xenon. The sample from fuel pin 17 was predominantly nitrogen, indicating that air coolant had entered the pin and oxygen was gettered by the hot fuel pellets. The gas samples were analyzed by means of a mass spectrometer, and the data were used to calculate the fission product release fraction and pin-to-pin power. The percent of fission product Kr-86 released to the fuel pin internal volume varied from 0.071 to 0.31%. In all cases, the release fraction was less than that value which would have resulted from direct recoil from the fuel pellet surfaces. The pin-to-pin power ratio was calculated on the basis of the Xe-136 produced. The production of Xe-136 in the fuel pins is a function of both the fission density and the effective neutron flux and, consequently, is a function of the operating power of the pin. Agreement between pin-to-pin average pin power ratios determined by pre-irradiation flux runs and the Xe-136 method was reasonably good; the two ratios agreed within 16% for all 19 pins.

e. IB-14R Metallurgical Evaluation: Metallographic sections from the IB-14R in-pile test element were evaluated at the M-E-ATR hot cells. No evidence of the embrittling second-phase structure or gray ring at the tubing interior observed in the brittle specimens from the IB-8T-1 test element was detected in the cladding of the pins examined (6, 10, 12, and 13). The microstructures of the IB-14R claddings appeared typical of similar Hastelloy X materials exposed out-of-pile. Most of the spiral fins of the IB-14R sections were deformed, probably as a result of the sectioning technique used in the ARA hot cell where specimens were cut from the tubing with a tubing cutter. Fins

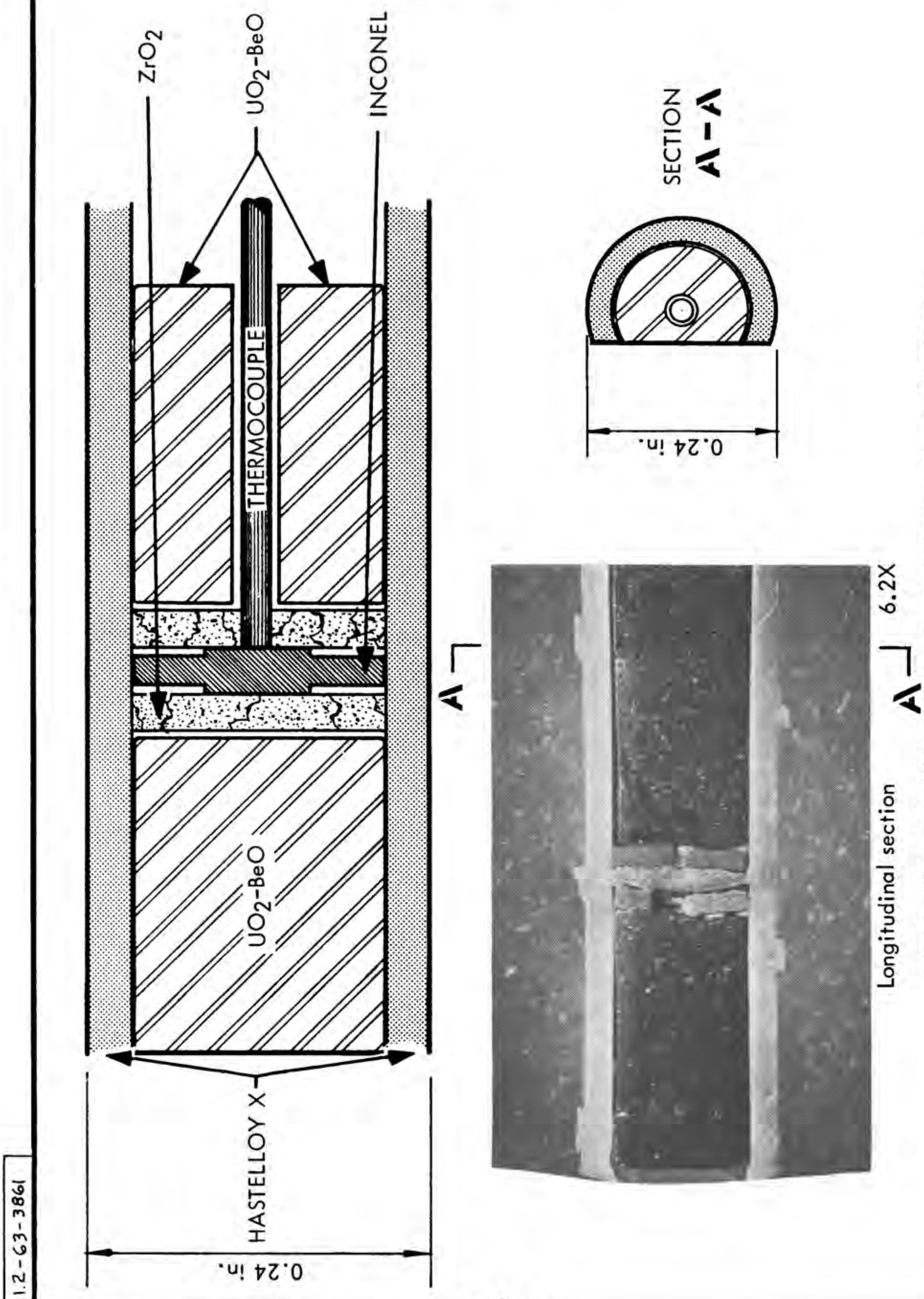
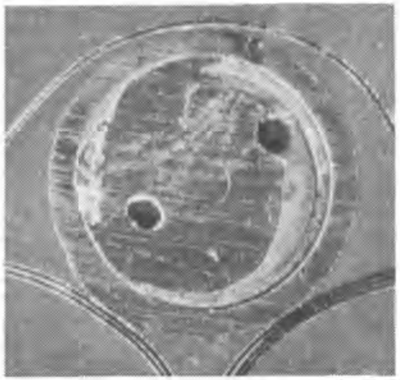


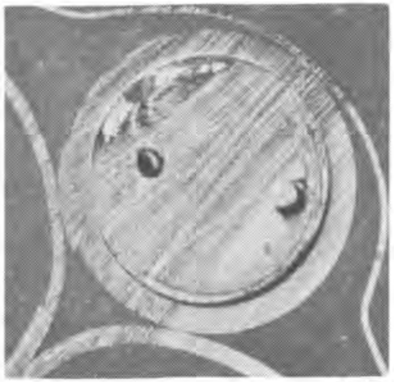
FIGURE 3-3. THERMOCOUPLE 10 OF THE IB-14R TEST ELEMENT

11.2-63-3858



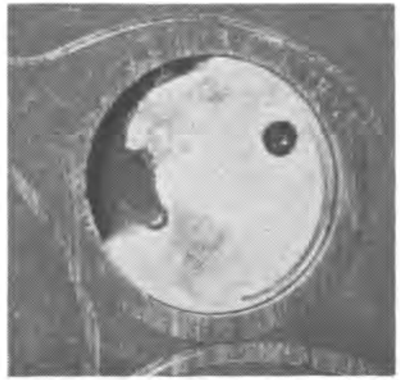
6.2X

0.094* INCONEL DISK



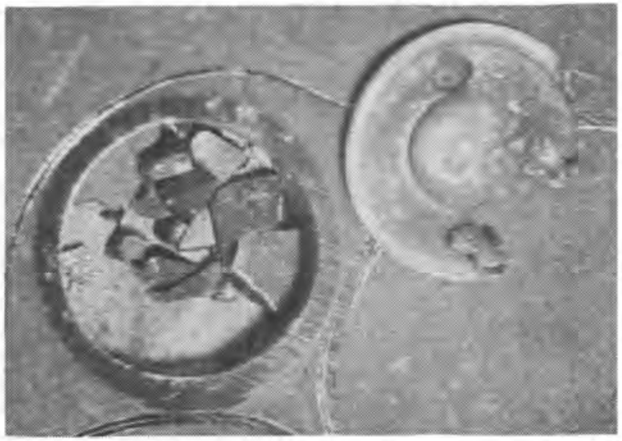
6.2X

0.095* INCONEL DISK

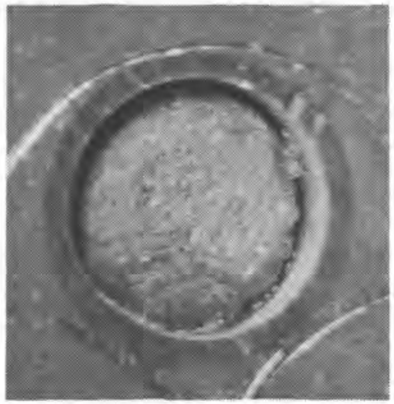


6.2X

0.101* INCONEL DISK, ZrO_2, UO_2-BeO FUEL



ZrO_2, UO_2-BeO FUEL 6.2X



6.2X

65 wt % UO_2-BeO FUEL, HASTELLOY X CLAD

FIGURE 3-4. THERMOCOUPLE 11 OF THE IB-14R TEST ELEMENT
Transverse cross sections
(Cusp-shaped springs are mounting aids)

*Distance in inches below the original cut surface which were not crushed during sectioning appeared to be in excellent condition; no erosion or detrimental oxidation was evident. Fins which were badly deformed during sectioning showed extensive plastic deformation indicative of good ductility and integrity. The UO_2-BeO fuel appeared to be in excellent condition. Relatively little cracking occurred and there was no significant rearrangement of the BeO and UO_2 phases. Relatively heavy oxidation (for this exposure duration) was observed in the flats between fins in the lower areas of pin 12 and 13. On pin 12, at a point 8.5 in. from the bottom of the pin, metal loss due to oxidation and spalling reached 0.001 to 0.0015 in. The original wall thickness in this area was about 0.019 in. Surfaces of fins appeared to be less oxidized than the valleys between fins. Oxidation of the finned-to-unfinned transition area was less than that noted closer to the bottom of the finned area. On pin 12 (at 14.8 in. from the bottom of the pin), 0.002 in. intergranular oxide penetration occurred on the surfaces of the unfinned area adjacent to the transition and also on the valley of the finned area. There was no measurable metal loss by oxidation or spalling.

Additional metallographic specimens were obtained from the IB-14R pin 17 (observed to contain high nitrogen by gas analysis after operation) and the IB-14R inner liner. Evaluation of these sections was delayed until October because of other programs scheduled in the M-E-ATR hot cells.

<u>f. IB-17R In-Pile Test:</u> The IB-17R-1 instrumented test element completed 1179 hr of operation with air coolant in the AGN-GETR loop in April 1963. Disassembly of the element was completed during this quarter and fission gas data were analyzed. Gamma scan profiles were obtained for each of the 19 fuel pins. The IB-17R-1 element was in good condition after the test, and no fission products were detected in the air coolant during the test. A patchy red deposit was present on the fuel pins and lower spider after testing. A spiral twisting of fuel pins 1, 2, 3, 10, 11, 12, 13 and 18 occurred and was barely visible in a side view (see Figure 3-5) but easily detected in an end view (see Figure 3-6).

Gas samples extracted from the IB-17R-1 fuel pins were analyzed for fission product and atmospheric gases. Fuel pins 2 through 19 contained predominantly helium, xenon and krypton, positively indicating that no leakage had occurred during testing. The gas from fuel pin 1 was contaminated with air and argon during sampling, but there is no reason to suspect that leakage or unusual fission product release occurred in this pin. The production of fission gases in each fuel pin was calculated from the thermal output of the test element and the pin-to-pin power ratios. The measured fission product gases were then compared to the total production to obtain the fractional release for each pin. The results of these calculations are shown in Table 3-2.

The excellent agreement between power ratios determined by Xe-136 and pre-irradiation flux runs is apparent. The release fraction for Kr-86 is higher than for the UO_2-BeO fuel in test elements IB-8T-1, -2 and IB-14R, but is acceptably low. (IB-17R-1 fuel is 75 wt% UO_2-BeO, and IB-8T is 60 wt% UO_2-BeO.) A report of the IB-17R gas analysis was issued (Ref. 14).

Test elements IB-17R-2 and -3 continued to operate in the AGN-GETR air-cooled loop. On September 22, the IB-17R-2 element had logged 3,921 hr and the IB-17R-3 had logged 2,742 hr of operation. Typical operating conditions for the loop are presented in Table 3-3.

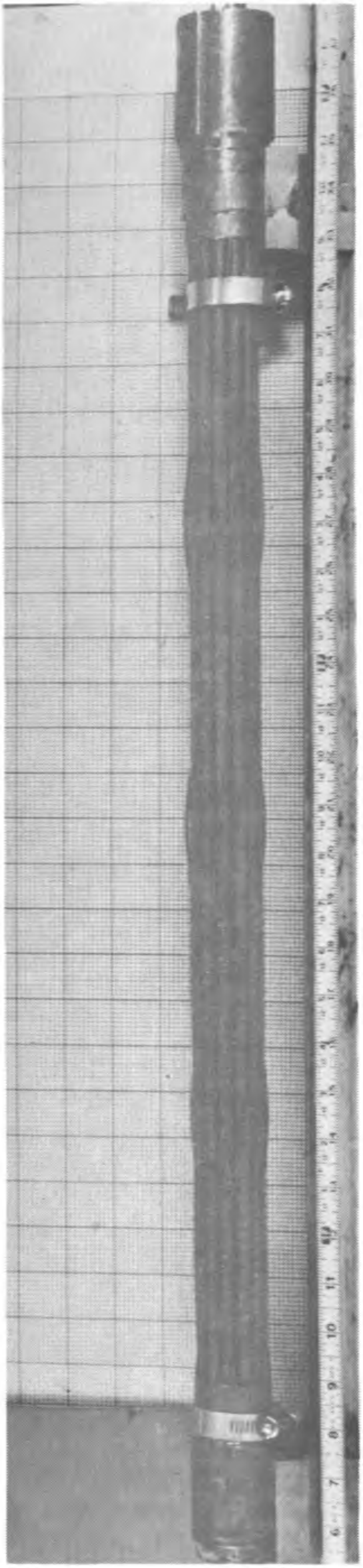


FIGURE 3-5. IB-17R-1 TEST ELEMENT FUEL PIN BUNDLE AFTER 1179 HOUR TEST
(12 o'clock orientation is up)

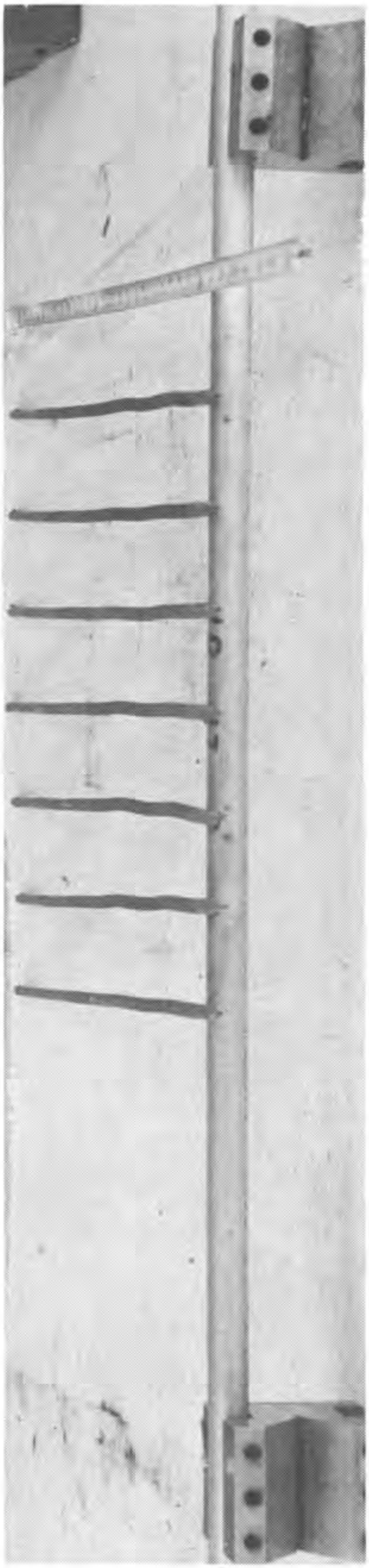


FIGURE 3-6. SPIRAL TWISTING OF IB-17R-1 FUEL PINS
(Left to right nos. 10, 11, 12, 1, 2, 3, and 13)

TABLE 3-2 - IB-17R-1 GAS ANALYSIS DATA

Pin No.	Pin to Pin Power Ratio*	Pin to Pin Power Ratio**	% Kr-86 Released	Fissions cc x 10^{-19}
1	1.43	1.49	1.04	5.05
2	1.39	1.42	1.07	4.91
3	1.21	1.24	1.02	4.27
4	0.98	0.99	0.64	3.46
5	0.86	0.87	0.61	3.04
6	0.80	0.81	0.97	2.83
7	0.88	0.82	0.69	3.11
8	0.98	0.96	0.63	3.46
9	1.09	1.13	0.62	3.85
10	1.31	1.33	1.49	4.63
11	1.49	1.46	1.57	5.26
12	1.52	1.52	1.74	5.37
13	0.86	0.84	1.13	3.04
14	0.69	0.69	0.58	2.44
15	0.57	0.58	1.02	2.01
16	0.61	0.60	1.05	2.16
17	0.76	0.73	0.68	2.69
18	0.88	0.87	1.15	3.11
19	0.68	0.65	1.05	2.40

* Based on Xe-136
**Based on pre-irradiation flux run.

TABLE 3-3 - IB-17R OPERATING DATA*

Test Element	IB-17R-3		IB-17R-2
Inlet Temperature, °F	802		805
Outlet Temperature, °F	1195		1175
Clad Temperature, °F			
Thermocouple No.		5	1208
		6	1215
		12	1610
		13	1035
		18	1160
		6	1180
ΔP, psi	9.7		10.6
Flow, lb/hr	2010		1875
Power, kw	59		52.5

*As of 1100, 12 September 1963.

The two downstream loop filters were removed and replaced with micro-metallic sintered stainless steel filters with removable elements. General Electric will sample these filters for Co-58 and Co-60 after each GETR cycle.

g. Thermal and Neutronic Analysis: A rough draft of the writeup of the AGN version of the GAM fast cross-section code was initiated during the quarter. Theoretical development of the P-1 equations used to calculate neutron flux in a reflector region was completed. This code is used to calculate a flux spectrum and, subsequently, to average fast nuclear cross-sections to obtain the few-group fast constants needed for reactor analysis. The basic library data includes 75 subgroups (as opposed to 68 in the original version) which can be used to generate constants for diffusion, isotropic transport, or anisotropic transport calculations.

h. IB-17R Out-of-Pile Support: Coolant/cladding and cladding/fuel compatibility tests are being performed out-of-pile to provide control data for comparison with IB-17R in-pile test elements.

The coolant/cladding control test accumulated 1179 hr at temperatures ranging from 1300° to 1800°F in air at which time four tubing samples were removed. These samples were sectioned for metallographic examination and tensile testing. The exposure of the remaining sixteen IB-17R tubing samples continued; it is planned that this test will continue for durations equivalent to the IB-17R-2 and IB-17R-3 in-pile tests (approximately 6000 hr and 1000 hr respectively).

Six capsules containing UO_2-BeO fuel in IB-17R cladding were fabricated and placed in a furnace pressurized to 300 psi in air at 1800°F (the temperature of the fuel-cladding interface) to duplicate in-pile test conditions and produce collapse of the cladding around the fuel pellets. Test durations will be equivalent to IB-17R-2 and IB-17R-3 3xposures.

i. ML-1-II Core Procurement: A detailed stress analysis of the ML-1-II fuel element assembly and the fuel pin assembly was completed. The presence of alternating thermal stresses in the fuel pin required an examination of the fatigue life of the fuel pin cladding. This investigation and the preparation of a final design report were initiated. The ML-1-II detail and assembly drawings were reviewed and modified as required.

IV. ML-1A PROJECT

4.0 ML-1A PRELIMINARY DESIGN

The establishment of the work scope for the design of the ML-1A power plant was initiated. A proposed scope for the ML-1A preliminary design effort was prepared (Ref. 15). This document served as the basis for discussions at USAEC-ID on 8 August 1963, which resulted in the development of a revised scope (Ref. 16). Costs and schedules for this scope were developed and presented (Ref. 17). The review of this latter document by USAEC-ID resulted in a verbal request for a revised scope for the preliminary design effort within an expenditure limit of about $300,000. This revised scope was developed and presented (Ref. 18). The scope presented was reduced by 1) eliminating all "improvements" design items and including design effort only in those areas of known deficiency in the ML-1 power plant, and 2) by making early arbitrary decisions in many design areas in lieu of the design studies originally proposed.

Discussion with USAEC-ID and USAEC-ARM personnel on 9 September 1963 indicated that the revised scope transmitted on 30 August (Ref. 18) was unacceptable in that the power plant design would be deficient in several areas (notably, operational shielding at the control cab and auxiliary power startup requirements). At this meeting AGN was requested to revise the ML-1A preliminary design scope and cost estimate to include the necessary design effort to correct the above deficiencies, to discuss the draft of the ML-1A Qualitative Material Requirement (QMR), to discuss the various alternatives by which the QMR requirements could be satisfied, to present discussions and recommendations for the early decisions required to reduce preliminary design costs, and to perform a preliminary system analysis and energy balance. The additional design scope and cost estimate to provide for the deficient items was developed (Ref. 19).

The QMR was reviewed and alternative means of meeting the operational shielding requirements at the control cab were presented (Ref. 20). Redesign of the shield tank to provide additional operational shielding, based on a preliminary shielding analysis, was recommended. The problems associated with meeting the requirement for a 60 kw auxiliary power startup were discussed, and the design approach presented. Other problem areas in meeting the QMR requirements were cited; these were 1) providing 50 cycle power output capability (this added weight and complexity to the power plant), and 2) satisfying the frequency recovery time requirement after a rapid load change.

The decisions required to reduce design scope were studied and the conclusions presented (Ref. 21). The decisions were:

1) Establish as reference a 2.0% boric acid shield solution. This can be done if low-cobalt (0.01%) stainless steel is specified for reactor components.

2) Establish a leak rate of 0.5 scfm for the precooler. This defines the gas handling skid requirements and permits the design to proceed.

3) Chose a reference turbine-compressor set. This significantly reduces the power conversion skid packaging and lubrication system design effort. The CSN-2 t-c set was recommended.

4) Specify a commercially available alternator as the reference design.

The preliminary ML-1A systems analysis and energy balance was completed and presented (Ref. 22). The performance analysis and experimental performance results of the various ML-1 power plant components were analyzed, and anticipated characteristics established for ML-1A. The results of the analysis are shown in Table 4-1.

TABLE 4-1 - ML-1A SYSTEM CHARACTERISTICS

Net thermodynamic power	437.87 kw
T-C set parasitic losses	-37.46 kw
Gross shaft power	400.41 kw
Alternator efficiency	94%
Gross electrical power	376.38 kw
Auxiliary power requirements	-60.00 kw
Net Electric Power	316.38 kw

Work was started in other selected areas of the ML-1A preliminary design. The subjects being investigated include:

1) A review of the instrumentation and controls required for the ML-1A power plant.

2) An evaluation of control cab weight, and methods of satisfying the 5000 lb weight limit.

3) A nuclear analysis of the effect of increasing the reactor pressure tube thickness to 0.030 in.

4) An evaluation of the power conversion skid layout and weight, and methods of rearranging the skid to accommodate a commercial alternator.

5) A market survey to select a suitable commercially available alternator.

6) A feasibility study and cost analysis relative to the use of low cobalt stainless steel for reactor pressure vessel and structural components.

7) An analysis of the effect on demineralizer resin radioactivity of activated silver from the control blades.

GENERAL REFERENCES

a. AGCRSP, Quarterly Progress Report, 1 April through 30 June 1963, IDO-28612, 15 August 1963, Aerojet-General Nucleonics, San Ramon, California

b. AGCRSP, ML-1 Reactor Stability Tests, AGN TM-402, June 1963, Aerojet-General Nucleonics, San Ramon, California

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1. Reliability Study of Beckman Model 109 Hydrocarbon Analyzer, IDOP-107 (OIL-649), 26 September 1963

2. Detailed Plan and Procedure for Modifications to the ML-1 Reactor for Reassembly, AN-AGCR-553, transmitted with sr-491, 18 July 1963

3. Detailed Plan and Procedure for Reassembly of the ML-1 Reactor, AN-AGCR-575, transmitted with sr-519, 16 August 1963

4. ML-1 Lower Cap Fix, AN-AGCR-562, transmitted with sr-511, 5 August 1963

5. 1744 Hour Inspection, ML-1 Pressure Vessel Mock-up, AN-AGCR-542, transmitted with sr-480, 9 July 1963

6. Letter, R. H. Chesworth to R. E. Swanson, "Follow-Up Action - Stewart Committee Visit", 25 September 1963, symbol sr-533

7. Metallurgical Evaluations of IB-14R and IB-2L-17 Specimens, AN-AGCR-557, transmitted with sr-500, 30 July 1963

8. Trip Report - Installation of Reactivity Shims and Instrumented Fuel Elements in the ML-1 Reactor, AN-AGCR-589, 23 September 1963

9. Stratos TCS-670A Turbine-Compressor Set Open-Cycle Test Report, AN-AGCR-558, transmitted with sr-504, 5 August 1963

10. Improved ML-1 Speed and Temperature Controller, AN-AGCR-563, transmitted with sr-531, 12 September 1963

11. Thermal Shock Test, ML-1-II Element, AN-AGCR-580, transmitted with sr-531, 12 September 1963

12. Thermal Shock Tests, ML-1-II Fuel Element, Supplemental Report, AN-AGCR-586

13. Post-Irradiation Examination of IB-14R Clad Temperatures, Interim Report, AN-AGCR-556, transmitted with sr-531

14. Fission Product Gas Release in the IB-17R-1 In-Pile Test Element, AN-AGCR-603, 18 October 1963

15. ML-1A Preliminary Design Scope, AN-AGCR-570, hand-delivered to AEC at ML-1A Design Scope Meeting, Idaho, 8 August 1963

16. ML-1A Preliminary Design Scope, AN-AGCR-571, transmitted with sr-509, 12 August 1963

17. ML-1A Preliminary Design, Cost Estimate and Schedule, AN-AGCR-578, transmitted with sr-523, 23 August 1963

18. Revised ML-1A Preliminary Design Scope, Cost Estimate and Schedule, AN-AGCR-581, transmitted with sr-528, 30 August 1963

19. Revised ML-1A Preliminary Design Scope, Cost Estimate and Schedule, AN-AGCR-587, transmitted with sr-534, 27 September 1963

20. Review of QMR for ML-1A, AN-AGCR-591, transmitted with sr-534, 27 September 1963

21. Recommendations for Decisions Indicated in sr-528, AN-AGCR-592, transmitted with sr-534, 27 September 1963

22. ML-1A Preliminary Energy Balance and Systems Analysis, AN-AGCR-573, transmitted with sr-534, 27 September 1963

APPENDIX A

ML-1 PLANT CHARACTERISTICS

1. GENERAL

Design performance at 100°F		
Gross electrical output	400 kw	
Net electrical output	330 kw	
Reactor thermal power	2.9 Mw to gas; 3.3 Mw total	
Cycle efficiency	13.3%	
Plant thermal efficiency	10%	
Coolant flow	92,000 lb/hr	
Dose rate at control cab @ 500-ft during full power operation	5 mr/hr (with expedient shielding as needed)	
Dose rate at 25 ft, 24 hr after shutdown (direction of transport vehicle driver with P-C skid in place)	15 mr/hr	
Overall plant dimensions	279 x 113 x 93 in. high	
Overall plant weight and dimensions	Weight	Dimensions (in.)
Reactor package	30,000 lb	111 x 110 x 93 high (plus ion exchange column on end)
Power conversion package	30,000 lb	168 x 113 x 93 high
Control cab	6500 lb	145 x 82 x 81 high
Auxiliary equipment	15,000 lb	- - - - - - - - - -
Operating supplies (startup and 90 day operation):		
Demineralized water	2900 gal	
Nitrogen (with 0.5 vol% oxygen)	2400 scf	
Oxygen	200 scf	

Anhydrous boric acid (B_2O_3)	1200 lb
Mixed bed ion exchange resin	900 lb max.
Lubricating oil	60 gal
Filter elements	7
Plant startup time	12 hr
Auxiliary power requirements	
Pre-startup	30 kw max.
Normal startup	75 kw max.
Normal shutdown	45 kw max., 3 kw ave
Emergency shutdown	none
Reactor drying	36 kw max.

2. REACTOR THERMAL CHARACTERISTICS

Power density	700 kw/ft^2
Maximum heat flux	140,500 Btu/hr/ft^2
Average heat flux	78,200 Btu/hr/ft^2
Heat transfer surface	126.5 ft^2
Maximum to average heat flux ratio	
Axial	1.5
Radial	1.2
Maximum fuel center temperature (including hot spot factors)	2160^{o}F (BeO-UO_2) 2650^{o}F (UO_2)
Maximum moderator temperature	190^{o}F
Maximum surface temperature of fuel cladding (nominal, average)	1520^{o}F
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1750^{o}F

3. REACTOR NUCLEAR CHARACTERISTICS

Average thermal neutron flux (fuel)	1.9 x 10^{12} neut/cm^2-sec
Average fast neutron flux (fuel)	1.7 x 10^{13} neut/cm^2-sec
Maximum to average thermal flux ratio	3.9
Hydrogen to U-235 atom ratio	40
Core buckling	0.0059 cm^{-2}
Fermi age	60 cm^2
Square of thermal diffusion length, L^2	2.05 cm^2
Thermal utilization, f	0.75

Infinite multiplication factor, k	1.54
Neutron lifetime	1.9×10^{-5} sec
k_{eff}, cold, clean core; no shims or burnable poison	1.067
Operating k_{eff}, cold, clean core, with shims and burnable poison	1.014
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.6% in 10,000 hr
Maximum	6.5%
Prompt temperature coefficient, $\Delta k/k\text{-}^{\circ}C$	
at $0^{\circ}C$	$+0.3 \times 10^{-6}$
at $90^{\circ}C$	-0.5×10^{-6}

4. REACTOR VESSEL

Materials	
Tube sheet	Stainless Steel, Type 304, 2.94 in. thick
Pressure tubes	Stainless steel, Type 321
Source tube	Stainless steel, Type 321
Gas ducts, plenums	Stainless steels, Types 304-L, 321 and 347
Baffle*	Stainless steel, Type 321; Tungsten; and Inconel X (springs)*
Outside diameter	30.960 in. max. (exclusive of upper flanged connection)
Overall height	79.5 in.
Pressure tube length	24 in. between inside surfaces of tube sheets
Design pressure	345 psia (gas)
Design temperature	$525^{\circ}F$ (max.)*
Wall thicknesses	Tubes 0.020 in. Plenum 2.12 in. min
Source tube	0.020 in. wall thickness; 0.500 in. OD

5. REFLECTOR

Composition, top	2 in. H_2O; 4.5 - 5.0 in. stainless steel; 1.5 in. W
bottom	3-4 in. stainless steel; 3 in. W

radial	1.8 in. Pb; 2 in. W; 180^{o} segment 4 in. Pb; 180^{o} segment
Total heat generation	6×10^{5} Btu/hr
Maximum power density	360 Btu/hr-in.^{3}

6. BIOLOGICAL SHIELDING

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

7. CORE (EXCLUDING REFLECTOR)

Diameter	22 in. equivalent
Height	22 in.
Number of fuel elements	61
Number of coolant passages	61
Number of coolant passes	1
Type of geometry of fuel elements	Cluster of 19 pins (18 fueled)
Cold, clean critical mass, U-235 no shims, no burnable poison	37 kg
U-235 loading	49 kg
Enrichment, inner 6 pins	93% U-235 as UO_2
outer 12 pins	31 vol% UO_2, 93% enriched U-235 69 vol% BeO

Core composition

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

8. FUEL ELEMENT

Dimensions	1.72 in. OD x 32 in.
Fuel material	BeO-UO_2 (outer pins); UO_2 (inner pins)

Number of pins per element	19 (12 w/BeO-UO_2; 6 w/UO_2; 1 empty)
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 (pin internal)	He
Pellet diameter	0.176 in. (nominal)
Type burnable poison	Cadmium
Reactivity worth of burnable poison	0.6% at startup

9. CONTROL ELEMENTS

Type	Tapered blades
Location	Moderator
Number: Shim blades	3 pairs (3 actuators)
Safety blades	2 pairs (2 actuators)
Regulating blades	1 pair (1 actuator)
Absorber material: Safety and shim blades	5 wt% Cadmium- 15 wt% Indium- 80 wt% Silver
Dimensions (each blade)	4 x 10.5 x 0.25 to 0.62 in.
Regulating blades	Stainless steel
Dimensions (each blade)	4 x 9 x 0.25 to 0.62 in.
Cladding material	none
Reactivity worth of control elements:	
Safety and shim blades	0.058 $\Delta k/k$
Regulating blades	0.004 $\Delta k/k$
Total	0.062 $\Delta k/k$
Actuating time for regulating blade:	
Drive	13.3 sec for full insertion or withdrawal
Scram	0.35 sec (max.) for full insertion from signal*
Safety and shim actuator:	
Drive	4.0 min for full insertion or withdrawal
Scram	0.35 sec (max.) for full insertion from scram signal*

10. MODERATOR

Type	Water
Reactor inlet temperature	180°F
Reactor outlet temperature	190°F
Pressure	30 psi max.
Flow rate	300 gpm
Type of flow circulation	Forced
Purity:	
Total solids	1 ppm
Resistivity	10^5 to 10^6 ohm-cm
Total heat removal rate	1.5×10^6 Btu/hr

11. REACTOR WORKING FLUID FLOW

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

12. POWER CYCLE

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

Cycle characteristics:

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

13. TURBINE-COMPRESSOR SET

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

14. ALTERNATOR

Output	60 Cycle Operation	50 Cycle Operation
Rating	500 KVA 3 Ø	417 KVA 3 Ø
Voltage	2400/4160 V	2000/3467 V
Rotor shaft speed	3600 rpm	3000 rpm

Case

Diameter, maximum	40.25 in.
Length, without starting motor	30 in.
Length, with starting motor	35.5 in.

Weight, alternator only	5900 lb
Starting motor	400 lb
Temperature, operating (hot spot)	$300^{o}F$ internal max.

15. RECUPERATOR

Length (including insulation)	81 in.
Outside diameter (including insulation)	49.25 in.
Headers	
High pressure inlet	8 in.
High pressure outlet	8 in.
Low pressure inlet	20 in.
Low pressure outlet	14 in.
Effectiveness	79%
Pressure loss	
High pressure $\Delta p/p$	2.5%
Low pressure $\Delta p/p$	0.85%
Type	Shell and tube regenerator
Tubes	4 passes x 840 tubes
Shell	1 pass
Surface	External fins
Materials	300 series stainless steel

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

Dimensions:	
Length, overall	166 15/16 in.
Pre-cooler	122 5/16 in.
Moderator cooler	32 1/8 in.
Oil cooler	11 5/16 in.
Width	113 in.
Thickness, overall	32 in.
Core	15 in.
Fans and plenums	17 in.
Materials	
Tubes and fins	Series 1100 aluminum
Headers	Series 2219 aluminum
Weight	6500 lb

Pre-cooler:

Header, inlet	One, 14 in.
Header, outlet	One, 10 in.
Effectiveness	90%
Total $\Delta p/p$	3.25%
Air flow	247,500 lb/hr
Type	Fin fan air-to-gas exchanger
Tubes	1105 tubes, single pass
Surface	Internal and external fins

Moderator cooler:

Headers, inlet and outlet	4 in.
Total Δp	2.77 psi
Water temperature	
In	190°F
Out	180°F
Airflow	73,250 lb/hr
Type	Fin fan air-to-water exchanger
Tubes	88 tubes per pass, three passes
Surface	External fins

Oil cooler:

Connections, inlet and outlet	1 1/2 in.
Total Δp	9.38 psi
Oil temperature	
In	180°F
Out	150°F
Oil flow	18,900 lb/hr
Air flow	27,500 lb/hr
Type	Fin fan air-to-oil exchanger
Tubes	45 tubes, 2 passes
Surface	Internal and external fins

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L E G A L   N O T I C E

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GENERAL TIRE

AEROJET-GENERAL NUCLEONICS