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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

Quarterly Progress Report
1 July through 30 September 1964

13 November 1964



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QUARTERLY PROGRESS REPORT

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Approved by:

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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT*

1 July Through 30 September 1964

ABSTRACT

This document summarizes the technical progress of the Army Gas-Cooled Reactor Systems Program under Contract AT(10-1)-880 between the U. S. Atomic Energy Commission and Aerojet-General Corporation to develop a mobile, low-power, nuclear power plant for military field operation.

ML-1 power plant testing was resumed on 1 September 1964; the onstream factor for the month was 77%.

Laboratory studies of corrosion of aluminum in shield solution were completed; corrosion was attributed to heavy metal ions and chlorides in the shield solution. Limits were established for ML-1 operation.

The final report of the full power and limited endurance run of the ML-1 (ANSOP 16625A) indicates that the power output of the t-c set during this test was lower than predicted; the shielding performed somewhat better than predicted.

Burst tests of improved precooler samples indicated a design deficiency. The final design of the improved air-side cooling arrangement for the precooler was completed. A subcontract was awarded for the design and manufacture of a 3600/1800 rpm gear set for use with the new alternator. The final design of the improved starting system was initiated. The design of the overspeed scram chassis was completed and development of the improved speed and temperature control system continued.

Metallurgical examination of IB-17R-2 cladding samples revealed an unanticipated second phase. The IB-17R-3 test continued without incident. Tests indicated that fuel pin tip plating is not required for ML-1-II elements. Burst tests indicate that the finned cladding is satisfactory for the ML-1-II elements.

The ML-1 Technology Program was initiated with a series of tests to define the limits of the Hastelloy X cladding technology. The ML-1A preliminary safety analysis was published. The modification of the GCRE facility continued; completion of this work is scheduled for 31 December 1964.

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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT

1 JULY THROUGH 30 SEPTEMBER 1964

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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

QUARTERLY PROGRESS REPORT*

1 July Through 30 September 1964

I. PROGRESS TO 30 JUNE 1964 - SUMMARY

The Army Gas-Cooled Reactor Systems Program evolved from studies conducted at ORSORT in 1954 and by Sanderson-Porter Company in 1955 to evaluate the feasibility of the development of a mobile, nuclear power plant for military use. These studies indicated the feasibility of such a concept 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 based on the design and performance of a demonstration plant. The programs to develop the reactor and power conversion equipment for the plant began in late 1956 and Aerojet was selected as the systems contractor to integrate all Program activity in 1959. The following major projects have been undertaken:

- 1) The design of a reactor test facility (GCRE) was performed by Aerojet under contract with the USAEC. The construction of the test facility at the NRTS was supervised by the USAEC-ID. The design work began in mid-1957 and construction was completed in late 1959.
- 2) A turbine-compressor (t-c) set test facility (GTTF) at Ft. Belvoir, Virginia, was completed by Aerojet in 1959 by installing equipment in accordance with the design provided by, and under contract with, the Department of the Army, APCDB.
- 3) The design, fabrication and test operation of a test gas-cooled reactor (GCRE-I) was performed by Aerojet under contract with the USAEC. 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 permit developmental and lifetime testing of fuel elements. The heterogeneous, water-moderated, nitrogen-cooled reactor operated at nominal thermal power of 2.2 Mw. The reactor first

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achieved criticality in February 1960 with plate-type fuel elements and operated with these and with a replacement core of pin-type (prototype for the power plant) elements until April 1961 when the reactor was shut down for investigation of a failure in the calandria. This investigation continued through the remainder of 1961. The decision was made to deactivate the GCRE-I in early 1962 and the GCRE facility was placed in standby condition (Item 7 below summarizes the GCRE modification and re-activation program).

4) The design and fabrication of a developmental t-c set (TCS-560) was accomplished by the Stratos Division of Fairchild Engine and Aircraft Co. under contract with the Department of the Army, APCDB. This unit was delivered in late 1959 and evaluation testing began in early 1960 in the PCTF. This testing was performed by Aerojet under contract with the Department of the Army, APCDB, and the program of evaluation testing and modification continued until May 1963 when Aerojet was relieved of cognizance for the developmental program.

5) The design and construction of a test facility for the ML-1 power plant at the NRTS, Idaho, supervised by the USAEC-ID, was completed in late 1960. Modifications to the test facility to increase the working space in the auxiliary control building, to provide improved ventilation for the power plant, and to provide improved facilities for shield solution handling in the test building were completed in 1963 and 1964. The modifications were based on designs prepared by Aerojet; the construction was supervised by the USAEC-ID.

6) The design, development and fabrication of two core loadings for the GCRE-I were completed by Aerojet under contract with the USAEC. The first core loading consisted of 75 plate-type fuel elements and was completed in the fall of 1959. The second core loading, consisting of 75 pin-type elements, was completed in mid-1960. Neither of these core loadings was operated long enough to demonstrate long-term reactivity or lifetime characteristics because of the failure of the reactor calandria.

7) The design, development and fabrication of the first core loading for the reactor of the demonstration power plant (ML-1) was completed by Aerojet under contract with the USAEC. This core loading, consisting of 61 elements (plus spares), was completed early in 1961. The core loading has been in operation in the ML-1 reactor since the spring of 1961; activities relating to this operation are discussed in Section 2.4.

8) The design and development of a second core loading for the ML-1 reactor was initiated by Aerojet under contract with the USAEC in 1962. By 30 June 1964, the design and development were essentially complete and a proposal had been submitted to the USAEC for authority to initiate the fabrication of the core loading.

9) The design and fabrication of two t-c sets for the demonstration power plant was completed by subcontractors under a contract between Aerojet and the Department of the Army, APCDB. The activities relating to the t-c sets are summarized on the following page:

a) TCS-670 - This set was designed and fabricated by the Stratos Division of Fairchild Engine and Aircraft Co. to specifications prepared by Aerojet. The unit was delivered early in 1961 and, after preliminary testing revealed that the machine did not satisfy the design specifications, modification was undertaken. During open-cycle tests of the modified unit in 1963, the set failed because of insufficient internal clearances to accommodate thermal expansion. Additional modifications were made and, although the set operated satisfactorily in the open-cycle configuration, seizure occurred during subsequent closed-cycle tests. Evaluation of this failure resulted in the decision in 1963 to defer further modification or testing of the TCS-670.

b) CSN-1 - This t-c set was designed and fabricated by Clark Bros. Co. to specifications developed by Aerojet. The unit was delivered in March 1961 and, after preliminary testing, installed on the power conversion skid which was delivered to the NRTS for testing with the demonstration power plant in June 1962. The set performed acceptably during ML-1 testing in September 1962 and February 1963 although the power output was less than the design value. Inspection following the February operation revealed abnormal bearing wear and some cracking in the turbine blades. A new bearing design was developed jointly by Clark Bros. and Aerojet, and the turbine blade design was modified to improve the strength. The t-c set with new bearings and turbine blades was returned to the NRTS and operated satisfactorily during April and May 1964. Inspection of the machine following this operation revealed that the first stage turbine blades had been damaged; the necessary repairs were completed and the unit was en route to the NRTS on 30 June 1964. The current status of activity relating to the CSN-1 t-c set is discussed in Section 3.2a.

10) The design, fabrication and test operation of a demonstration power plant (ML-1) were performed by Aerojet under contract with the USAEC. The design and fabrication of the ML-1 control cab and reactor skid were completed early in 1961 and these components were delivered to the NRTS. The reactor achieved initial criticality on 30 March 1961. Operational tests to verify predictions of control rod worth, reactivity, temperature coefficients and shielding effectiveness, and to develop general core physics data were conducted from April 1961 to June 1962. After delivery of the power conversion skid to the NRTS in June 1962, final plant checkouts were completed and initial operation of the power plant was conducted in September 1962. Test operations were resumed in January 1963 following a shutdown for modification and maintenance. During these tests, the ability of the reactor to operate at full design power (3.3 Mw) was demonstrated and 247 kw of shaft output power was measured. At the conclusion of this test run, evidence of a leak in the reactor pressure vessel was observed and, after confirmation of the leak, the reactor skid was partially disassembled, the leak repaired, and the skid reassembled. During this period, the CSN-1 t-c set was modified (see Item 9-b above). Test operation of the power plant resumed in mid-April 1964. The plant operated for more than 660 hours during a limited endurance test and was shut down at the end of May. Inspection at the conclusion of this test revealed

the damage to the CSN-1 turbine. (Test operation of the power plant in the current quarter is discussed in Sections 1.0, 2.0 and 3.0 of this report). The ML-1 Plant Characteristics are presented in Appendix B.

11) The development of performance specifications for a field-operable, gas-cooled, nuclear power plant (ML-1A) based on the ML-1 design was completed by Aerojet under Contract with the USAEC on 30 June 1963.

12) A design study and the development of conceptual designs for a "second generation" gas-cooled, mobile, nuclear power plant (ML-2) were performed by Aerojet under contract with the USAEC. Preliminary feasibility studies of advanced concepts were completed in early 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 requirements, and minimum startup and relocation times. The final report of the study was published in October 1962. At the direction of the USAEC, a limited evaluation of a reactor concept not fully considered in the basic study was performed in May and June 1963.

13) The preparation of the preliminary design of a field-operable, gas-cooled, nuclear power plant (ML-1A) based on the ML-1 design and the ML-1A performance specification (Item 12 above) was completed by Aerojet under contract with the USAEC. This work was initiated in mid-1963 and the preliminary design report was published in June 1964.

14) The design of modifications to the GCRE facility (see Item 1 above) to permit testing of the ML-1 reactor skid in that facility was performed by Aerojet under contract with the USAEC. The design work was initiated in the fall of 1963 and completed early in 1964. Construction to implement the design was begun in April 1964 under the supervision of USAEC-ID and was in progress on 30 June 1964 (Section 7.0 discusses the current status of this activity).

This report is organized under five major headings: Summary of Progress to 30 June 1964, ML-1 Project, ML-1 Technology Program, ML-1A Project, and GCRE Facility. Significant areas of activity are identified by numbers 1.0 through 7.0 (second order identification) and details are presented as decimals of the appropriate second order identification. Figures and tables are identified with the second order identification and are included in the text close to the point of reference. Two types of references are cited: Numerical designations refer to reports which received general distribution; alphabetical designations refer to in-contract reports.

II. ML-1 PROJECT

1.0 ML-1 TEST OPERATIONS

At the beginning of July, the ML-1 power plant was shut down for repairs to the turbine-compressor set following more than 600 hours of test operation which terminated on 29 May 1964. The reactor and power conversion skids were uncoupled and the reactor was flooded for inspection of the core to investigate the cause of the higher-than-anticipated indicated temperatures on certain instrumented fuel elements. The fuel element in core position 5-F had been removed and inspected; no indication of the reason for the abnormal temperature readings or any other effects of the power operation of the element was observed. The borescopic examination of selected pressure tubes was in progress (Ref. 1)*.

The borescopic examination of ML-1 reactor core positions 5-F and 6-E did not reveal any non-standard conditions. The fuel element (ML-1-I S/N-23) which had operated in core position 6-E was transferred to a hot cell for visual inspection. This inspection did not reveal any evidence of non-standard conditions. A spare fuel element (ML-1-I S/N-48, modified to accept a thermocouple in the unfueled central pin) was installed in core position 6-E and the thermocouple from the instrumented fuel element in core position 1-A was inserted in this element.

The main power and control cable (W-1304) between the control cab and the power conversion skid was inspected to investigate the reason for the repeated tripping of the main 440 v supply circuit breaker in the control cab. The outer rubber sheath and braided metal shield were opened at several locations. Significant amounts of moisture were observed in one region and evidence of insulation failure on several of the individual conductors was apparent. Approximately 35 ft of the cable, including the damaged section, was removed and the conductors were spliced. The outer rubber sheath and braided metal shield were removed from a 125-ft length of the cable to permit the evaporation of the moisture. The unprotected section of the cable was placed on a wooden cable rack approximately 6 in. above ground level and protected with a metal cover. Subsequent tests indicated an increase in insulation resistance and it was concluded that power plant operation could be performed satisfactorily with the spliced cable. In the meantime, procurement of replacement cable was initiated. *References are listed following the main body of text. Numerical designations identify reports which received general distribution; alphabetical designations are used for in-contract, or limited distribution reports.

The CSN-1A t-c set with repaired first stage turbine blades was reinstalled on the power conversion skid and the power plant was reassembled in preparation for the "Thermodynamic Performance Test" (ANSOP 16650). Pre-startup procedures were completed and power plant operation began on 1 September 1964. As of 30 September 1964, 554 hours and 12 minutes of testing had been accumulated under ANSOP 16650 and the plant onstream factor was 77%. The plant operations during ANSOP 16650 are summarized in Figure 1-1. Testing was interrupted on six occasions during September (Table 1-1).

TABLE 1-1 - SUMMARY OF TEST INTERRUPTIONS DURING
THE ML-1 THERMODYNAMIC PERFORMANCE TEST

<u>Date</u>	<u>Type of Interruption</u>	<u>Cause of Interruption</u>	<u>Down Time, hr:min.</u>
9/3/64	Manual Scram	Main lubricating oil pump seal failure	33:54
9/8/64	Power Reduction to 3 kw	TV camera repair	2:08
9/10/64	Power Reduction to 3 kw	TV camera repair	1:32
9/11/64	Power Failure Scram	Substation power failure; Start motor winding failed during scram recovery	84:14
9/15/64	Manual Scram	Recharge emergency cooling system	5:21
9/23/64	Manual Scram	TV camera repair	16:11

Two of these interruptions are discussed below:

1) During the attempt to recover from the scram resulting from a failure of substation electrical power on 11 September, the behavior of the start motor, as indicated by the instrumentation in the control cab, appeared erratic. Visual inspection of the start motor revealed smoking and arcing, so the motor was shut down immediately. Subsequent investigation revealed that the insulation on the stator winding had failed and that rewinding would be required. The motor was removed from the power plant assembly, rewound and tested within approximately 48 hours. Power plant operation was resumed after a total outage of less than 85 hours.

2) On 15 September, during attempts to verify an indication of a low supply pressure in the emergency cooling system, the system was actuated when an indicating lamp was removed from the instrument panel for a functional check. The introduction of the "cold" emergency cooling gas reduced the turbine inlet temperature which, in turn, increased the load on the start motor to the limit requiring plant shutdown. Subsequent investigation revealed that the emergency coolant control system could be shorted from the lamp socket to the chassis by the metal base of the lamp, thus automatically activating the system. The chassis was tagged to prevent recurrence of the incident until modifications could be completed. The cooling system supply was recharged and power plant operation resumed after an outage of approximately 5.5 hours.

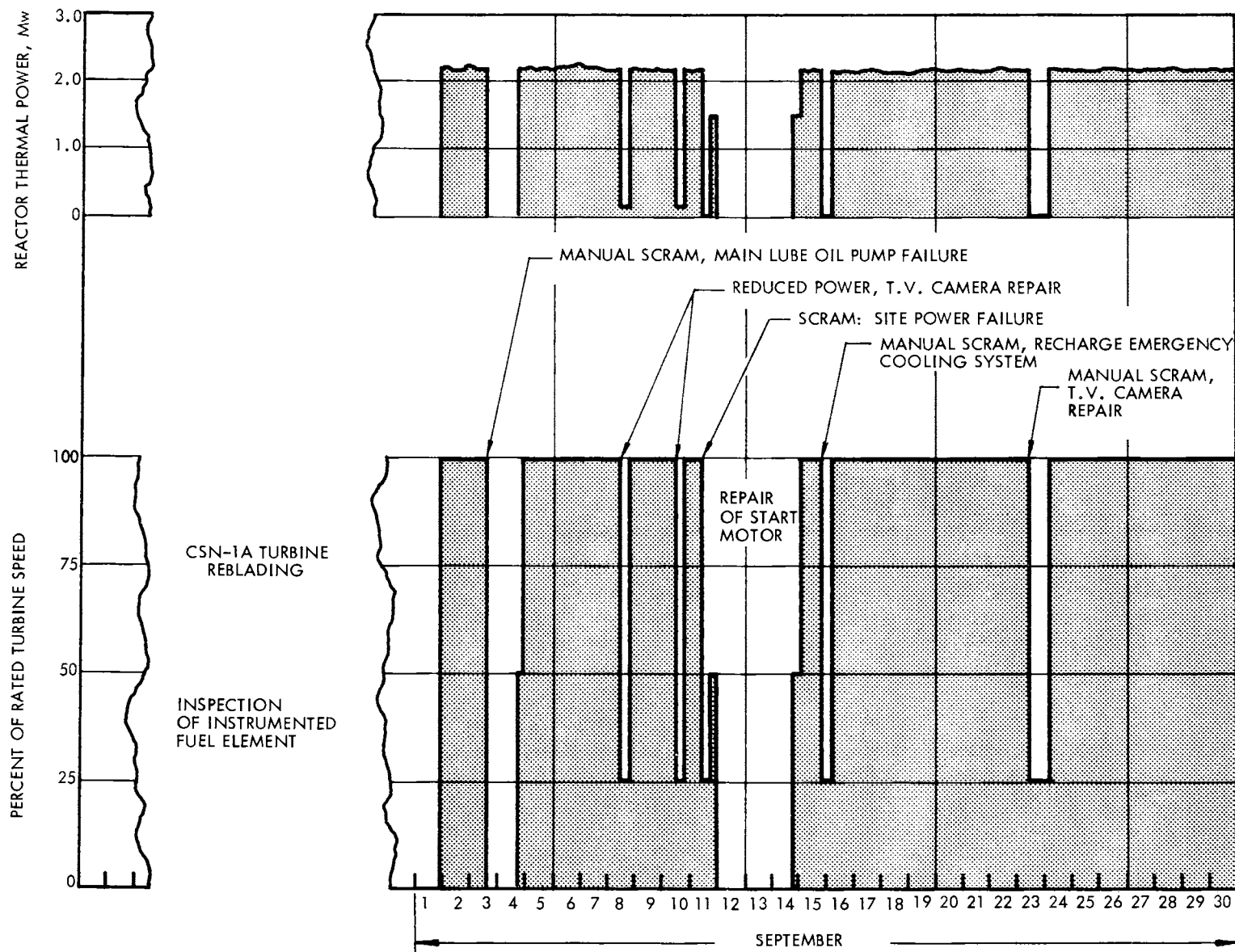


FIGURE 1-1. ML-1 THERMODYNAMIC PERFORMANCE TEST (ANSOP 16650)

2.0 ML-1 OPERATIONS ENGINEERING SUPPORT

2.1 Reactor and Auxiliaries

a. Corrosion of Aluminum: Work to define the cause and extent of the corrosion of aluminum parts exposed to the ML-1 reactor shield solution and to devise methods for limiting such corrosion was completed.

The laboratory corrosion test program, initiated in 1963 (Ref. 2), was completed in the prior quarter (Ref. 1). The evaluation of the results (Table 2-1) led to the following conclusions:

- Severe pitting and intergranular attack occurs in aluminum exposed to boric acid solutions containing chloride and heavy metal ions.
- Minor pitting occurs in aluminum exposed to solutions of boric acid containing iron ions.
- Very minor pitting occurs in aluminum exposed to solutions of boric acid; this attack is attributed to impurities in the acid solutions.
- Relatively little attack is observed on aluminum exposed in demineralized water.
- Type 3003 aluminum is generally more corrosion resistant than Type 6061 when exposed in demineralized water and pure and impure boric acid solutions.

Shield solution impurity limits were established for ML-1 reactor operation based on the results of the evaluation of the laboratory studies. These limits will control corrosion of the ML-1 shield solution components to less than 0.005 in./year (Table 2-2).

A corrosion evaluation program was initiated to provide data on the performance of aluminum alloys in the corrosive environments which exist in the ML-1 reactor shield tank. This program was initiated after the impurity control procedures were in effect and involves the exposure and subsequent evaluation of specimens of Types 6061 and 3003 aluminum at various locations in the ML-1 shield tank. The examination of specimens after 664 hours of reactor

operation revealed evidence of minor pitting and of extensive oxide film stripping. The frequency and extent of the pitting attack was greatest on specimens located in the bottom (more stagnant) region of the tank. The maximum pit depth was 0.002 in. and the average depth was 0.001 in. No intergranular attack was noted in any of the specimens examined. The cause for the oxide film stripping is not known and was being investigated at the end of September. A summary of the aluminum corrosion investigation was published (Ref. a).

TABLE 2-1 - CORROSION OF ALUMINUM AFTER 4050 HR EXPOSURE

<u>Test Solution</u>	<u>Aluminum Alloy</u>	<u>Corrosion Observed</u>
Demineralized water	6061	+45 mg/dm ² weight change
	3003	+40 mg/dm ² weight change
10% boric acid, Technical Grade	6061	-50 mg/dm ² weight change
	3003	-30 mg/dm ² weight change
10% boric acid, Technical Grade with 35 ppm iron	6061	0.001 in. pitting
	3003	0.001 in. pitting
10% boric acid, Technical Grade with 15 ppm lead	6061	0.001 in. pitting
	3003	0.001 in. pitting
10% boric acid, Technical Grade with 4 ppm copper	6061	0.002 in. intergranular
	3003	0.002 in. intergranular
10% boric acid, Technical Grade with 2 ppm chloride	6061	0.009 in. intergranular
	3003	0.005 in. intergranular
10% boric acid, Technical Grade with 4.5 ppm iron, 3 ppm copper, 4 ppm chloride	6061	0.039 in. intergranular
	3003	0.013 in. intergranular

TABLE 2-2 - ML-1 SHIELD SOLUTION IMPURITY LIMITS

<u>Impurity</u>	<u>Limits, ppm</u>
Chloride	1
Copper	2
Lead	5
Iron	20
Total of other heavy metals	1

b. Seven-Tube Mockup: This test was terminated in June after 5501 hours of testing (Ref. 1). A summary of the test program was published in September (Ref. b).

c. Moderator Standby Pump: The 15 gpm pump which circulates moderator water when the ML-1 reactor is shut down failed during a power plant shutdown. Circulation was maintained with the main pump. The spare pump was installed, and a flow switch was inserted in the pump discharge line to provide an indication of pump operation in the control cab. A replacement pump was ordered to serve as an operating spare.

d. Water System Sight Glasses: The sight glasses for the ML-1 reactor moderator water and shield solution levels were repositioned and fitted with special scales to improve the read out of these instruments on the closed circuit television system.

e. Control Rod Actuators: The bench tests initiated last quarter (Ref. 1) to demonstrate the effectiveness of the clutch modification were completed. The re-conditioned clutch was operated for 240.7 hours in a 160°F, high-humidity environment. During this test, 66,661 scram and withdrawal cycles were performed with no evidence of clutch slippage. A report was being prepared at the end of September to document the clutch modification and test program. A gear-driven potentiometer was tested concurrently with the clutch to demonstrate the suitability of such a device to provide a precise indication of the control rod position for use with the automatic temperature control system. The potentiometer operated for 138.7 hours (38,412 control rod cycles). The performance of the potentiometer was completely satisfactory and the signals generated were uniformly reproducible and highly accurate.

f. Reactor Plenum Cap: One pilot pin was broken during the removal of the reactor plenum cap. No attempt was made to remove the threaded portion of the pin but an adjacent stud was removed and a specially designed pilot pin was inserted in this location to guide the cap during installation. In addition, the diameter of the pilot pins was decreased from 0.906 to 0.857 in. and four jacking screws were added to the plenum cap lifting sling (Figure 2-1) to keep the cap level during installation and removal. These modifications facilitated the cap handling operations without altering the cap-to-plenum seal.

g. Reactor Shielding: A series of experiments at the ML-1, designed to develop data for verification of the performance of the design shielding analysis, was completed. The experiments included measurements of radiation levels during operation and after shutdown with 2 and 10 wt% boric acid shield solutions and with and without the wood expedient shield in place. Preliminary evaluation of the data indicates that the performance of the shield is in excellent agreement with the predicted performance; see Section 2.5 for further discussion of this subject.

2.2 Power Conversion

During the performance of ANSOP 16650, a seal in the main lubricating oil pump failed and the subsequent loss of lubricating oil from the system required that the plant be shut down. A spare pump was installed and power plant testing resumed. Inspection of the failed pump indicated that the main pump shaft had failed from fatigue and that the seal failure was a consequence of the shaft failure. A replacement pump was procured to serve as an operating spare.

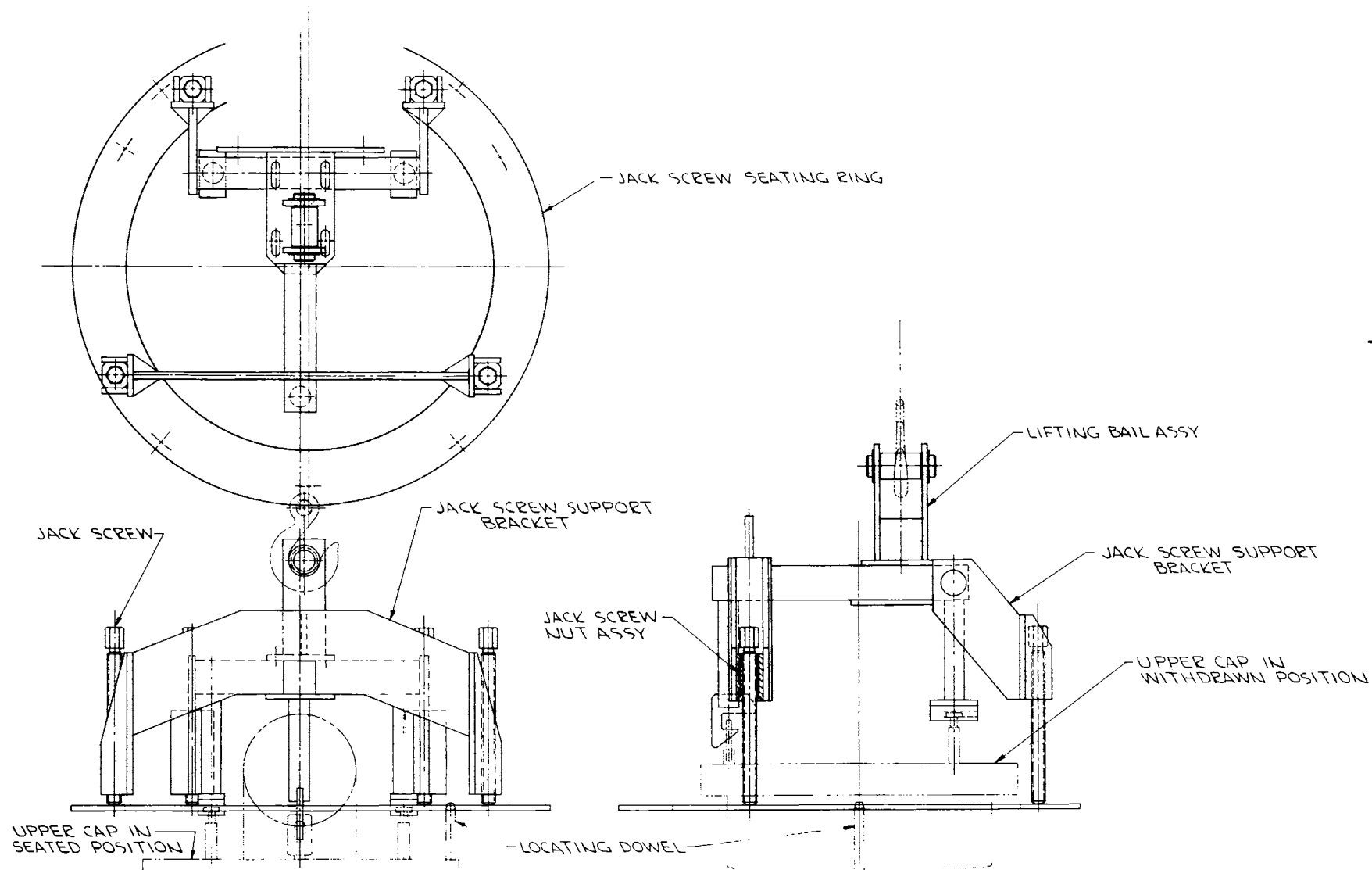


FIGURE 2-1. PLENUM CAP LIFTING SLING

2.3 Instruments and Controls

The following deficiencies and minor problems noted during ANSOP 16625A were corrected:

- The temporary repair of the electrical power and control cable was completed and procurement of a replacement cable was initiated.
- Circuitry was installed to indicate operation of the standby moderator pump.
- The gain adjustments on the linear power range nuclear instruments were relocated to the front panel of the chassis and the operating point of the driver transistors in the scram logic solid state switches was stabilized to prevent excessive transistor junction dissipation.
- Instrumentation was installed to provide more comprehensive data concerning the instantaneous power demand of the start motor.
- Modifications were made to provide indicating lights to show the position of circuit breakers in the cab and the status of the diesel-electric power sources.
- The rewinding of the start motor with Class H insulation and the addition of winding thermocouples and temperature switches was completed.

Preparation of as-built drawings continued throughout the period; approximately 120 drawings were revised to reflect changes made in the power plant instrumentation and controls systems. The review of the configuration of the dry critical junction box was initiated in anticipation of the use of this equipment during operation of the ML-1 reactor skid in the modified GCRE facility.

2.4 Fuel Elements

a. ML-1-I Thermal and Neutronic Analysis: During the conduct of ANSOP 16625A (Ref. 1), a graphical presentation of the ML-1 reactor operating envelope was developed which related the major operating parameters to prevent reactor operation under conditions which exceed the fuel element hot spot temperature limit (1750°F) as specified in ANTS 201. This envelope treated only the operating region where the reactor outlet temperature exceeded 900°F and, as a consequence, did not provide guidance over the full reactor operating range. A revised operating envelope was developed for use during ANSOP 16650 which covers the full operating range and defines the inter-relationships between the various parameters required to prevent fuel element hot spot temperatures in excess of 1750°F (Ref. c). The reactor operating map which limits the fuel element hot spot temperature to 1750°F with the ML-1-I core loading is shown in Figure 2-2 and the reactor operating limit (which includes the parametric limitations specified in ANTS 201 other than fuel element hot spot limit) is shown in Figure 2-3.

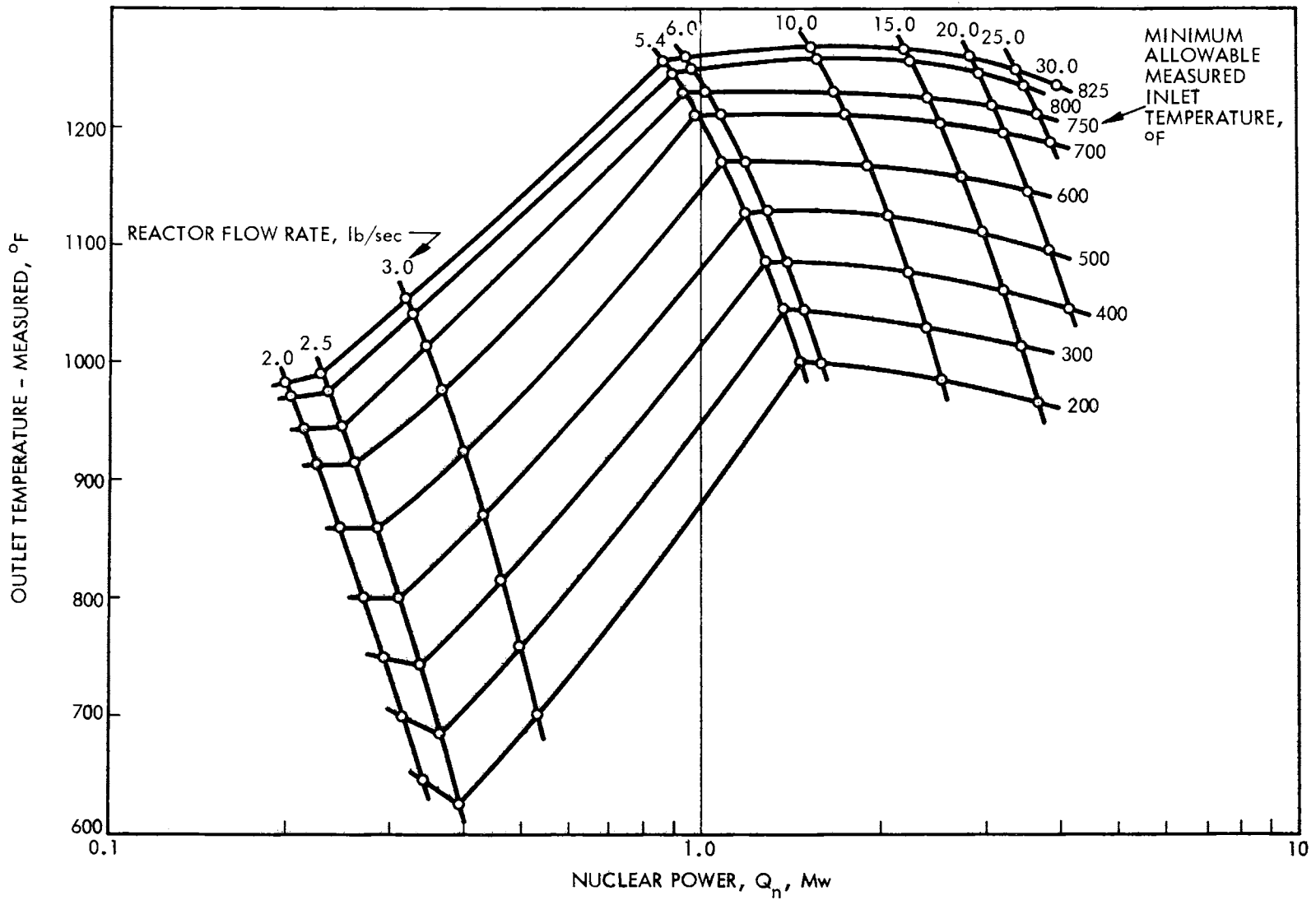


FIGURE 2-2. ML-1 REACTOR OPERATING MAP:FUEL ELEMENT HOT SPOT - 1750°F
(No limit placed on gas temperature rise through core)

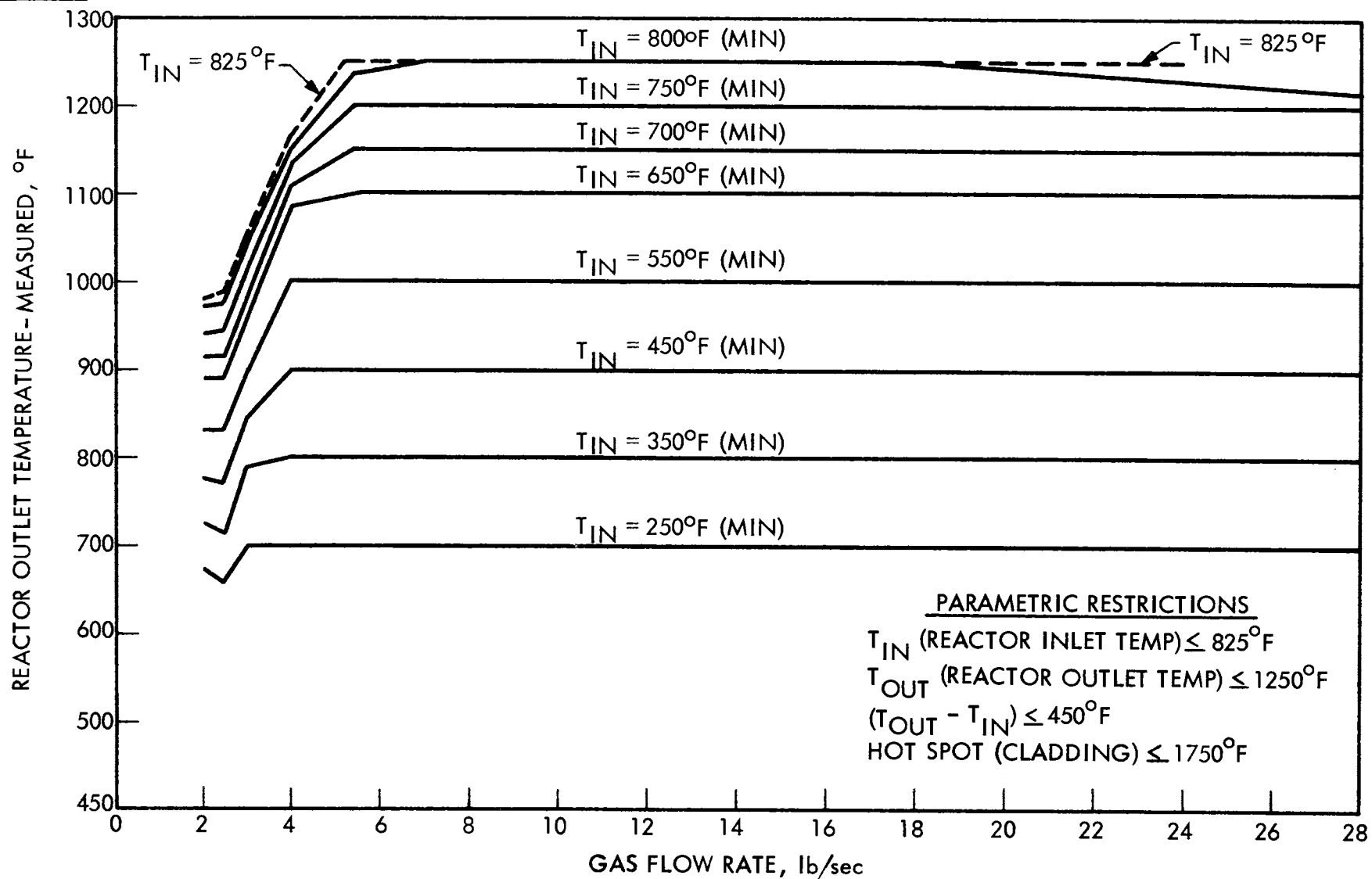


FIGURE 2-3. ML-1 REACTOR OPERATING LIMIT ENVELOPE

Selected data generated during the conduct of ANSOP 16650 were analyzed to determine if the instrumented fuel element temperature readings were consistent with those observed during ANSOP 16625A and to assess the information available from the instrumented fuel element now in core position 6-E. The analysis indicated that the fuel element temperature data from the two experiments were quite consistent, that the indicated temperature of the fuel element in core position 5-F was approximately 60°F higher than predicted, and that the indicated temperature of the fuel element in position 6-E was approximately 40°F higher than predicted. The analysis also showed that the six elements in the central ring in the ML-1-I core were operating at higher temperatures than other elements in the reactor. Although the available data will not permit a firm conclusion, it appears that this condition is the result of non-optimum orificing for the flow conditions existing in the reactor at this time. A summary of this analysis was published (Ref. d).

An analysis was performed, using the ANASIM computer code, to determine the temperature transient experienced by fuel elements in the ML-1 reactor in the event of a complete loss of coolant and a simultaneous reactor scram. The hot spot factors developed in the ML-1A preliminary design (Ref. 3) were used and both nominal and hot spot fuel pin cladding temperatures were derived. The results of this analysis are summarized in Table 2-3. The greater heat capacity of the ML-1-II fuel elements is reflected in the values for the maximum temperature predicted following the accident.

TABLE 2-3 - PREDICTED FUEL ELEMENT CLADDING
TRANSIENT TEMPERATURES FOLLOWING ACCIDENT

<u>Core Loading</u>	<u>Initial Temperature, °F⁽¹⁾</u>	<u>Maximum Temperature, °F</u>	<u>Time After Scram, sec⁽²⁾</u>
ML-1-I	1750	2000	175
ML-1-I	1800	2065	125
ML-1-II	1750	1965	80

(1) Maximum steady state temperature prior to accident.

(2) Time at which maximum transient temperature occurs.

Work continued on the development of a method of determining the angular flux within the ML-1 cell. The approach currently being investigated involves the use of the basic transport equation for angular flux, assuming that the scalar flux is known. The primary expressions were developed and a computer program prepared to evaluate the theoretical work. At the end of September the computer code had been checked out and sample calculations were in progress.

b. IB-8T In-Pile Test: Metallurgical studies of specimens from the IB-8T-2 test element continued at BMI. The microprobe analysis of the fuel/cladding interface was completed and chemical analysis of the irradiated cladding was in progress at the end of September.

c. Metallurgical Support of ML-1-I Air Cycle Operation: The exposure of low-cobalt (0.07 wt%) Hastelloy X tubing, identical to that used in the ML-1-I core, at high temperatures (1300-1800°F) in air continued throughout the quarter

under the ML-1 Technology Program (see Section 5.1). The evaluation of samples exposed for 7500 hours was completed. Representative microstructures of specimens at various temperatures are shown in Figure 2-4. The general change in structure observed in these specimens is similar to that seen in other work with low-cobalt Hastelloy X; the fine precipitate present at 1300°F becomes coarser and more angular and tends to migrate to the grain boundaries with increasing temperature. The oxidation penetrations measured in the specimens are summarized in Table 2-4; similar measurements made on samples exposed for shorter periods are also presented in this table for comparison.

TABLE 2-4 - AVERAGE MAXIMUM OXIDATION
PENETRATION OF ML-1-I TUBING

<u>Exposure Temperature, °F</u>	<u>Penetration in inches</u>			
	<u>1000</u>	<u>2500</u>	<u>5000</u>	<u>7500</u>
1300	0.0000	0.0004	0.0004	0.0016
1450	0.0002	0.0012	0.0021	0.0018
1600	0.0006	0.0019	0.0027	0.0033
1750	0.0018	0.0028	0.0034	0.0046
1800	0.0020	0.0035	0.0044	0.0058

Microhardness measurements were made of the specimens after 7500 hours of exposure. As shown in Table 2-5, the hardness of the material decreases as the microstructure changes; the largest hardness values were measured in specimens exposed at 1300°F and the hardness decreases as the precipitate coalesces and migrates to the grain boundaries during exposure at higher temperatures.

TABLE 2-5 - AVERAGE MICROHARDNESS* OF ML-1-I TUBING

<u>Exposure Temperature, °F</u>	<u>Test Duration, hr</u>			
	<u>1000</u>	<u>2500</u>	<u>5000</u>	<u>7500</u>
1300	270	288	321	273
1450	256	275	247	252
1600	244	263	239	248
1750	235	242	233	238
1800	234	252	240	235

*Hardness units are dph.

The effects of exposure on the mechanical properties of Hastelloy X were determined by tensile testing. The results of these tests are shown in Table 2-6.

As was the case with the microhardness data, the mechanical properties data are strongly influenced by the exposure temperature. At the lower temperatures, where an extensive precipitate is present, the ultimate and yield strengths are generally high and elongations are low. As the exposure temperature is increased, the strength is reduced and the ductility is increased. These effects are shown graphically in Figure 2-5.

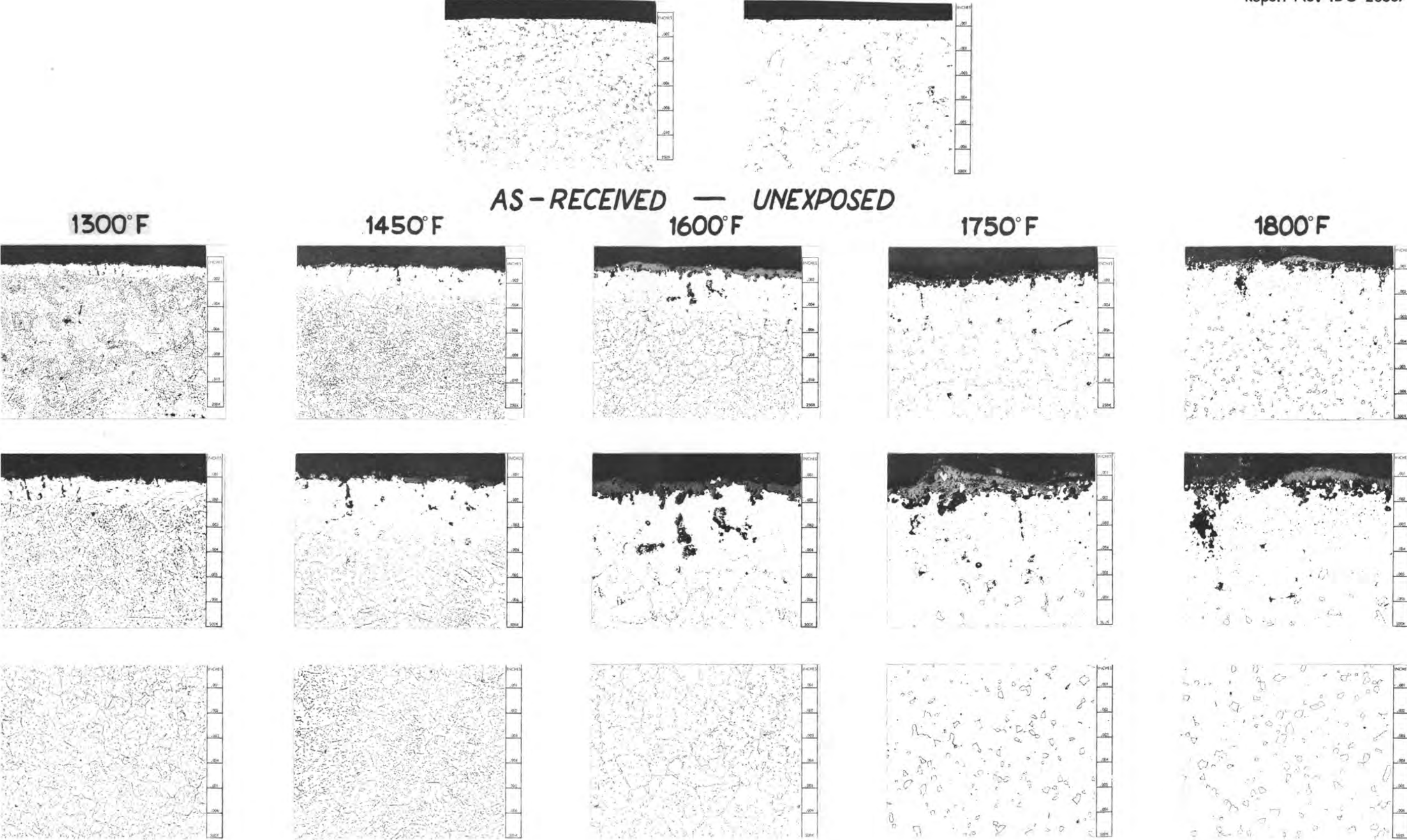


FIGURE 2-4. ML-1 CLADDING - 7500 HOURS

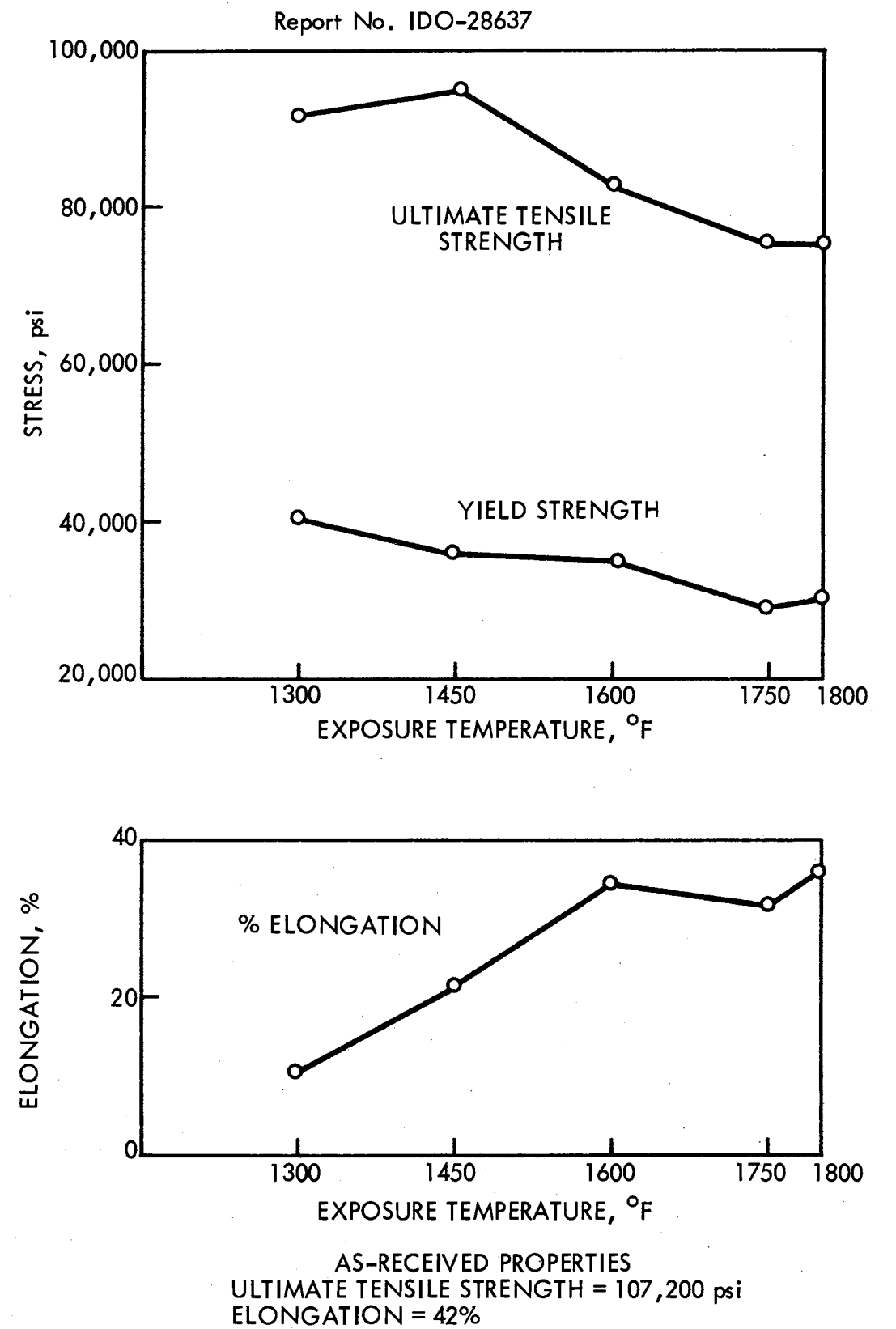


FIGURE 2-5. AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES OF ML-1 HASTELLOY X TUBING AS A FUNCTION OF TEMPERATURE OF AGING FOR 7500 HOURS IN AIR

11.4-64-2739

TABLE 2-6 - ROOM TEMPERATURE TENSILE PROPERTIES OF ML-1-I TUBING

<u>Exposure</u> <u>Temp., °F</u>	<u>Test</u> <u>Duration, hr</u>	<u>Tensile Strength</u> <u>0.2% Yield, psi</u>	<u>Ultimate</u> <u>Strength, psi</u>	<u>Elongation</u> <u>in 1 in., %</u>
	Unexposed		107,200	42
1300	1000	60,400	120,800	17
	5000	60,200	111,900	17
	7500	40,400	92,800	14
1450	1000	50,600	109,400	29
	2500	54,000	125,000	17
	5000	54,000	106,800	24
	7500	38,800	96,000	22
1600	2500	51,200	107,000	16
	5000	50,000	97,500	30
	7500	34,950	81,900	34
1750	1000	45,600	103,300	33
	2500	47,800	107,200	30
	5000	47,000	93,400	35
	7500	29,250	75,000	30
1800	5000	45,300	92,400	39
	7500	30,100	76,000	35

The continuous weighing experiment to measure the weight changes resulting from oxide film growth or spalling on Hastelloy X tubing samples exposed in air at 1750°F was terminated after 5456 hours of testing. The data generated during this test are summarized in Table 2-7 and shown graphically in Figure 2-6.

TABLE 2-7 - WEIGHT GAIN AND SCALE LOSS OF HASTELLOY X

<u>Pair</u> <u>No.</u>	<u>Test</u> <u>Temperature, °F</u>	<u>Cobalt</u> <u>Content, wt%</u>	<u>Total Scale Loss</u>		<u>Total Weight Gain</u>	
			<u>mg</u>	<u>mg/cm²</u>	<u>mg</u>	<u>mg/cm²</u>
1	1752	1.94	48.0	1.21	167.0	4.20
2	1754	1.94	56.2	1.40	171.7	4.25
3	1743	0.07	77.6	1.80	168.1	4.00
4	1767	0.07	100.4	2.36	218.9	5.15

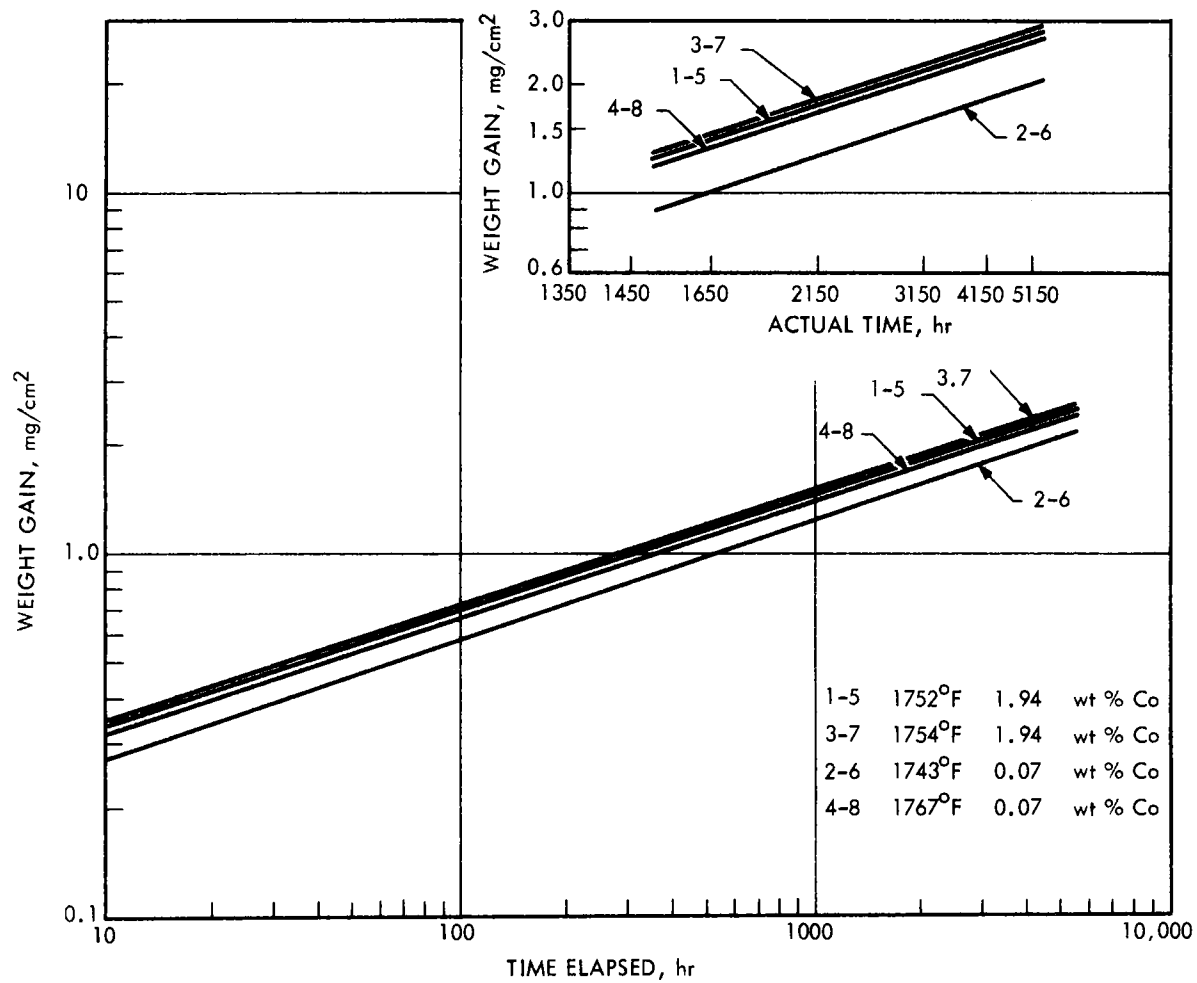


FIGURE 2-6. WEIGHT GAIN OF LOW AND HIGH COBALT HASTELLOY X AT THE INDICATED TEMPERATURES

From these data it appears that the corrosion rate of the low-cobalt Hastelloy X is greater than that of the commercial material. The slope of the curves in Figure 2-6 indicates that the oxidation growth rate is a cubic function (rather than the parabolic function typical of high temperature alloys) indicating that more than one oxide is formed and that the corrosion rate is slower than in other similar alloys. The report of the continuous weighing experiment was being prepared at the end of September.

d. ML-1-I Engineering Support: The analysis of the gases extracted from the fuel pins of GCRE element IB-2L-17 was completed to provide additional data on the dilution of fill gas. Only 17 pins were sampled; pins 12 and 18 had been disassembled for earlier investigations and were not available for sampling. The gas sample from pin 16 contained a large amount of argon (98.5%) indicating a leak in the sampling apparatus; hence data from this pin are not included in the results of the analysis summarized in Table 2-8.

TABLE 2-8 - ANALYSIS* OF GASES EXTRACTED FROM IB-2L-17 FUEL PINS

<u>Gas</u>	<u>Quantity, wt%</u>
Helium, minimum	98.5
Nitrogen, maximum	0.77
Oxygen, maximum	0.15
CO ₂ , maximum	0.09
CO, maximum	none detected

*of 16 pins sampled.

These data indicate that either (a) essentially no reactive gases were initially present in the pins, or (b) the majority of the gases present reacted with the fuel and/or cladding during the 1000-hour exposure.

A series of out-of-pile capsule experiments was planned to evaluate the mechanism of formation of CO₂ in the fuel pin and the reaction rates of this gas with the fuel and cladding. At the end of September, the capsules and test equipment were being fabricated; the test is scheduled to begin early in the next quarter.

Studies were performed to determine the mechanical effects of operating the ML-1-II fuel elements at a cladding hot spot temperature of 1800°F. These studies resulted in the following conclusions (Ref. e and f):

- The room temperature strength of Hastelloy X after exposure at 1800°F for 5000 hours is about 4% less than that observed in the same material exposed at 1750°F for the same time. No further decrease in strength was observed after exposure for 7500 hours.
- The average maximum depth of oxide penetration in Hastelloy X exposed at 1800°F for 7500 hours is about 0.0012 in. greater than that observed in the same material exposed at 1750°F for the same time (see detailed discussion under Section 2.4-c).

- The calculated hoop stress in the fuel pin cladding following a loss of coolant accident after 10,000 hours of operation at a hot spot temperature of 1800°F is approximately 280 psi. The 10-hour stress rupture strength of Hastelloy X at the peak calculated cladding temperature (2065°F) following such an accident is about 1000 psi (from laboratory tube burst data) and the melting point of Hastelloy X is about 2300°F.
- The axial differential thermal expansion between the fuel pins and the outer liner/lower spider assembly during steady state operation at a hot spot temperature of 1800°F will result in a relative position between the fuel pin and spider such that approximately 0.091 in. of additional movement can be accommodated before the fuel pin tip bottoms out in the guide hole.
- The axial differential thermal expansion following a coolant loss accident from operation at a hot spot temperature of 1800°F results in relative positions of the fuel pin and spider such that additional expansion of 0.030 in. can be accommodated before the fuel pin tips bottom out.

2.5 System Performance Analysis

a. ANSOP 16625A Analysis: The analysis of the data generated during the conduct of ANSOP 16625A ("ML-1 Full Power and Limited Endurance Test") was completed and the final test report published (Ref. 4). During this test, a total of 1493.35 Mwh of reactor operation was accumulated; 823.28 hours of t-c set rotation were logged which included 664.55 hours at self-sustaining conditions. All the major test objectives were achieved and, except in the area of net output power, the performance of the plant was significantly improved over that observed during previous tests. The maximum measured shaft power output during the test was 139 kw. Operation was limited throughout the experiment by the indicated temperature of one fuel element which restricted the maximum obtainable turbine inlet temperature to 1150°F.

Significant plant parameters recorded during ANSOP 16625A at maximum reactor power, at maximum net output power and at the conditions established for endurance testing are summarized in Table 2-9.

The maximum power output obtained during earlier plant operation (ANSOP 16625) was 252 kw; at this time the turbine inlet temperature was 1200°F and the ambient temperature was 16°F. Extrapolation of the maximum power output data under ANSOP 16625A indicates that, at comparable turbine inlet and ambient temperature conditions, the output power would have been about 250 kw. This value does not reflect the improvement in t-c set performance expected to result from the modification of the turbine effective flow area performed after ANSOP 16625. Analysis of the ANSOP 16625A data does not indicate any improvement in compressor performance but does indicate an apparent shift in speed characteristics resulting in a reduction in flow of approximately 7% accompanied by a small increase in pressure ratio. A more definitive analysis of the cause of the power deficiency was not possible from the data developed during ANSOP 16625A. The performance of the plant during this test is shown graphically in Figure 2-7.

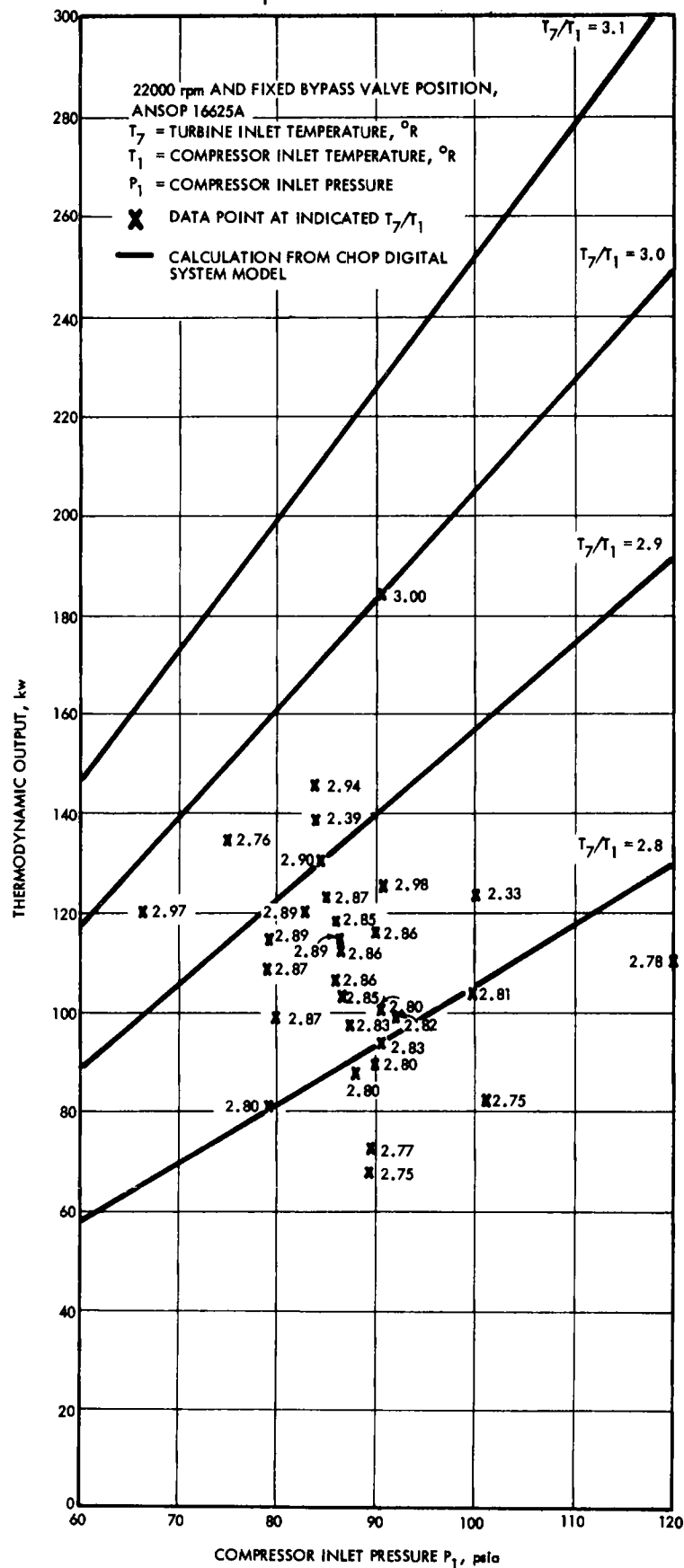


FIGURE 2-7. PARAMETRIC PERFORMANCE DIAGRAM FOR ANSOP 16625A

TABLE 2-9 - SUMMARY OF TEST DATA - ANSOP 16625AMaximum Reactor Power

Reactor power to gas	2633 kw
Turbine inlet temperature	1147°F
Turbine speed	22,000 rpm
Compressor inlet pressure	120 psia
Compressor inlet temperature	105°F
Precooler air inlet temperature	58°F
Shaft power to dynamometer	76 kw

Maximum Output Power

Reactor power to gas	2267 kw
Turbine inlet temperature	1149°F
Turbine speed	22,000 rpm
Compressor inlet pressure	90 psia
Compressor inlet temperature	77°F
Precooler air inlet temperature	50°F
Shaft power to dynamometer	139 kw

Endurance Operating Conditions

Reactor power to gas	1900 to 2100 kw
Turbine inlet temperature	1025 to 1150°F
Turbine speed	22,000 rpm
Compressor inlet pressure	85 to 90 psi
Compressor inlet temperature	55 to 115°F
Precooler air inlet temperature	40 to 95°F
Shaft power to dynamometer	22 to 100 kw

The shielding data obtained during the conduct of ANSOP 16625A and following the shutdown which terminated this test permitted the first comprehensive evaluation of the performance of the ML-1 shielding. Data accumulated during operation with 10% boric acid shield solution indicate that the dose rates were generally about 50% lower than predicted (Figures 2-8, 2-9, and 2-10). The wood expedient shielding did not significantly alter the gamma dose rate during operation but reduced the neutron dose rate two or three times. Measurements taken after shutdown indicate that the gamma dose rate was essentially as predicted (Figure 2-11) but that the photoneutron contribution was only about 25% of the predicted value, with the consequence that the total dose rate was somewhat less than predicted (Figure 2-12).

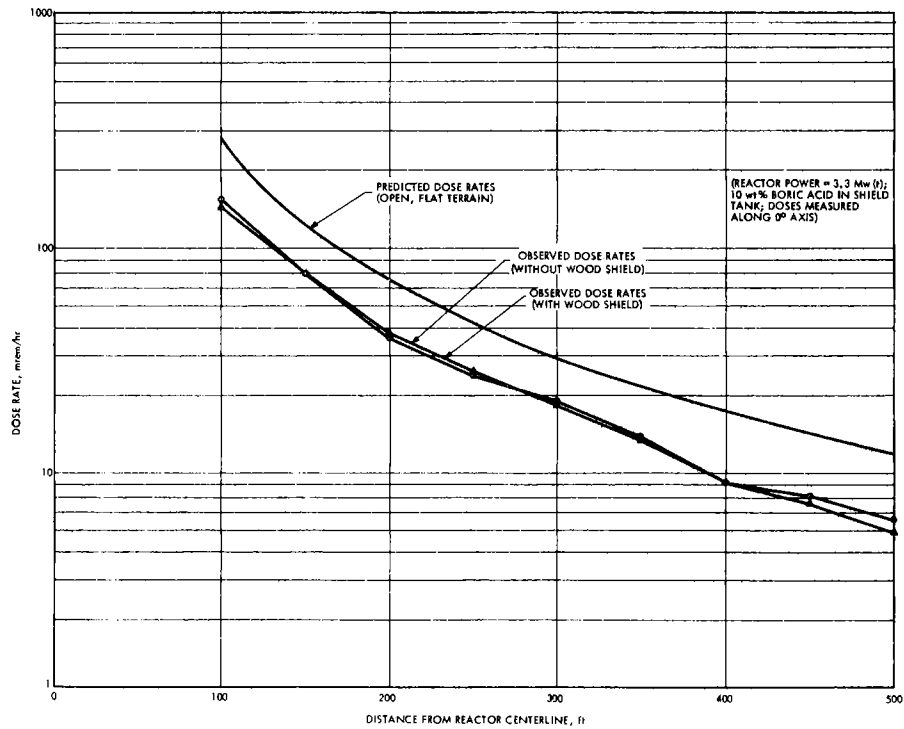


FIGURE 2-8. GAMMA DOSE RATES DURING ANSOP 16625A OPERATION

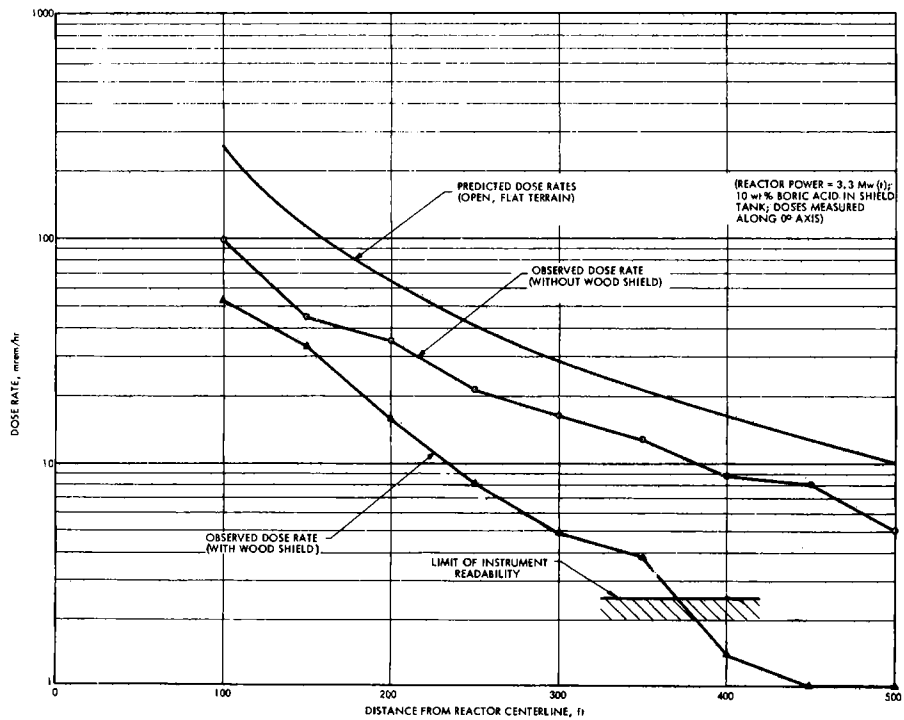


FIGURE 2-9. NEUTRON DOSE RATES DURING ANSOP 16625A OPERATION

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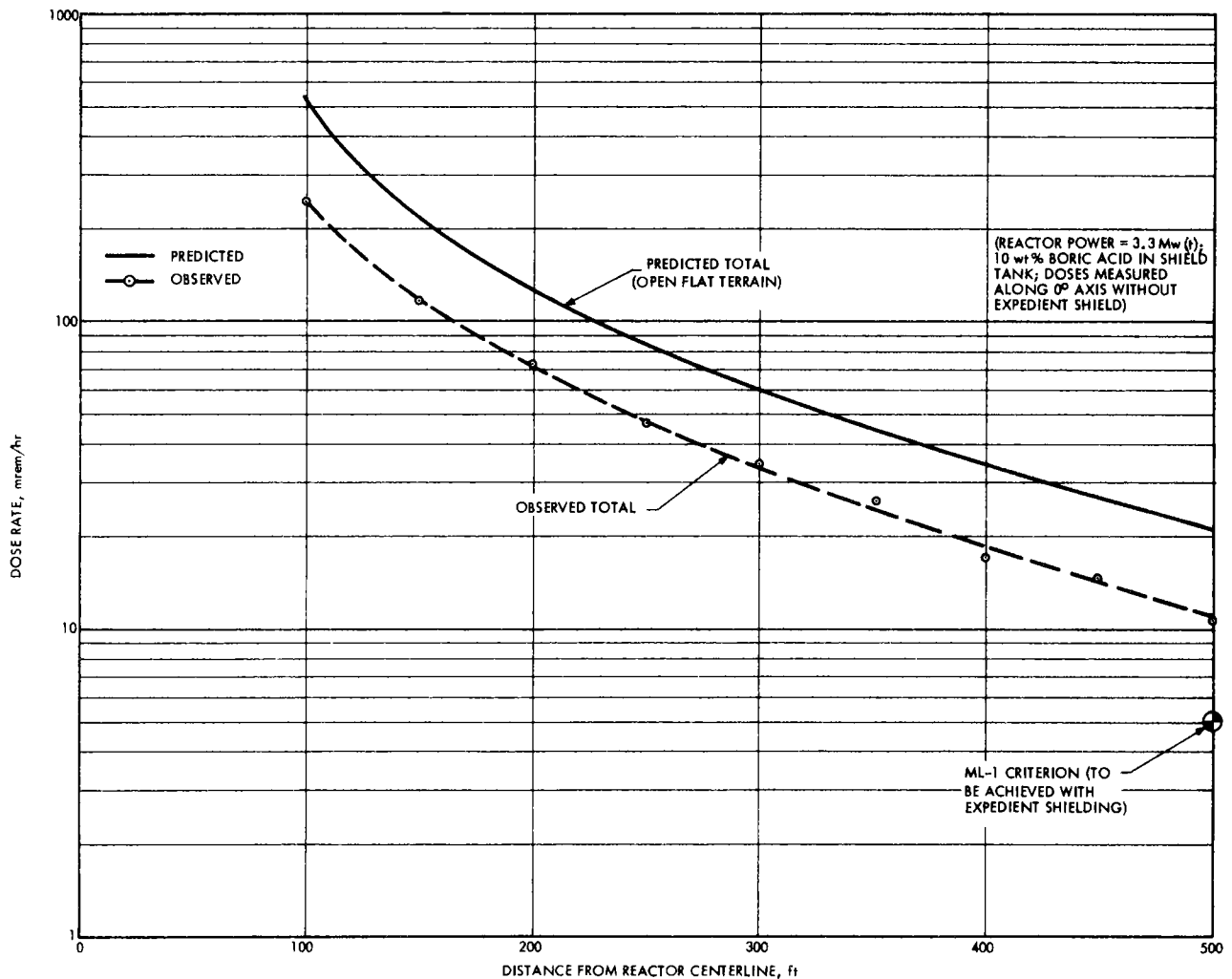


FIGURE 2-10. TOTAL DOSE RATES DURING ANSOP 16625A OPERATION

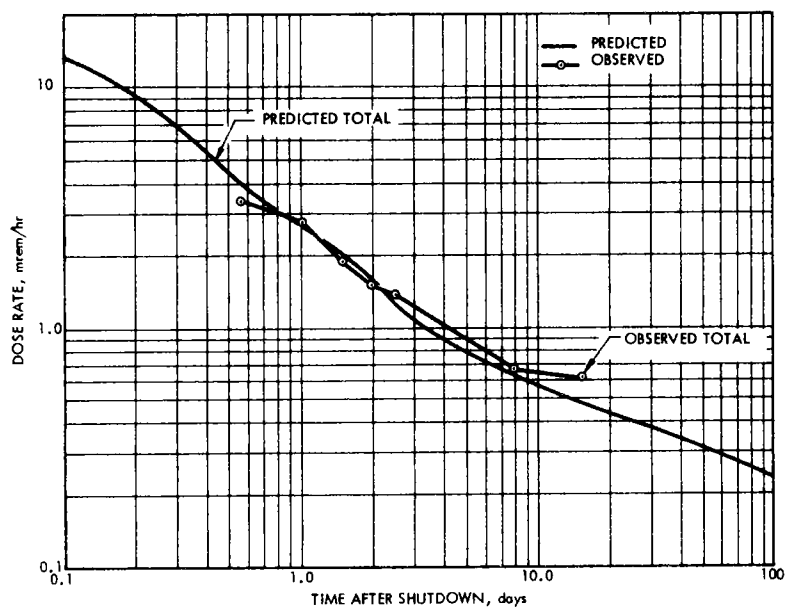


FIGURE 2-11. GAMMA DOSE RATES FOLLOWING SHUTDOWN FROM ANSOP 16625A
(Doses measured on 0° axis at 25 ft from reactor with power conversion skid in place and tank empty)

11.2-64-2743

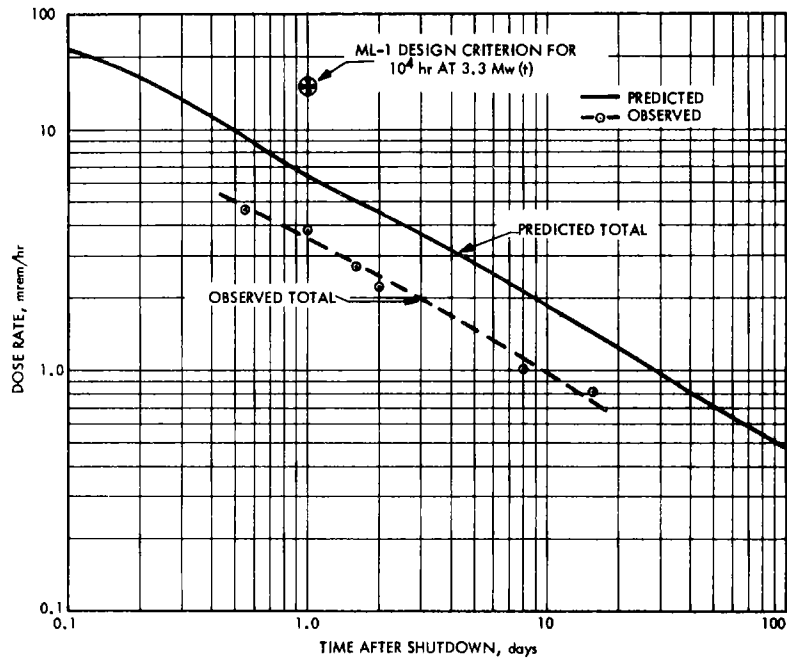


FIGURE 2-12. TOTAL DOSE RATES FOLLOWING SHUTDOWN FROM ANSOP 16625A
(Doses measured on 0° axis at 25 ft from reactor centerline with power conversion skid in place and tank empty.)

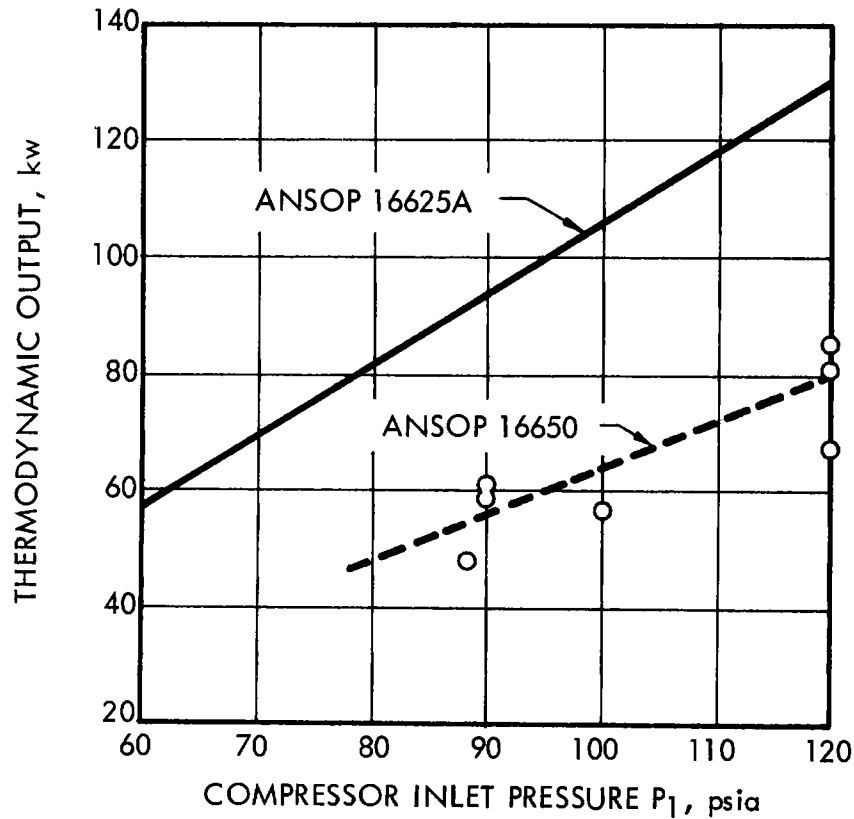


FIGURE 2-13. PARAMETRIC PERFORMANCE DIAGRAM FOR ANSOP 16625A AND ANSOP 16650 FOR $T_1/T_7 = 2.8$

11.2-64-2744

b. Computer Codes: Following the completion of the reduction of data generated during ANSOP 16625A, the DRML-1 data reduction code was modified to print out several additional parameters which significantly reduce the number of hand calculations required for analysis of plant performance. In addition, a new data reduction code was developed to process the data from the CSN-1A interstage instrumentation, and the inlet and outlet temperature and pressure rakes installed before ANSOP 16650. By the end of September, the data recorded at more than 50 selected data points during the conduct of ANSOP 16650 had been reduced and preliminary analysis was in progress. It appears that evaluation of the turbine interstage performance will be limited because of the failure of the second stage rotor pressure tap (within the t-c set) early in the experiment.

c. ANSOP 16650 Data Reduction and Preliminary Analysis: Test data obtained by the end of September during the conduct of ANSOP 16650 permitted an extension of the performance characteristics of the system and of all major components throughout much of the ML-1 operating regime. The preliminary analysis of these data indicates that the general performance of the system and the main components are substantially unchanged from that observed during ANSOP 16625A. However, one significant difference in performance has been observed which requires additional investigation. This difference is the significant reduction in power plant output (Figure 2-13). Although the data are badly scattered, it is clear that the output of the plant is approximately 30 kw lower than that observed during ANSOP 16625A under the same conditions (Figure 2-7).

The preliminary analysis of the shielding data obtained during ANSOP 16650 with 2% boric acid solution indicates that the gamma dose during operation is about 30% higher than was with the 10% boric acid solution; this result is in good agreement with the prediction.

d. Test Planning: The test plan for the ML-1 thermodynamic performance test (ANSOP 16650) was completed and published (Ref. g). This plan was designed to obtain CSN-1A performance data throughout the operating range consistent with ML-1 plant characteristics and operating limits. Test plans were also published for the experiments to be conducted concurrently with ANSOP 16650; these included shielding evaluations during operation and shutdown with 2% boric acid solution (Ref. h), measurements of the external temperature of components and ducts (Ref. i), and measurement of the displacement of the dummy alternator and primary loop expansion joints (Ref. j). A description of the open cycle testing for the CSN-2 t-c set was prepared and published (Ref. k) which presented the test objectives and the information necessary for the design of the test setup and the preparation of the test plan.

e. General Analysis and Support: Problems were run with the CHOP code to determine the effects on power plant performance of operation of the CSN-1A t-c set at speeds up to 24,000 rpm. The results indicated that the plant output power would probably decrease as the speed of the t-c set increased above 22,000 rpm because of the combined effects of reduced precooler effectiveness and increased parasitic losses (Ref. m)*. However, the internal aerothermodynamic characteristics of the CSN-1A t-c set are not considered by the CHOP code and the results discussed above might be modified if these characteristics were considered.

A set of detailed drawings of the ML-1 scram circuits was completed and preliminary drafts of procedures for measuring response time of each circuit were prepared.

*NOTE: Lower case L was not utilized as a reference identification.

3.0 ML-1 DEVELOPMENT AND IMPROVEMENT

3.1 Reactor and Auxiliaries

A gas generation and storage skid as specified in the ML-1A preliminary design (Ref. 3) will be assembled in breadboard form and tested to demonstrate the feasibility of the concepts and the performance of the components. The concept provides oxygenated nitrogen by a process which liquifies air in a cryogenerator, removes the excess oxygen, vaporizes the liquid, and compresses and stores the gas. The ML-1 gas skid was disassembled to permit the use of the skid base and gas storage spheres in the new mockup. The preparation of layout drawings for the mockup and the procurement of components were initiated.

3.2 Power Conversion

a. Clark T-C Set (CSN-1): By 1 July 1964, the CSN-1A rotor assembly with new first stage turbine blades and a repaired turbine inlet liner had been shipped from Clark Bros. to the NRTS (Ref. 1). Following receipt of the rotor assembly, the CSN-1A was reassembled at the NRTS by Clark Bros.' technicians. New journal bearings, identical with those which had operated successfully during ANSOP 16625A, were installed during this reassembly. All critical assembly dimensions were recorded and this information was transmitted to Clark Bros. for evaluation and inclusion in the report of the repair. In addition, all available CSN-1A turbine and compressor interstage instrumentation was activated to provide the data for t-c set analysis during ANSOP 16650.

The t-c set was installed on the power conversion skid and, following completion of the assembly of the skid and system pressure checks, the unit was cold rotated in accordance with procedures recommended by Clark Bros. This procedure provides, sequentially, for the manual rotation of the output shaft to check breakaway torque, brief operation at 25% rated speed to determine coast-down time and post-rotation breakaway torque and continued rotation at 25% speed until coastdown time and post-rotation breakaway torque are stabilized. The initial breakaway torque was 75 to 90 ft-lb and the shortest coastdown time measured from 25% rated speed was 35 sec. These values stabilized at 55 to 60 ft-lb and 37 sec at the end of the 25% rated speed rotation. Subsequent rotation at 50% rated speed was uneventful; all parameters relating to t-c set operation were well within the anticipated range.

The CSN-1A interstage instrumentation functioned normally at the beginning of ANSOP 16650 but the turbine interstage instrumentation failed early in the experiment. The compressor instrumentation continued to function properly and produced acceptable data. Investigation established that the difficulty with the turbine instrumentation is inside the t-c set and cannot be corrected until the next disassembly.

On 3 September 1964, the main lubricating oil pump shaft failed, damaging the shaft seal and permitting most of the lubricating oil to leak from system (see Section 2.2). Although the lubricating oil pressure differentials and flow rates were lower than normal during the plant shutdown which followed this malfunction, flow was maintained at all times. The maximum temperature observed on the turbine bearing was 190°F; other bearing temperatures were below this value. Following the replacement of the oil pump, the cold rotation procedure described above was repeated prior to resuming normal operation. The initial breakaway torque values varied from 135 to 190 ft-lb but these decreased to 55 to 60 ft-lb before terminating the procedure. These high torque values are typical of conditions following the first shutdown from hot rotation after re-assembly of the unit and reflect a realignment of the turbine blade labyrinth seal with the mating honeycomb.

Subsequent power plant operation was normal except for a slow decrease in the compressor end seal pressure differential and seal gas flow rate. This decrease corresponded to an increase in pressure differential across the filter in the seal gas supply from the seventh stage bleed. After the filter was replaced during a short shutdown, the pressure differential and flow rate returned to normal. Visual examination of the replaced filter revealed a very fine, tan-colored deposit; the deposit was being analyzed at the end of September.

Preliminary evaluation of the ANSOP 16650 data indicated that the t-c set performance was somewhat poorer than that observed during ANSOP 16625A. The compressor appears to be performing in essentially the same manner as was observed during earlier tests but the turbine efficiency seems to have decreased slightly. Detailed analysis of the data was in progress at the end of September and a summary of the performance analysis will be published soon after the completion of ANSOP 16650.

A proposal for analysis and model testing to define the required modifications to the CSN-1A compressor inlet design was prepared and submitted to the USAEC (Ref. n). Modification of the compressor inlet configuration to improve the flow distribution at the entrance to the inlet guide vanes was proposed as the first step in improving compressor performance.

b. Stratos T-C Set (TCS-670A): There was no activity associated with the TCS-670A during the quarter.

c. Dash 2 T-C Sets (CSN-2 and TCS-670-2): A detailed review of the design of the CSN-2 to define the installation configuration and lubrication and seal gas system requirements was completed. At the end of September, a similar review was in progress for the TCS-670-2.

The aerothermodynamic analysis (Ref. o) of the CSN-2 compressor was revised to include the latest technical information from Clark Bros. and re-run on the computer. A revision to the analysis report will be published following the evaluation of the results of the computer run. Aerothermodynamic analysis of both the CSN-2 and TCS-670-2 turbines was initiated during the quarter using the Turbo "A" computer code.*

d. Bearings: A two-stage program (Ref. p) is being conducted to establish the reliability and stability range of CSN-1A type bearings (Ref. l). The design and fabrication of the bearing test rig and the wooden support structure for the drive motor, speed increaser and test fixture were completed during the current quarter. The test rig was assembled and the instrumentation and controls were being calibrated at the end of September. Testing, in accordance with the Phase 1 test plan (Ref. q), will be initiated early in the next report period.

Professor D. D. Fuller, AGN consultant on bearings, submitted an analysis of the suitability of the current CSN-1A bearing design for operation at reduced pressure differentials. This analysis, which was being reviewed at the end of September, indicates that the existing bearing design is satisfactory for operation at reduced oil pressure differentials. The report will be forwarded to the USAEC at the completion of the review.

e. Seals: A literature search to establish the state-of-the-art of high-speed seal concepts suitable for use in the AGCRSP was completed during the prior quarter. A summary of the results of the literature search was completed by the end of September and will be published in the next quarter.

f. Equipment Testing: The preparation of procedures and the training of personnel for the conduct of bearing development tests (see d. above) was completed during the report period.

The checkout and modification of the prime mover system continued throughout the quarter in preparation for the testing of the Fairbanks-Morse alternator (see Section i below). A floating coupling was installed to facilitate the alignment of the alternator to the prime mover, a zero-speed control system was installed to permit operation below 100 rpm, and a high-torque shutdown safety device was installed.

Operational tests of the Besler heater revealed that the temperature sensing elements were defective; these units were repaired by the vendor and re-installed in the system.

g. Precooler: The design of the improved plate-fin precooler continued at Stewart-Warner Corporation (the vendor for the precooler) throughout the period.

A burst test sample which simulated the cross section of the nitrogen inlet end of the precooler was subjected to tests in accordance with the procedure of paragraph UG-101 of Section VIII of the ASME Unfired Pressure Vessel Code 1959. The minimum bursting pressure allowable under the code is 602 psig; the test sample failed at 510 psig at 525°F (Ref. r). A separator plate in the *A gas turbine analysis code developed by AGN consultant, Dr. M. H. Vavra and described in internal communication AGN-VA-20.

core failed adjacent to one of the center bars in the high pressure channel (Figures 3-1 and 3-2). The rupture resulted from excessive clearance between the brazed fin and the edge of the center bar; the sharp, unyielding edge of the center bar also caused stress concentrations which contributed to the failure.

As a result of the test, the high pressure (nitrogen side) fins were resized to satisfy the code burst pressure requirements. The design specifications for the fins are presented in Table 3-1. The fin pitch was not altered from the 14 per inch configuration specified in the original design.

TABLE 3-1 - IMPROVED PRECOOLER FIN DESIGN SPECIFICATIONS

<u>Temperature Zone, °F</u>	<u>Fin Thickness, in.</u>	<u>Materials Removed by Perforation, %</u>
450-525	0.012	5.75
335-450	0.012	11.5
130-335	0.008	11.5

Sample core sections, using the fin design specified above, were fabricated and tested. The high temperature sample (see Table 3-1) was tested at 525°F and failed at 730 psig. An intermediate temperature sample was tested at 450°F and failed at 880 psig. The low temperature sample had not been tested at the end of September. Inasmuch as the two samples tested satisfied the code requirement (602 psig), it appears that the redesign of the fins is satisfactory.

Stress concentrations at the center bars were reduced by repositioning these components and improving the "hat section" configuration of the fin to reduce the gap between the fin and the fin supports (Figure 3-3).

A sample of the outlet configuration was burst tested; failure occurred at 420 psi at 215°F. Since this sample did not satisfy the code requirement (602 psi), the sample was disassembled and analyzed to determine the cause of the failure. This analysis revealed that the failure was caused by stresses induced by the pressure against the end cap of the collector. This end cap (a 1-inch thick plate) was pierced by a covered hole to permit access for cleaning. The analysis indicated that the hole had weakened the structure sufficiently to permit the end cap to warp, causing excessive stress on the precooler core. At the end of September, the sample was being rebuilt, without the access port, for retest.

Analytical techniques to compare the Larson-Miller and Sherby-Dorn extrapolation techniques for estimating the allowable stress limits in aluminum at 525°F after 50,000 hours were developed. The allowable 1% creep stress limit for Type 5052 aluminum was predicted to be 700-800 psi by both techniques. This value will be verified by creep tests using the AGN-developed centrifugal creep testing machine. At the end of September, preliminary tests had established rotational speed and testing techniques and the actual creep testing of aluminum samples was scheduled to begin early in the next quarter.

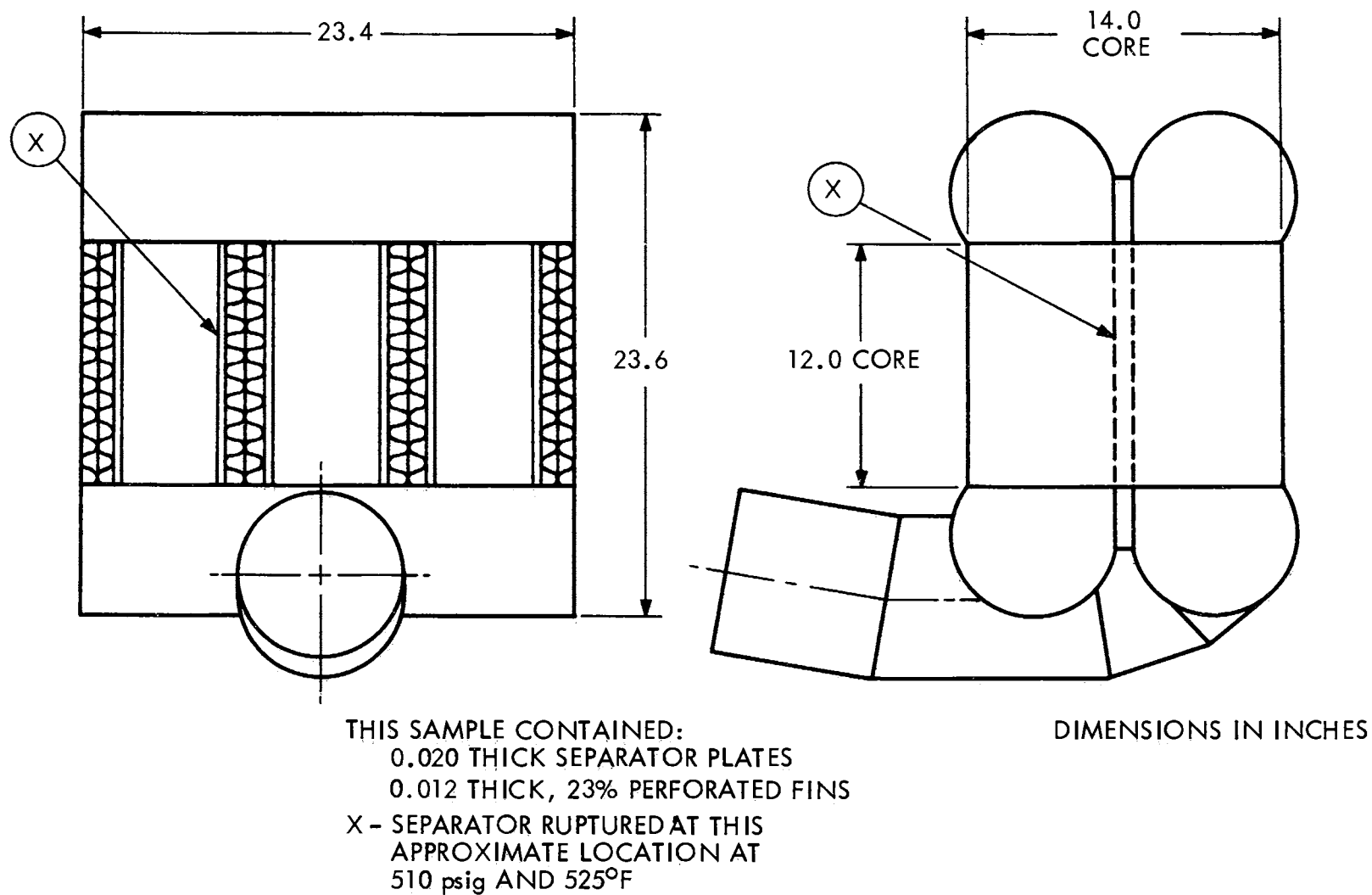


FIGURE 3-1. SCHEMATIC DIAGRAM OF THE NITROGEN INLET SIDE BURST TEST SAMPLE, ML-1 IMPROVED PRECOOLER

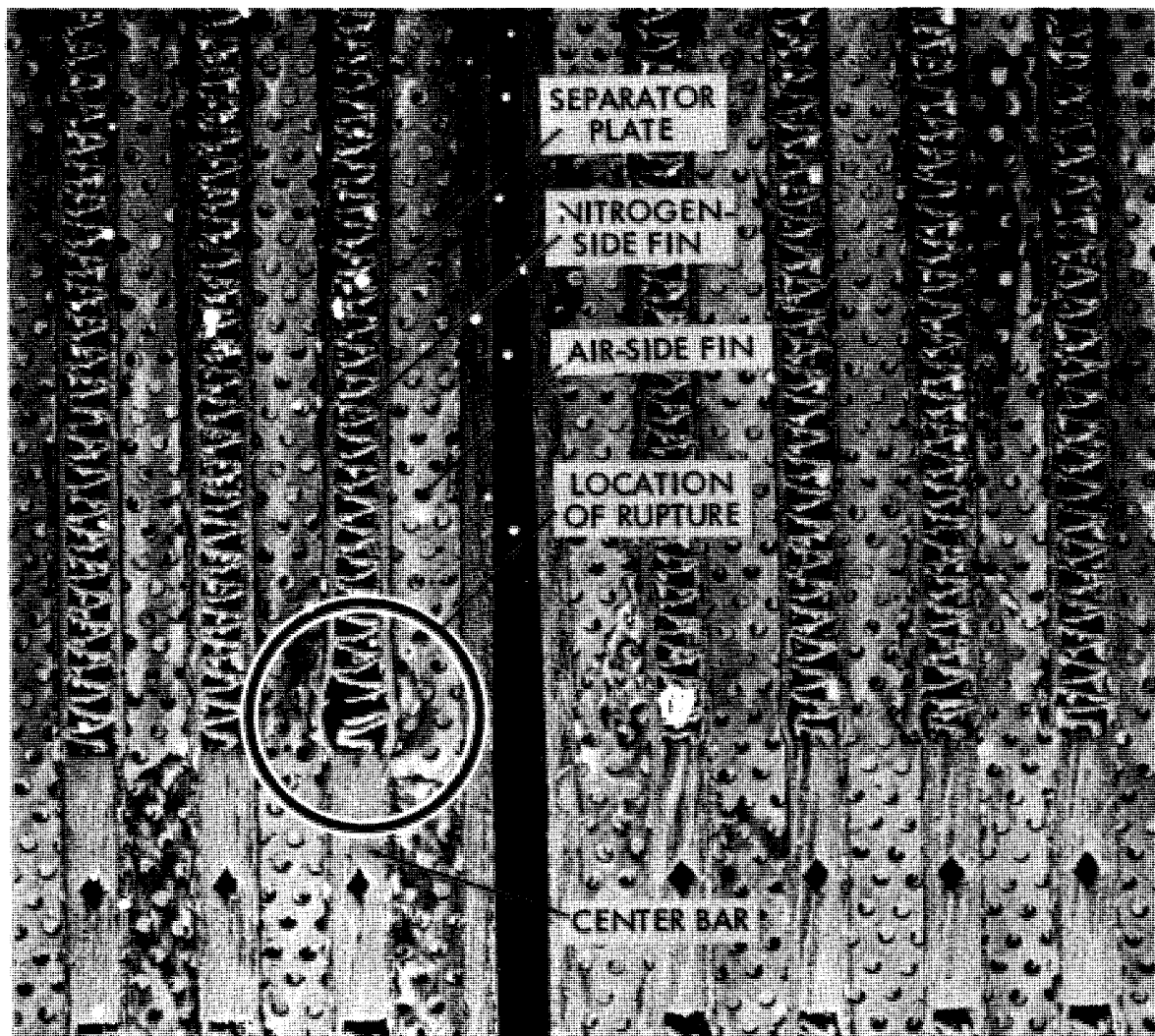


FIGURE 3-2. RUPTURE OF PRECOOLER BURST TEST SAMPLE

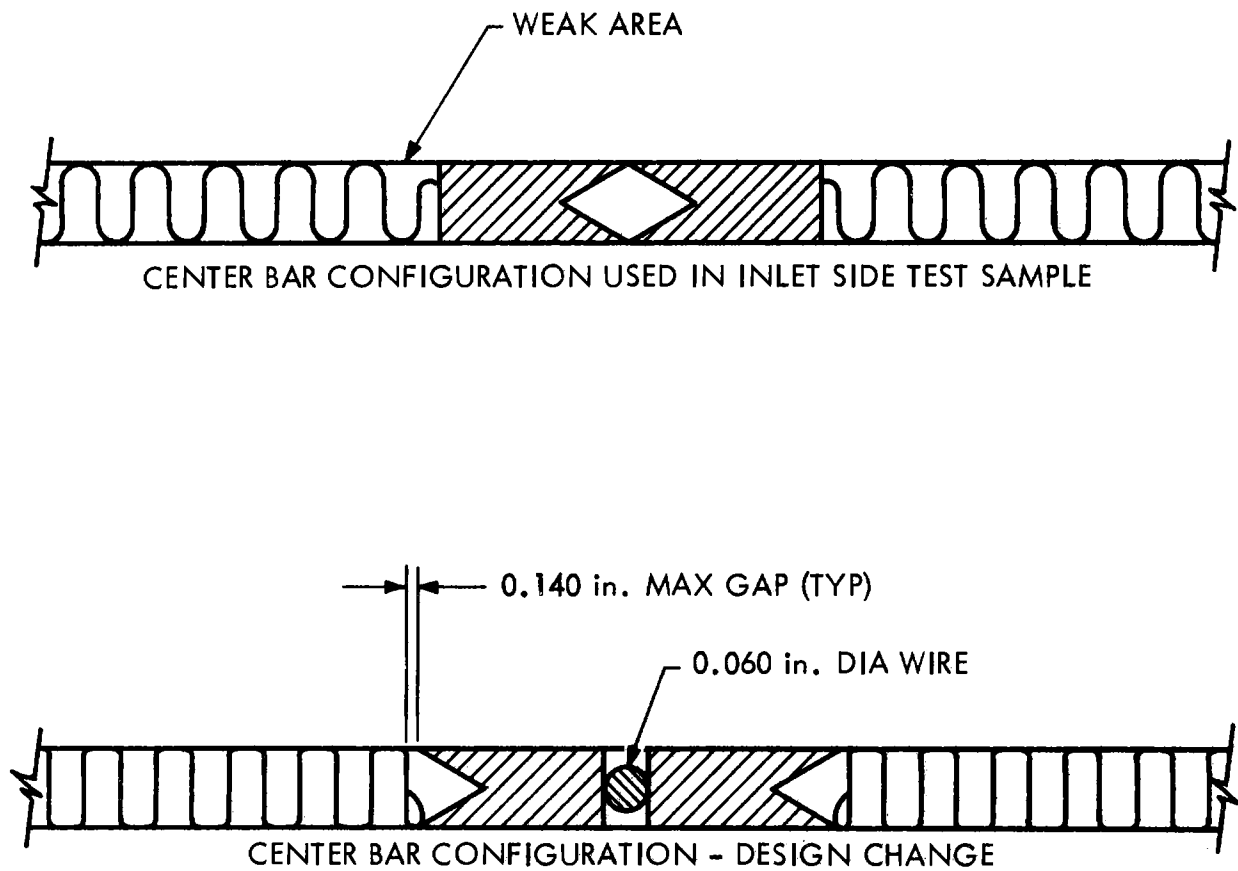


FIGURE 3-3. NITROGEN INLET END OF IMPROVED PRECOOLER

h. Precooler Air-Side Cooling Assembly: The final design of the improved air-side cooling assembly to increase the cooling air flow rate and improve the distribution of cooling air flow was completed (Ref. s). This design incorporates 36-in. diameter, 1800-rpm fans. The larger, slower-speed fans improve the flow distribution by covering more of the area under the precooler core and also permit the use of standard fans whose characteristics have been verified by actual tests. The design of the support structure provides maximum strength with minimum weight and minimizes the obstructions to the flow of cooling air. The improved design also facilitates removal of the precooler core and of the individual fan assemblies. The design characteristics of the system are shown in Figure 3-4. The improved assembly is 205 lb heavier than the ML-1 structure despite the lighter support structure because the 1800 rpm fans and motors weigh more than those used in the ML-1.

i. ML-1 Alternator: The improved ML-1 alternator is a four-pole, air-cooled, drip-proof unit with moisture-resistant insulation and self-lubricating ball bearings. The machine is rated at 600 kw at 4160/2400 volts at 0.8 power factor and an ambient temperature of 125°F. The alternator is being procured from Fairbanks-Morse and Company.

Certified prints of the alternator provided by the vendor were reviewed and approved for the initiation of final design. The following minor changes were included in the design requirements:

- The design pressure on the shaft seal at the turbine end of the alternator was changed from 5 to 90 psig to minimize the loss of process gas after power plant shutdown. This change required the use of a different seal concept from that originally specified by the vendor.
- An atmospheric vent between the shaft seal and the turbine end bearing was specified to prevent seal leakage from entering the alternator windings.
- Oil inlet ports in the turbine end mounting flange were specified for lubrication of the 2:1 gear reduction unit (see below).

At the end of September, the final design of the alternator was 90% complete and procurement of materials had been initiated. Fabrication of the unit is scheduled to begin in November 1964.

j. Alternator Gear Set: The selection of an 1800 rpm alternator for the ML-1 power plant required that provision is made for reducing the speed of the t-c set output shaft (3600 rpm) to 1800 rpm. Proposals were requested from 12 gear manufacturers for a suitable speed reduction unit to replace that normally installed on the t-c set. Three responses were received to this request for proposals. A technical review of the proposed systems and discussions with Clark Bros. and Stratos led to the conclusion that the preferred arrangement would retain the reference speed reduction unit in the t-c set and provide a second unit to complete the speed reduction. The advantages of this approach are:

- The 3600/1800 rpm gear set can incorporate either a star gear or gear train concept to eliminate the problems associated with high centrifugal forces on planetary gear bearings.

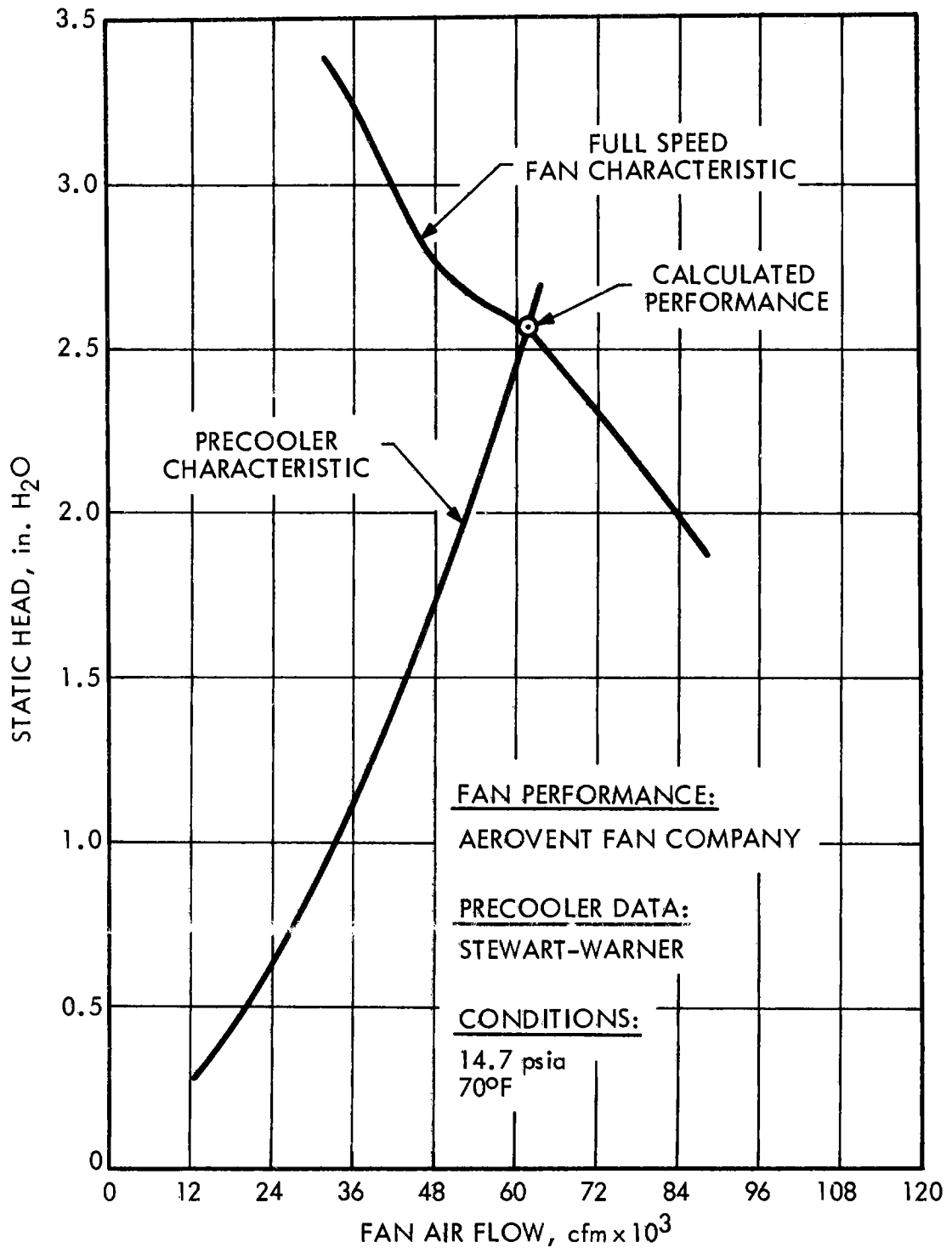


FIGURE 3-4. DESIGN CHARACTERISTICS OF IMPROVED AIR-SIDE COOLING ASSEMBLY

11.2-64-2748

- Spur gears can be used in the 3600/1800 rpm unit because of lower pitch line velocities. This minimizes the problems associated with thrust loads on helical gear bearings.
- Either the Clark Bros. or Stratos t-c set can be used with the 1800 rpm alternator or with a 3600 rpm load absorber without significant modification.
- The requirement to demonstrate the performance of a new high speed gear reducer is avoided; the high speed gear sets included in the CSN-2 and TCS-670-2 t-c sets are identical with those used in the CSN-1 and TCS-670. The gear set in the CSN-1 is well-tested and proven; limited testing indicates that the TCS-670 unit will perform satisfactorily.
- The 3600/1800 rpm gear set can be mounted and balanced on the alternator and tested with that unit.

The disadvantages associated with this concept are as follows:

- The introduction of a second gear set in the drive train increases the overall length of the rotating machinery and the number of rotating components.
- The output shafts of the speed reducers on the Clark Bros. and Stratos t-c sets rotate in opposite directions; this requires that the alternator be capable of satisfactory performance when rotating in either direction.
- The introduction of a second gear set will probably decrease the total gear efficiency.

Discussions with the vendor of the requirement for alternator rotation in either direction resulted in the evolution of a design which will permit the alternator to perform satisfactorily in either case with minor changes in the external wiring. The requirement for additional length can be accommodated by a minor rearrangement of the components on the skid. The loss in gear efficiency will be relatively small (less than 1%). As a consequence, it was concluded that the optimum approach involved the use of a 3600/1800 rpm gear set between the t-c set and the alternator.

Requests for proposal for such a gear set were submitted to several gear set manufacturers; two acceptable responses were received and Western Gear Corporation was selected as the vendor for the unit. The Western Gear design incorporates a two-stage spur gear train (1.67:1 and 1.2:1) to achieve the required 2:1 speed reduction. A review of the preliminary design indicated that the use of hardened and ground spur gears is acceptable at the prevailing pitch line velocities and that tooth loading is acceptable. The bearings specified in the design appear to be satisfactory for 10,000 hours of operation with self-lubrication and a lifetime of 30,000 hours with forced-feed lubrication is anticipated.

The design of the interface between the alternator and gear set was completed and reviewed with Fairbanks Morse, Clark Bros., and Stratos. This design resulted in certain changes to the drive end of the alternator as discussed in Section i above and permitted the initiation of the final design of the speed reducer by Western Gear. This work was in progress at the end of September.

k. Power Conversion Skid Modification: The disassembly of power conversion skid No. 1, including the removal of the lubrication and electrical systems, was completed. This permits the skid structure to be modified to accommodate the longer rotating machinery system and the relocation of the moderator and lubricating oil coolers to accommodate the improved precooler assembly.

The extension of the skid base and the installation of support rails for the rotating machinery were completed at the end of September. Modifications to the recuperator to accommodate the altered location of the improved precooler were in progress. Modifications of the turbine inlet duct design to incorporate a flow-measuring venturi were completed and fabrication of this unit was initiated. Arrangements were made to calibrate the venturi at water flows up to 700 lb/sec at 70°F; these conditions develop a Reynolds number (1.85×10^6) equivalent to that of nitrogen at 1200°F, 300 psia and 26 lb/sec.

Studies to define the requirements for the modified lubrication system for use with the TCS-670-2 t-c set revealed that the capacity of the skid-mounted lubricating oil cooler is inadequate. The existing cooler has a capacity of 87 kw and it is now estimated that more than 100 kw is required. The design of a modified cooling system for use during skid testing, which will provide an oil-to-water heat exchanger in series with the ML-1 lubricating oil cooler, was completed. During testing, the water for this exchanger will be cooled in the skid-mounted moderator cooler. The increased capacity of the moderator/lubricating oil cooler specified in the ML-1A design is sufficient to accommodate the requirements of the TCS-670-2 during power plant operation. Other modifications to the lubrication system design included the simplifications made possible by the use of an atmospheric lubricating oil sump and the elimination of the requirements for the oil cooling of the alternator.

1) Starting System: The USAEC approved a proposal (Ref. t) to proceed with the final design of an improved, variable-speed starting system to eliminate the high power requirements of the existing, discrete-speed, ML-1 start motor. The design is based on the use of a variable-displacement, pressure-compensated pump driven by a single-speed a.c. induction motor. The pump drives a hydraulic motor and the torque generated by the motor is transmitted to the alternator shaft through a timing belt. The speed reduction is accomplished by sizing the timing belt pulleys. A mechanical overriding clutch on the alternator shaft permits shutdown of the starting system when the power plant reaches self-sustained conditions and automatically re-engages the system if t-c set rotation is required during reactor shutdown. This arrangement will prolong the life of the starting system and generally improve plant reliability.

The starting system provides 300 ft-lb of breakaway torque and maintains this torque up to 25% of rated t-c set speed. Beyond this point, the system provides 25-30 kw of driving power up to 60-75% of t-c set rated speed. At the end of September, consideration was being given to either adjusting the set

points on the hydraulic pump and motor or changing the pulley ratio. These changes will provide a minimum of 25 kw of driving power at all speeds up to full speed of the t-c set, without changing the breakaway torque.

3.3 Instruments and Controls

a. Overspeed Scram Chassis: The final design of the improved overspeed scram chassis was completed and the design report was published (Ref. u). The improved design provides for complete separation (except for the power supply and self-monitoring system) of the turbine overspeed valve and overspeed scram control channels. Two speed sensors are provided: one on the high speed shaft inside the t-c set, and one on the output shaft at the gear box. Provision is made for operability checks prior to startup and for adjustment of the set points during operation without inducing a scram. The control functions for the standby oil pump and startup compressor (which were previously incorporated in this circuit) have been removed; separate pressure sensitive circuits are provided for these functions.

b. Automatic Temperature Controller: Tests of the improved ML-1 speed and temperature control system indicated that additional shielding was needed on the signal leads. This shielding was installed and further evaluation of the temperature controller revealed that the output signal generated by the Metricite regulating rod position indicator contained unacceptable phase shift and wave form distortion. A position indicating system, based on a d.c. potentiometer, was designed and tested on the regulating rod mockup (see 2.1-e). The test revealed that this instrument has sufficient accuracy and stability to satisfy the requirements of the temperature control system. This arrangement will not alter the control rod position indicating system installed in the ML-1 control cab.

3.4 ML-1-II Core Elements

a. ML-1-II Thermal and Neutronic Analysis: A method was developed to estimate the maximum nominal and maximum hot spot temperature of the uninstrumented IB-17R-3 test element operating in the GETR loop. This method is based on the correlation between the cladding temperatures and other operating parameters developed during tests of the IB-17R-1 and -2 elements. The parameters involved are the coolant inlet and outlet temperatures, coolant flow rate and the GETR control rod position. Since the effects of flow rate and rod position are small, and generally masked by the data scatter, the following equations satisfactorily estimate the fuel cladding temperature:

$$T_{S_{\max}} = T_{\text{in}} + 1.9 \Delta T_b$$

$$T_{\text{HS}_{\max}} = T_{\text{in}} + 2.3 \Delta T_b$$

where

$T_{S_{\max}}$ is the maximum nominal surface temperature,

$T_{HS_{\max}}$ is the maximum hot spot temperature,

T_{in} is the coolant inlet temperature and

ΔT_b is the bulk temperature rise across the test element.

Under typical operating conditions where $T_{in} = 850^{\circ}\text{F}$ and the coolant outlet temperature is 1200°F , $T_{S_{\max}}$, as derived from the above formula, is 1450°F and $T_{HS_{\max}}$ is 1720°F .

An analysis was performed with the ANASIM code to compute the temperature transients in the ML-1-II fuel elements in the event of a simultaneous loss of coolant flow and reactor scram. The difference between the heat capacity of the ML-1-I and ML-1-II elements is demonstrated by the fact that, assuming long term operation at 1750°F hot spot temperature prior to the accident, the maximum temperature reached by the ML-1-II fuel element is 1965°F but the ML-1-I element reaches 2060°F .

Preparation of a draft report describing the AGN/GAM fast cross-section code was completed. This code calculates a 75-group spectrum for either a core or reflector region and generates few-group nuclear constants for use in diffusion or transport codes. A revised library data tape for the AGN/GAM was prepared.

The nuclear design report for the ML-1-II core was revised to include the results of the re-evaluation of europium burnout effects and new specifications for europium poison in the ML-1-II elements.

A description of the initial low power experiments to be performed with the ML-1-II core was prepared. The test method selected involves the irradiation of 20% enriched uranium foils (inserted in special test liner assemblies) in 21 fuel element positions.

Calculations were performed to define the pattern and configuration of reactivity shims for the ML-1-II core. The results of this work indicate that 53 heavy (65.3 grams of silver) shims and 6 light (32.7 grams of silver) shims will be required.

b. IB-17R-2 Metallurgical Evaluation: The results of the metallographic examination of samples of the IB-17R-2 cladding, fuel and inert parts were reported last quarter (Ref. 1).

Additional metallographic examinations were performed at the MTR hot cells on specimens removed from pin 1 (which contained a significant quantity of nitrogen) and pin 3 (which contained only a trace of nitrogen). The examination of specimens from pin 1 revealed the formation of a second phase in the cooler

portions of the fuel pin (Figures 3-5 and 3-6). The presence of a second phase in these specimens was not unexpected because of the presence of nitrogen in the fuel pin. However, the occurrence of the second phase in the cooler sections of the tubing is at variance with the findings of the IB-8T-1 examination; this phenomenon was being investigated at the end of September. Examination of specimens from pin 3 also revealed the presence of the second phase, a situation considered highly unusual in the light of the IB-8T-1 and -2 findings. The quantity of second phase increased with increasing exposure temperature; specimens in the colder region of the pin were characterized by a belt of blocky structures on the inner surface (Figure 3-7) which is similar in appearance to the pi phase observed in many of the IB-8T-1 pins. The appearance of second phase formation in the higher temperature regions of the fuel pin is shown in Figures 3-8, 3-9 and 3-10. Some of the specimens from both pin 1 and 3 revealed a layer phase on the inside of the tubing (Figure 3-11). This phase is somewhat different in appearance from the second phase discussed above.

The BeO-UO₂ fuel in pins 1 and 3 appeared quite similar to that observed in samples from pins 10 and 12; however, some unusual formations were noted around the fuel particles in pin 1 and in cracks in the fuel particles in pin 3. This unusual structure is visible as small spherical particles in Figures 3-12 and 3-13. By the end of September, arrangements had been completed to transfer specimens of pins 1 and 3 to the AGN hot cell for additional evaluation of the second phase formation in both the cladding and the fuel. A specimen from pin 1 had also been transferred to BMI for extraction and subsequent analysis to identify the second phase in the cladding.

The removal of the fuel from samples of the IB-17R-2 fuel pins (transferred to BMI early in the quarter for tensile testing) was initiated. Evidence of limited attack on the cladding by the reagent used to remove the fuel was noted; such attack has not been observed previously although identical procedures and reagents were used. At the end of September, the tubing specimens were being examined metallographically to investigate the cause of the attack.

c. IB-17R In-Pile Test: The test irradiation of the uninstrumented ML-1-II prototype fuel element (IB-17R-3) in the GETR in-pile test loop continued without incident throughout the quarter. At the end of September, the IB-17R-3 had accumulated 8861 hours of exposure at an average power of about 54 kw. No problems were experienced with the coolant circulating compressors; at the end of September, four units were operating satisfactorily and a spare unit had been checked out and was available for use. The Fibrofax filters in the gas loop were replaced with new micrometallic filters; no evidence was noted during this quarter of the severe plugging observed earlier (Ref. 1) and the amount of dust in the loop appears to have been reduced significantly.

d. IB-17R Out-of-Pile Support: Coolant/cladding and cladding/fuel compatibility tests are being performed out-of-pile to develop control data for evaluation of the IB-17R in-pile tests. During the last quarter, samples which had been exposed for 5820 hours (comparable to the exposure of the IB-17R-2 test element - 5819 hours) were removed and metallographic evaluation of the coolant/cladding specimens completed (Ref. 1).

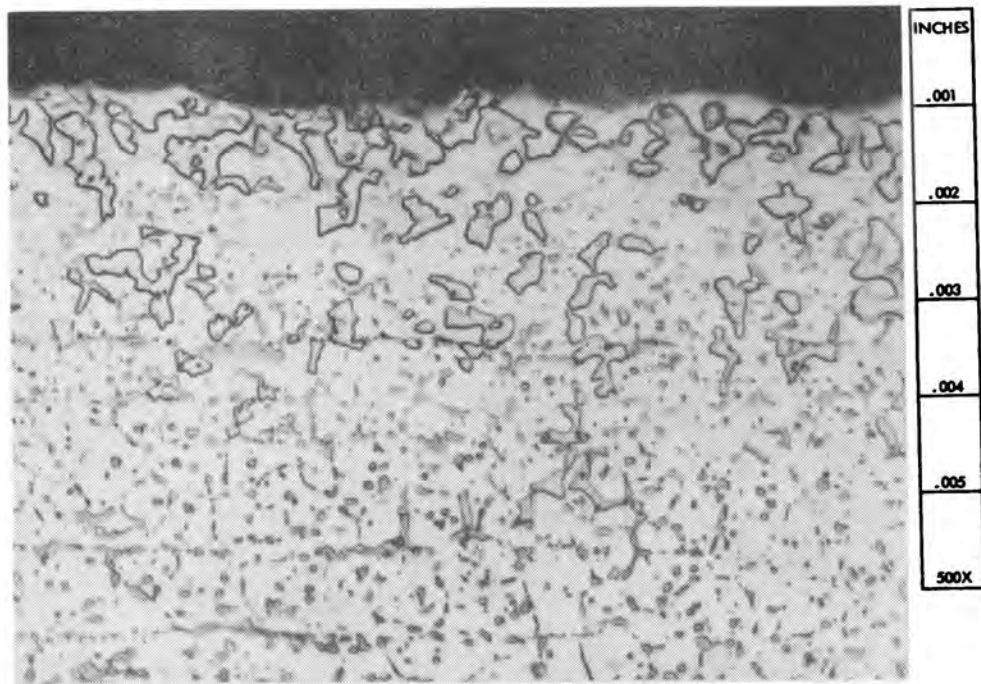


FIGURE 3-5. SECOND PHASE FORMATION ON INSIDE OF IB-17R-2 PIN 1 AT $X/L = 0.3$; APPROXIMATE TEMPERATURE, 1450°F

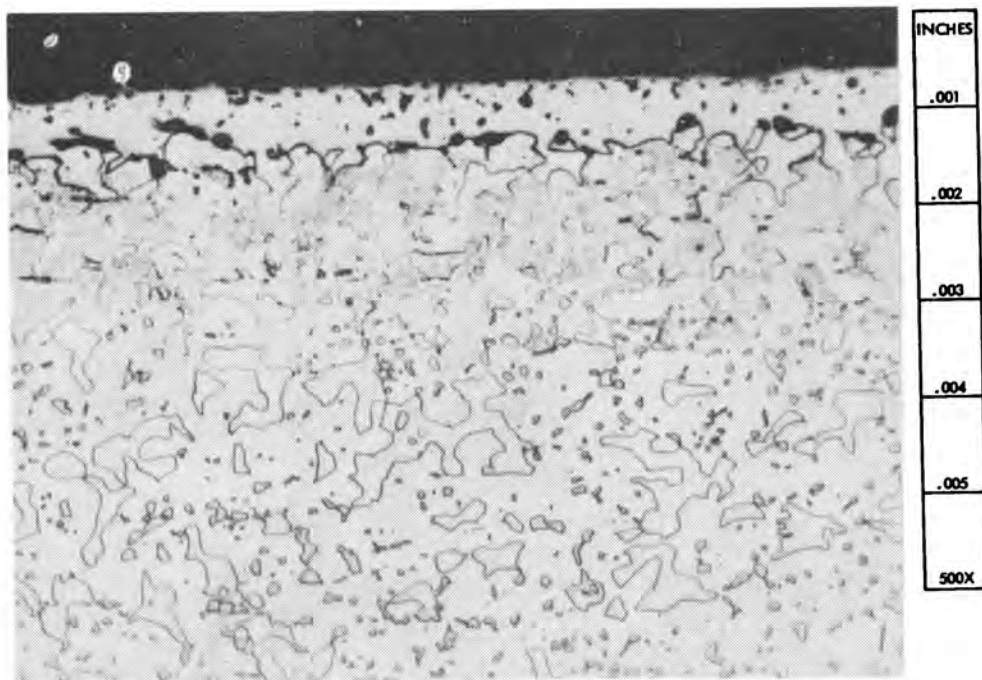


FIGURE 3-6. LAYER AND SECOND PHASE FORMATION ON INSIDE OF IB-17R-2 PIN 1 AT $X/L = 0.5$; APPROXIMATE TEMPERATURE, 1600°F

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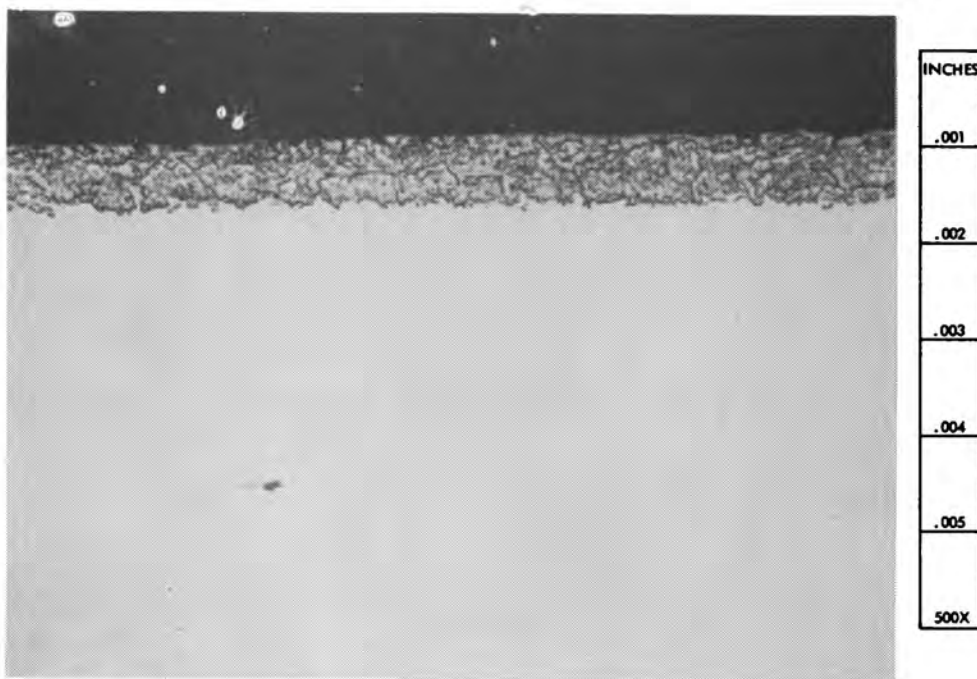


FIGURE 3-7. BAND CONTAINING BLOCKY SECOND PHASE FORMATION ON INSIDE OF IB-17R-2 PIN 3 AT $X/L = 0.3$; APPROXIMATE TEMPERATURE, 1360°F

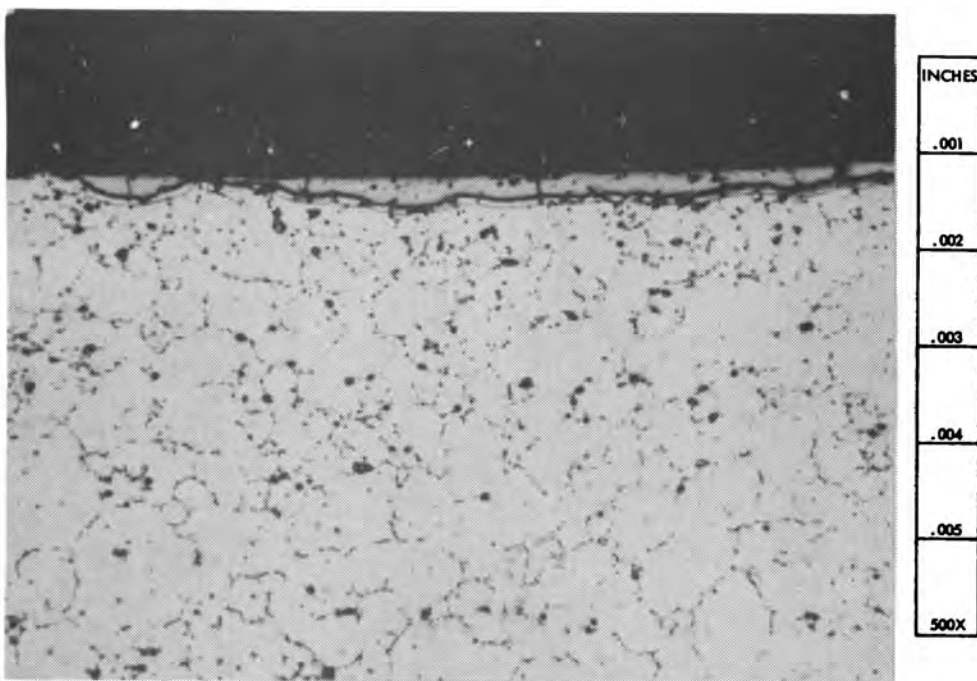


FIGURE 3-8. LAYER PHASE ON INSIDE OF IB-17R-2 PIN 3 AT $X/L = 0$; APPROXIMATE TEMPERATURE, 1220°F

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FIGURE 3-9. SECOND PHASE FORMATION ON INSIDE OF IB-17R-2 PIN 3 AT $X/L = 0.5$; APPROXIMATE TEMPERATURE, 1500°F

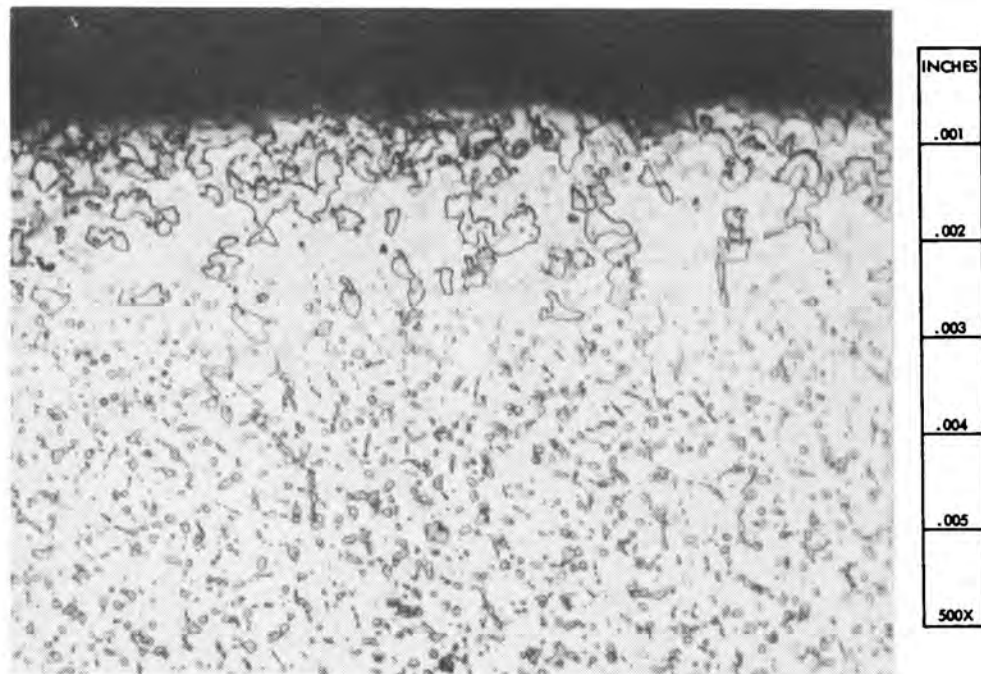


FIGURE 3-10. SECOND PHASE FORMATION ON INSIDE OF IB-17R-2 PIN 3 AT $X/L = 0.8$; APPROXIMATE TEMPERATURE, 1520°F



INCHES
.001
.002
.003
.004
.005
500X

FIGURE 3-11. LAYER PHASE ON INSIDE OF IB-17R-2 PIN 3 AT $X/L = 1.0$;
APPROXIMATE TEMPERATURE, 1450°F

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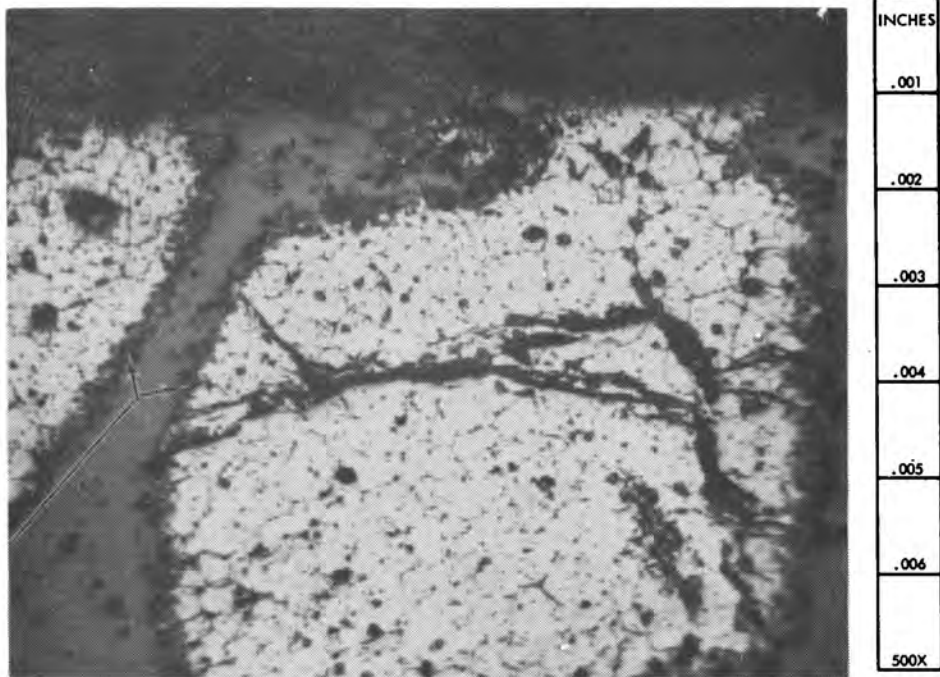


FIGURE 3-12. PHASE OBSERVED AROUND FUEL PARTICLES IN IB-17R-2 PIN 1

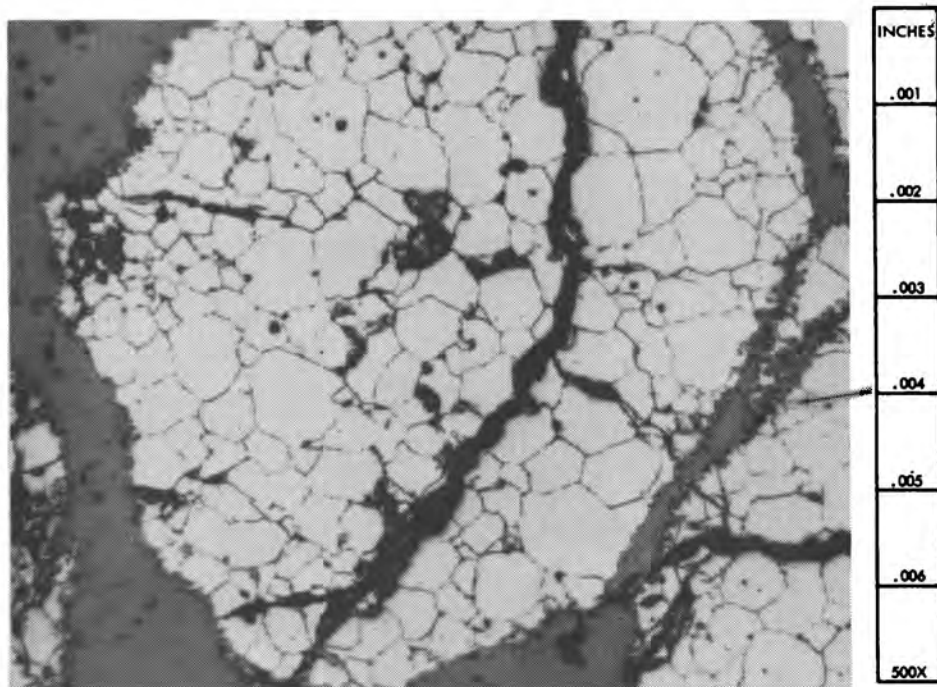


FIGURE 3-13. PHASE OBSERVED IN CRACKS IN FUEL PARTICLES IN IB-17R-2 PIN 3

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The room temperature properties of the tubing exposed in the 5820-hour coolant/cladding tests were determined. The data presented in Table 3-2 indicates that the strength properties of the high-cobalt material changed only slightly with increased exposure temperature and that the elongations increased with exposure temperature as with the low-cobalt material.

**TABLE 3-2 - ROOM TEMPERATURE TENSILE PROPERTIES OF HIGH-COBALT
HASTELLOY X TUBING EXPOSED IN AIR FOR 5820 HOURS**

Specimen No.	Exposure Temp., °F	Ultimate Tensile Strength, psi	Yield Strength, psi	Percent Elongation	
				in 1 in.	in 3 in.
FKA-103	1300	105,000	50,000	15	12
FKA-103	1300	108,500	56,000	*	12
FKA-84	1450	94,800	42,600	22	13
FKA-84	1450	104,000	49,300	*	12
FKA-103	1600	87,500	38,100	34	18
FKA-103	1600	93,000	40,700	27	13
FKA-84	1750	100,800	44,900	34	20
FKA-84	1750	100,200	43,300	33	19

*Data invalid.

The metallographic examination of the cladding/fuel specimens removed during the last quarter was completed. No reaction was detected between the fuel and the cladding although some internal oxidation was observed on the inner surface of the cladding. This oxidation is attributed either to oxygen absorbed from the fuel or to inadequate back-filling with helium during fabrication of the specimen. From the appearance of the cladding/fuel interface (shown in Figure 3-14), it is apparent that the pellets were not cracked although small cracks were observed in the UO_2 particles (Figure 3-15). The porosity of the BeO matrix is greater than would be expected in a fuel pellet with 95% of theoretical density. Fine, metallic-appearing particles were observed in the UO_2 (Figure 3-16); these particles have been observed previously but have not yet been identified.

The compatibility tests operated satisfactorily throughout the quarter; the inspection of samples exposed for 10,000 hours is scheduled for early in the next quarter.

e. Chromium-Plated Pin Tip Testing: The tests initiated (Ref. 1) to determine if hard-chromium plating of the lower tip of the fuel pin is necessary were completed. The three test assemblies were exposed as follows:

- Assembly A - 1250 hours in demineralized water followed by 1250 hours in reference gas at 1200°F
- Assembly B - 1250 hours in reference gas at 1200°F followed by 1250 hours in demineralized water
- Assembly C - 2500 hours in reference gas at 1200°F

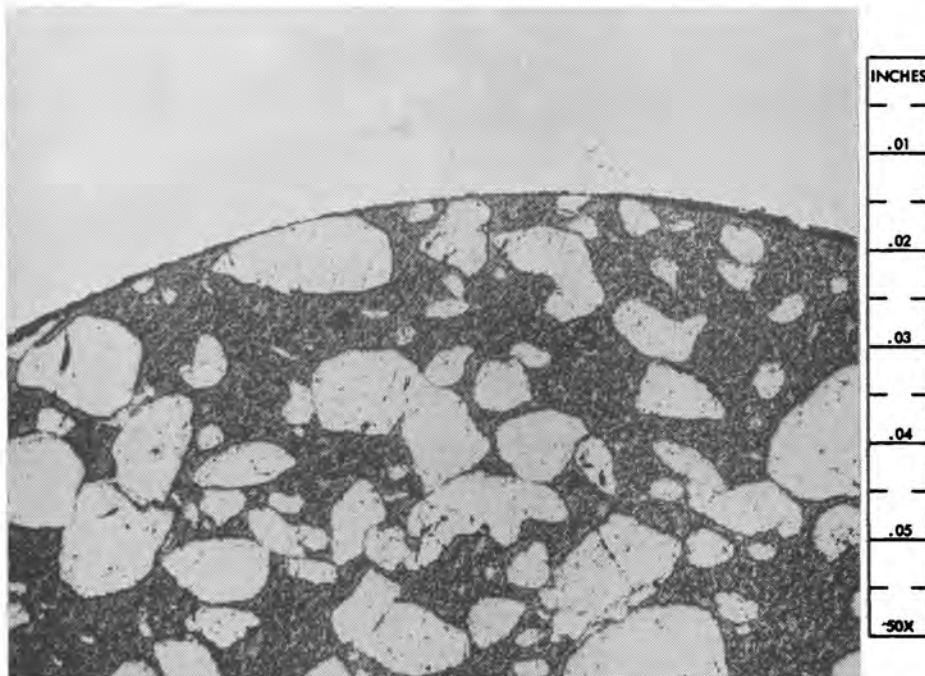


FIGURE 3-14. FUEL/CLADDING INTERFACE OF IB-17R-2 CONTROL SAMPLE (As Polished)

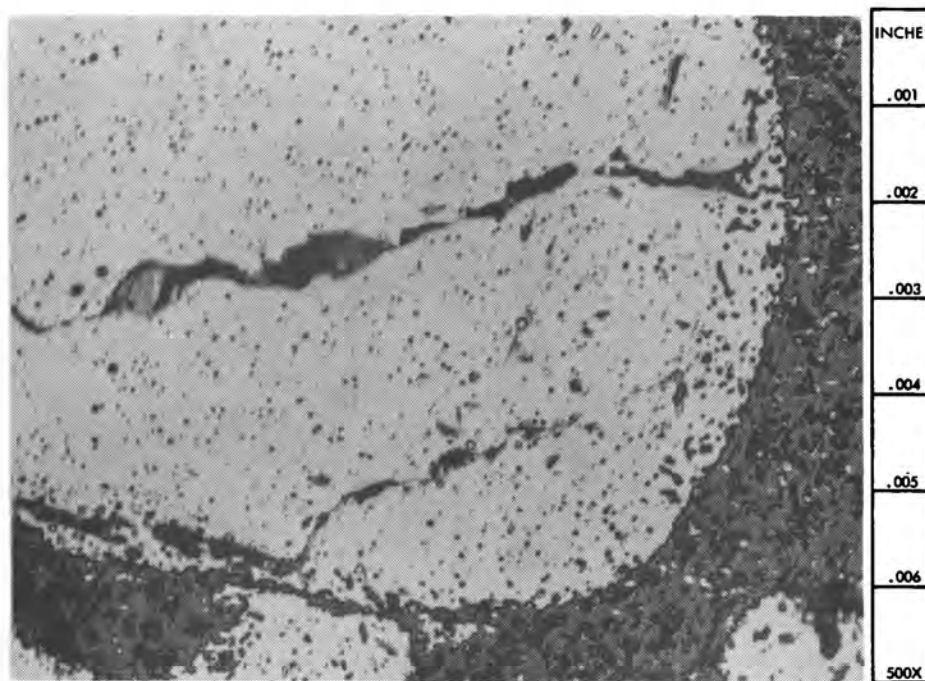


FIGURE 3-15. FUEL PARTICLE IN IB-17R-2 CONTROL SAMPLE (As Polished)

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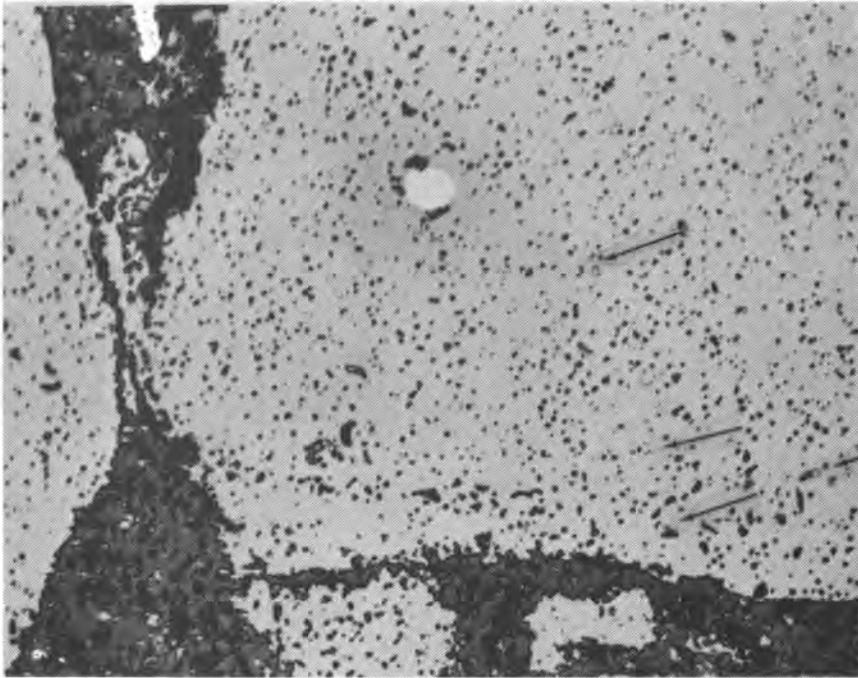


FIGURE 3-16. UNIDENTIFIED PARTICLES IN IB-17R-2 CONTROL
SAMPLE FUEL

Inspection of the test specimens revealed that both the plated and unplated pin tips were covered with a black oxide powder from the Hastelloy X test racks. Tests were performed to determine the force necessary to move the pin tip in the test assembly. The results of these tests, performed with both 5 and 10 lb lateral loads on the pin tip specimens indicate that the chromium plating of fuel pin tips does not improve the coefficient of friction significantly and consequently is not necessary for the ML-1-II elements (Table 3-3).

**TABLE 3-3 - FORCE REQUIRED TO REMOVE PIN TIPS
FROM TEST ASSEMBLY AFTER ENVIRONMENTAL TESTING**

Assembly A*				Assembly B*			
Hole No.	Force, lb			Hole No.	Force, lb		
	Plated	Unplated			Plated	Unplated	
1	3.25	3.50		1	3.125	3.50	
2	3.25	3.25		2	3.00	3.25	
3	3.25	3.25		3	3.00	3.125	
4	3.50	3.50		4	2.875	3.25	
5	3.00	3.25		5	2.75	3.125	
Average Force, lb	3.25	3.25		Average Force, lb	2.95	3.25	
Friction Coefficient	0.325	0.335		Friction Coefficient	0.295	0.325	

Assembly C*				Assembly C**			
Hole No.	Force, lb	Hole No.	Force, lb	Hole No.	Force, lb	Hole No.	Force, lb
	Plated		Unplated		Plated		Unplated
1	3.25	9	3.125	15	6.50	5	7.125
2	3.50	10	3.125	16	7.50	6	8.125
3	3.75	11	3.25	Average Force, lb	7.00		7.625
4	3.00	12	3.25	Friction Coefficient	0.350		0.381
5	3.25	13	3.00				
6	4.125	14	2.75				
7	3.125	15	3.50				
8	3.50	16	3.50				
Average Force, lb	3.44	16	3.50				
Friction Coefficient	0.344		0.317				

*Five-pound load.

**Ten-pound load.

f. Tube-Burst Testing: Tests initiated last quarter (Ref. 1) to determine the tube-burst characteristics of finned and smooth Hastelloy X fuel pin tubing at various temperatures continued. The results of tests performed through September are shown in Table 3-4.

TABLE 3-4 - TIME-TO-BURST FOR FINNED TUBES
AT VARIOUS TEMPERATURES AND PRESSURES

<u>Test No.</u>	<u>Temperature, °F</u>	<u>Pressure, psig</u>	<u>Time for Rupture, hr</u>
2	2200	300	1.1
12	2200	180	6.8
3	2200	100	50.6
5	2100	300	2.1
11	2100	220	10.0
7	2100	100	98.1
10	2000	370	8.8
8	2000	300	11.5
9	2000	100	337.5

Calculations indicate that the maximum temperature experienced by the ML-1-I fuel pins during a loss of coolant accident is 2065°F, and the pins would remain at this temperature less than one hour. In the "worst case" situation, where a small leak in the cladding resulted in a 300 psi internal pin pressure, the data of Table 3-4 indicates that the tube would not rupture in less than two hours at 2100°F.

Burst tests on smooth tubing, to provide data for comparison with the finned-tube tests, were in progress at the end of the quarter.

g. ML-1-II Core Fabrication: A purchase order was placed for the ML-1-II upper and lower spider castings. Sample castings will be available for metallurgical, mechanical, and chemical evaluation about 1 November 1964. This evaluation, which will require about two months, will provide the basis for determining the vendors' qualifications for producing spiders. The production of the ML-1-II spider castings will not be authorized until this evaluation is complete.

Requests for quotation were transmitted to tubing vendors, but all vendors submitted qualifying comments on the tubing specification. At the end of September, the specification was being revised for resubmission for quotations.

Requests for expression of interest were solicited from 16 ceramic fabricators for the production of the ML-1-II BeO-UO₂ fuel. Only three positive responses were received. Visits were made to evaluate the capabilities of each of these vendors. This evaluation revealed that only one vendor had actually fabricated BeO-UO₂ pellets, but this vendor's experience did not include fabrication of pellets in the range of weight loading specified for the ML-1-II and

thus considerable development would be required. Consequently it was concluded that AGN has more experience than any other vendor in the fabrication of the fuel for the ML-1-II and that the fuel would be fabricated in the AGN fuel shops (Ref. v).

The bid package for procurement of the UO_2 powder was submitted to the USAEC for review. Comments resulting from this review were being incorporated in the specification at the end of September.

Detailed plans for the reactivation of the ceramic laboratory and the development of an improved processing technique for fabrication of the BeO-UO_2 fuel were completed. The drawings of the fuel element assembly fixtures were revised to conform to the ML-1-II configuration and the preparation of the fuel pin and fuel element assembly procedures was initiated. The preparation of the final design report for the ML-1-II fuel element was in progress at the end of September.

III. ML-1 TECHNOLOGY PROGRAM

4.0 PROGRAM DESCRIPTION AND OBJECTIVES

During the development program for the ML-1, many areas of basic technology could not be fully investigated under the end product-oriented program being conducted. In addition, the performance characteristics envelope of many of the developed components could not be defined for the same reason; a component was tested to demonstrate satisfaction of the ML-1 requirements only and no attempt was made to assess ultimate capability. As a consequence, the body of data describing the ML-1 technology is very limited and contains many unexplored or not completely explored areas.

Since accomplishment of the primary objective of the AGCRS Program (namely, the earliest possible "fielding" of a mobile, gas-cooled nuclear power plant for military use) is no longer as urgent as previously was the case and since the technology represented by the ML-1 concept is sound and has the potential for expansion and for use in various applications, a program to more fully exploit the ML-1 technology is being undertaken. The basic objective of this program is the precise definition of the state-of-the-art of the ML-1 technology to permit the expeditious and economical use of this technology in future programs.

a. Objectives: The specific objectives of the ML-1 Technology Program are as follows:

- 1) Definition of the limits of the existing technology
- 2) Determination of methods which appear to have a high probability of success for expanding the current limits
- 3) Implementation of methods of expanding the technology in selected areas and the subsequent redefinition of the limits
- 4) Exploitation of the technology by active promotion and by continuing efforts to identify and "sell" specific applications of the technology

b. Program: The program to accomplish the specific objectives described above will be undertaken in two phases. These are discussed below along with the general ground rules to be followed and specific examples of activities to be undertaken.

1. Phase I - Four significant activities will occur during this phase.

a) Analytical and experimental programs will be undertaken to define the limits of the current ML-1 technology. The current ML-1 technology is defined as the technology associated with nuclear devices incorporating small gas-cooled, heterogeneous, water-moderated reactors as a heat source and operating on a Brayton cycle with air or oxygenated nitrogen as the reactor coolant and working fluid. Typical investigations contemplated under this phase of the work include:

- 1) Experiments to define the time and temperature dependence of the corrosion of the ML-1 fuel pin cladding
- 2) Exposure in-pile to failure of a prototype ML-1-II fuel element (now in progress) to define the limit of this specific design under the test conditions and to establish the mechanism of failure
- 3) Application of analytical and experimental techniques to the problems of defining the temperatures and pressure limits of the existing calandria/pressure vessel technology
- 4) Experiments to define more precisely the relationship between the observed performance of t-c sets in open-cycle applications and the performance of the same units in a closed-cycle loop; this work will permit a more meaningful application of the open-cycle t-c set technology developed over the last 25 years to the design of rotating machinery for closed-cycle applications. (See Table 4-1 for a partial list of Phase I candidate investigations.)

b) In selected areas, methods of expanding the technology will be defined and program outlined for the verification of the new limits. For example, the conceptual design for a high performance calandria/pressure vessel will be prepared for subsequent fabrication and testing to demonstrate the improvement in limits. This design will incorporate all the findings of the earlier work to define the limits of the existing technology.

c) Some effort will be expended to summarize the description of the current ML-1 technology for subsequent updating and use to assist in the determination of potential applications of this technology.

d) Activity to provide suitable test facilities to support the Phase II work will begin.

TABLE 4-1 - CANDIDATE INVESTIGATIONS UNDER
PHASE I OF THE ML-1 TECHNOLOGY PROGRAM

REACTOR

Calandria/Pressure Vessel

- 1) Refine existing analytical techniques for the prediction of stress levels in nuclear reactor calandria and pressure vessels
- 2) Conduct laboratory tests to extend the body of data on physical characteristics of high performance alloys suitable for use in reactor calandria and pressure vessels for ASME certification
- 3) Perform tests to develop instrumentation and techniques suitable for realistic determination of stress in reactor components during both nuclear and non-nuclear testing

Shielding

Evaluate ML-1 shield design calculations and experimental data to develop empirical relations, computer codes, etc., to permit rapid and precise design of complex, multi-material shields

Control Rods

Perform laboratory and capsule tests to evaluate the physical properties of Ag-In-Cd alloys at temperatures up to the melting point for 50,000 hours

Insulation

Perform literature surveys and laboratory experiments to define characteristics of several fuel element and tube sheet insulation systems to provide the basis for selecting an optimum system for any small reactor application

FUEL ELEMENTS

Cladding

- 1) Perform laboratory corrosion tests with Hastelloy X in reference gas and air at temperatures approaching the melting point, and metallurgical evaluations to determine the corrosion properties and physical characteristics for periods up to 20,000 hours
- 2) Perform in-pile capsule tests of Hastelloy X and examinations to establish the effect of gamma, fast neutron and thermal neutron radiation as well as fission products and trace impurity elements on metallurgical and physical properties over a wide range of applicable temperatures up to 20,000 hours
- 3) Perform laboratory tests to determine the creep rupture strength of Hastelloy X at temperatures from 1800°F to near melting at 20,000 hours
- 4) Perform laboratory and in-pile tests to evaluate reactions between Hastelloy X and BeO-UO₂, Eu, B, etc., at temperatures up to the melting point for periods up to 20,000 hours

(Continued)

Table 4-1 - Continued

Fuel

- 1) Perform in-pile capsule tests to evaluate the performance of various BeO-UO₂ fuel compositions up to the eutectic at temperatures from ML-1 reference to near the melting point and at burn-ups up to 20%; check mechanical integrity, fission gas release, helium generation and microstructure of fuel
- 2) Perform a literature search to define the limits of UO₂ as a fuel and define the experimental program required to determine the properties of this material in the temperature and burn-up regions of interest in this program
- 3) Perform in-pile tests of "best" pellets developed in laboratory tests to evaluate BeO-UO₂ fuel fabrication variables

Burnable Poison

- 1) Analytically and experimentally evaluate burnable poison materials suitable for use in small reactors
- 2) Analytically and experimentally evaluate burnable poison configurations suitable for use in small reactors
- 3) Perform capsule irradiations to evaluate compatibility of selected burnable poisons with typical fuel and cladding materials

Spiders

Perform laboratory tests to define the corrosion and embrittlement resistance of cast and machined spiders of different materials to permit the selection of the optimum spider for any environment

Fabrication

- 1) Perform laboratory tests to evaluate BeO-UO₂ fuel fabrication variables (BeO grade, particle size, particle shape, binder, binder content, pressing pressure, baking temperature, sintering temperature, etc.) on the density, mechanical properties and fabricability of the ceramic
- 2) Perform a literature survey to evaluate the feasibility of the use of a UO₂ cermet in small reactor cores, including neutronic calculations as required

HEAT EXCHANGERS

- 1) Conduct literature searches and laboratory tests to define limits of materials currently in use and applicable to heat exchangers for small nuclear systems
- 2) Review the techniques for joining materials usable in heat exchangers and, where indicated, develop or demonstrate techniques for joining selected materials which appear to offer significant improvements in heat exchanger performance
- 3) Perform laboratory tests of sections of heat exchangers fabricated to demonstrate the applicability of new materials and joining techniques and to evaluate effectiveness and mechanical performance

(Continued)

Table 4-1 - Continued

BRAYTON CYCLE

- 1) Evaluate CCTL data for comparison with and revision of CHOP and analog codes
- 2) Develop the empirical relationships which relate ideal cycle performance to the ML-1 configuration or other compact configurations
- 3) Refine the empirical relationships which make the use of open-cycle t-c set test data possible for prediction of closed-cycle t-c set performance

POWER EXTRACTION EQUIPMENT

T-C Set

- 1) Determine by literature search the current state-of-the-art of materials for turbine blades
- 2) Spin test typical configurations of blades fabricated from materials compatible with ML-1 but superior to present ML-1 materials
- 3) Refine empirical multistage axial turbine design relationships by normalization to experimental data
- 4) Evaluate various turbine concepts to define limits of concepts by analytical and experimental (model tests) techniques
- 5) Refine empirical multistage axial and radial compressor design relationships by normalization to experimental data
- 6) Evaluate various compressor concepts to define limits of concepts by analytical and experimental (model tests) techniques
- 7) Experimentally evaluate the effects of blade surface finish on t-c set performance
- 8) Refine the empirical relations involved in turbine and compressor matching, based on literature search and normalization with experimental data

Seals

- 1) Perform analysis to define performance limits of existing t-c set seals
- 2) Verify the analytical seal performance limits by tests of most promising seal concepts
- 3) Exploit existing seal concepts to develop high performance (low leakage, high reliability) seals

Bearings

- 1) Refine empirical relations involved in bearing/rotor system design by literature search and normalization to experimental data
- 2) Design and experimentally evaluate low pressure differential bearings for closed-cycle t-c sets
- 3) Experimentally evaluate effects of various types of oil, and oil temperatures and pressures on performance of typical existing bearings

(Continued)

Table 4-1 - Continued

Start System

- 1) Perform parametric studies to define performance characteristics of various starting systems applicable to closed-cycle systems
- 2) Perform analysis to define optimum speed and torque characteristics required of starting systems for closed-cycle systems

Alternator

Determine the state-of-the-art limitations of alternator design and performance characteristics, relating output, weight, size, etc.

2. Phase II - The following significant activities are contemplated in this phase of the work.

a) Promising methods for expanding the ML-1 technology will be implemented and the limits will be subsequently redefined. In this activity, investigations will be permitted to deviate from the current ML-1 technology (as defined above) and will be restricted only to consideration of a small, gas-cooled nuclear device incorporating a heterogeneous nuclear reactor as a heat source. The selection of subjects for Phase II work will be strongly influenced by the results of the Phase I activities and thus no attempt has been made to develop a detailed list. However, in the extension of the limits of the ML-1 technology, it appears desirable, for example, to proceed in the direction of higher reactor outlet temperatures inasmuch as the corresponding gains in overall cycle efficiency for power generating applications will render the resultant technology more attractive. This increase in temperature implies increases in reactor fuel element temperature and in pressure vessel/calandria operating temperature. A reactor outlet temperature of 1400°F and a system pressure of 500 psi have been (somewhat arbitrarily) established as being logical first step extensions of existing technology. These goals are reflected throughout the implementation plan visualized for the technology exploitation program.

b) The summary of the description of the AGCRSP technology will be completed and expanded as results of the Phase I and II investigations become available. This summary will be used to identify potential applications to user agencies.

5.0 FUEL ELEMENT TECHNOLOGY

5.1 Hastelloy X Cladding Evaluation

a. Corrosion Resistance Studies: The laboratory exposure of low-cobalt Hastelloy X fuel pin tubing in air at temperatures ranging from 1300 to 1800°F (initiated under the ML-1 air cycle program) continued throughout the quarter. At the end of September this test had accumulated 9540 hours. It is anticipated that the specimens will be examined at the completion of 10,000 hours of testing to determine structural changes, oxide penetration rates, microhardness, and room and elevated temperature tensile properties.

Preparations for a continuous weight change test to evaluate the oxide formation and scaling properties of Hastelloy X in air at 1850°F were initiated. It is anticipated that this test will begin early in the next quarter.

The preparations for the initiation of tests to assess the corrosion resistance of Hastelloy X in air at 1900°F for more than 10,000 hours were virtually complete by the end of September. It is anticipated that the 100-hour and 1000-hour exposures will be completed in the next quarter and the 5000-hour test will be in progress.

b. Mechanical Properties: Preparations were initiated for experiments to determine the creep properties of Hastelloy X in air at 1800°F for 1000 hours and at 1900°F for 5000 hours. Samples of low-cobalt Hastelloy X, solution heat-treated at 2150°F, and commercial-cobalt Hastelloy X heat-treated at 1900°F and 2100°F, will be tested. The creep testing will be performed utilizing a technique developed at AGN under another USAEC contract (Ref. 5). A schematic drawing of the centrifugal creep machine is shown in Figure 5-1 and a typical test specimen is shown in Figure 5-2. The work completed during the current quarter included the modification of the creep test machine to accommodate 60 specimens and the design of the test specimens. At the end of September, requests for quotations for the fabrication of the test specimens had been distributed.

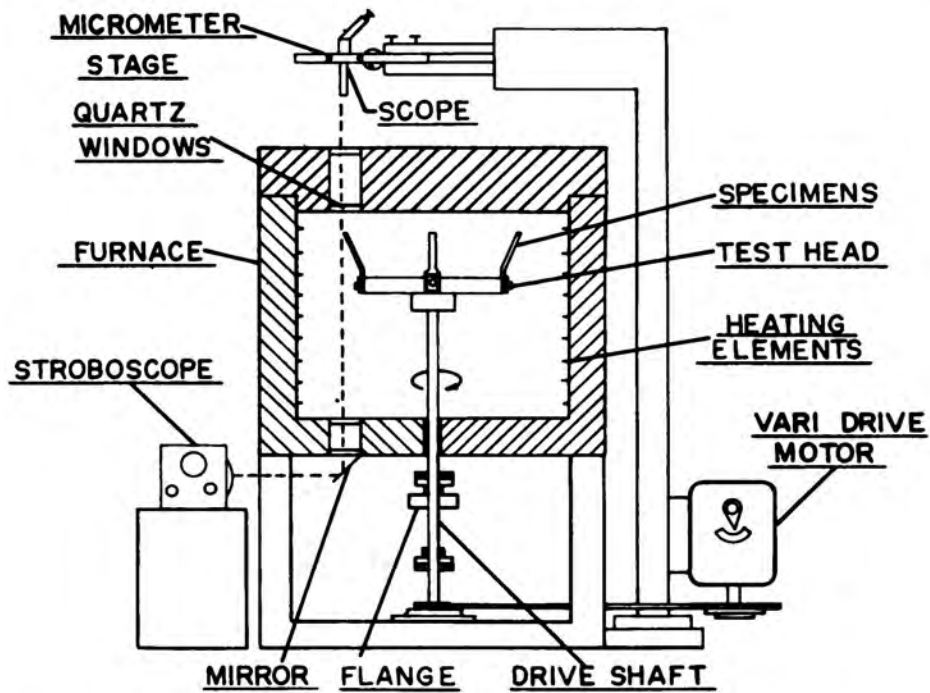


FIGURE 5-1. CENTRIFUGAL CREEP TEST MACHINE

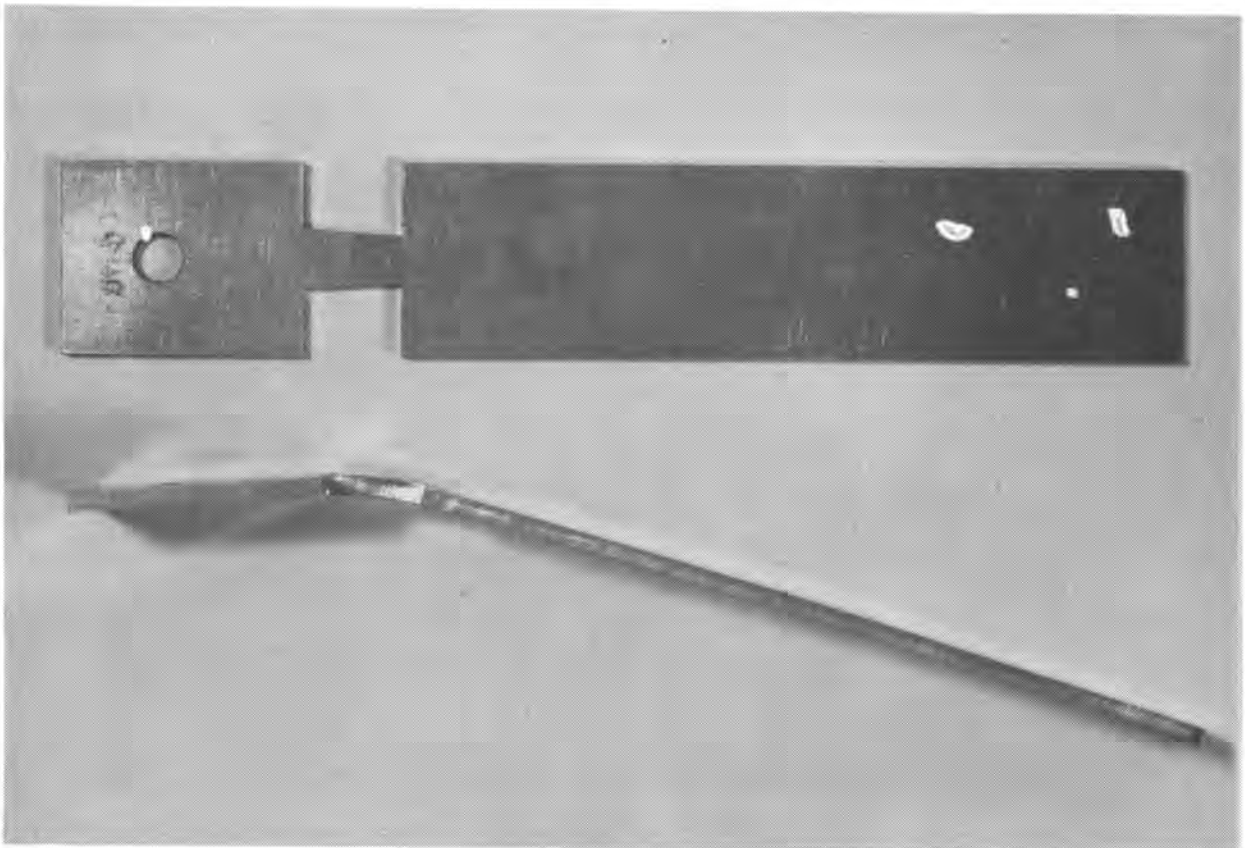


FIGURE 5-2. CREEP TEST SPECIMEN

112-64-2756

IV. ML-1A PROJECT

6.0 ML-1A PRELIMINARY DESIGN

A proposal for the preliminary design of the ML-1A turbine-compressor set was received from Clark Bros. (a similar proposal from Stratos had been received earlier). The ML-1A t-c set preliminary design work will be deferred until after initial evaluation of the CSN-2 and TCS-670-2 machines.

The preliminary safety analysis for the ML-1A nuclear power plant was published (Ref. 6).

Representatives of the ML-1A engineering staff presented the ML-1A preliminary design (Ref. 3) at the AGCRSP In-Process Review in Germantown in mid-September.

V. GCRE FACILITY

7.0 GCRE MODIFICATION

Title II Architect-Engineer services were provided throughout the quarter in support of construction at the GCRE site. During the quarter, one specification change, three design changes and 26 requests for Architect-Engineer Approval were processed. The facility modification is currently scheduled to be complete by 31 December 1964.

GENERAL REFERENCES

1. AGCRSP Quarterly Progress Report, 1 April Through 30 June 1964, IDO-28632, 15 August 1964, Aerojet-General Nucleonics, San Ramon, California
2. AGCRSP Quarterly Progress Report, 1 October Through 31 December 1963, IDO-28621, 15 February 1964, Aerojet-General Nucleonics, San Ramon, California
3. Preliminary Design Report for the ML-1A Nuclear Power Plant (Draft), AGN-TM-408, June 1964, Aerojet-General Nucleonics, San Ramon, California
4. Full Power and Limited Endurance Test of the ML-1 Nuclear Power Plant, IDO-28634, September 1964, Aerojet-General Nucleonics, San Ramon, California
5. Engineering Investigations of a Centrifugal Creep Testing Machine, AGN-8062, February 1963, Aerojet-General Nucleonics, San Ramon, California Contract AT(04-3)-368
6. Preliminary Safety Analysis for the ML-1A Nuclear Power Plant, IDO-28628, August 1964, Aerojet-General Nucleonics, San Ramon, California

AGCRSP REFERENCES*

- a. ML-1 Reactor Aluminum Corrosion Study, AN-AGCR-752, September 1964, transmitted with sr-845
- b. Seven-Tube Mockup Test Program, Summary Report, AN-AGCR-760, September 1964, transmitted with sr-851
- c. ML-1 Operating Limits (Revision), AN-AGCR-735, 16 September 1964, transmitted with sr-855
- d. Preliminary Fuel Element Data Analysis - ANSOP 16650, AN-AGCR-765, 16 September 1964, transmitted with sr-857
- e. Operation of ML-1-I Fuel Elements at 1800°F Cladding Hot Spot Temperature, AN-AGCR-764, 16 September 1964, transmitted with sr-857

*Note: Lower case "L" is not used in this list to eliminate confusion with Arabic 1.

- f. Mechanical Effects of Fuel Element Operation at 1800°F Hot Spot Temperature, 17 September 1964, AN-AGCR-766, transmitted with sr-857
- g. ML-1 Thermodynamic Performance Test, AN-AGCR-726, 7 July 1964, transmitted with sr-808
- h. Operational and Shutdown Shielding Measurements for ANSOP 16650, AN-AGCR-733, 17 July 1964, transmitted with sr-808
- i. Skid Surface Temperature Measurements, AN-AGCR-731, 17 July 1964, transmitted with sr-808
- j. Measurement of Component Displacements, AN-AGCR-732, 20 July 1964, transmitted with sr-808
- k. Clark CSN-2 Turbine-Compressor Set Open Cycle Performance Evaluation Tests, AN-AGCR-755, September 1964, transmitted with sr-839
- m. Effect of CSN-1A Overspeed Operation on Plant Performance, AN-AGCR-751, 21 August 1964, transmitted with sr-829
- n. CSN-1A Performance Improvement Modifications, AN-AGCR-754, 1 September 1964, transmitted with sr-836
- o. Analysis of Performance of Clark CSN-2 Axial Flow Compressor for ML-1, AGN-VA-26, November 1963
- p. Bearing Development Program, AN-AGCR-647, 26 June 1964, transmitted with sr-760
- q. CSN-Type Bearing Development Test Plan, Phase I, AN-AGCR-749, 21 August 1964, transmitted with sr-840
- r. Trip Report - Stewart-Warner, AN-AGCR-753, 26 August 1964, transmitted with sr-832
- s. Improved ML-1 Precooler Air Side Cooling Assembly - Final Design Report, AN-AGCR-745, August 1964, transmitted with sr-820
- t. Improvements Proposal No. 114 - Start Motor, AN-AGCR-748, 21 August 1964, transmitted with sr-819
- u. Improved Overspeed Scram Chassis, AN-AGCR-768, September 1964, transmitted with sr-866
- v. Letter, D. D. Knowles to C. D. Scott, "Fabrication of ML-1-II Core Loading," Contract AT(10-1)-880, 3 September 1964, symbol 7870:4497

APPENDIX A

AGCRSP BACKGROUND INFORMATION

This background of the Army Gas-Cooled Reactor Systems Program includes a short history of the Program, a description of the ML-1 power plant, and a selected bibliography.

A. HISTORY

The purpose of the Army Gas-Cooled Reactor Systems Program (AGCRSP) is to develop a mobile nuclear power plant for military field use. The current primary goal of the Program is the fabrication and test operation of a demonstration model of such a plant.

In 1955, at the request of the USAEC Division of Reactor Development, the Oak Ridge School of Reactor Technology performed a study which established the feasibility of the concept of a mobile, closed-cycle, gas-cooled nuclear power plant. Following this work, the Corps of Engineers Nuclear Power Field Office authorized the Sanderson and Porter Company to evaluate power conversion equipment and to prepare a conceptual design for the projected plant. At the conclusion of the Sanderson and Porter work, responsibility for development of the power conversion equipment for the plant was assigned to the Corps of Engineers and the development of the reactor was assigned to the USAEC.

As a result of the above arrangement, parallel programs were undertaken as follows:

- 1) The Corps of Engineers directed the Stratos Division of Fairchild Engine and Aircraft Corporation to develop a turbine-compressor set suitable for use in the projected plant. The construction of a test facility (GTTF) to evaluate the power conversion equipment was assigned to Aerojet-General Corporation. (The design of the facility was completed by Sanderson-Porter.)
- 2) Under the direction of the USAEC, Aerojet studied the feasibility of several concepts for the reactor to be incorporated in the power plant. The water-moderated concept was selected as the basis for development because of the modest extrapolation of technology required. Aerojet was

awarded the contract for the design and testing of a reactor based on this concept. At the same time, Aerojet was assigned responsibility for the design and construction of a test facility (GCRE) at NRTS.

Aerojet was designated as systems contractor and performance specifications for the demonstration power plant were evolved in June 1959. Fabrication of the reactor skid was completed in April of 1961, fabrication of the power conversion skid was completed in June 1962, and the power plant first operated as a unit (ML-1) in September 1962. Following a modification and checkout, the ML-1 power plant operated successfully for 101 hours in February and March 1963.

B. THE ML-1

The ML-1 is a closed cycle, gas-cooled nuclear power plant developed under the AGCRSP to demonstrate the feasibility of such a plant for military field use. During the design and construction, every reasonable effort was made to incorporate features into the plant which would be directly usable in the design of a field unit. However, since evaluation of the performance of the plant was a major requirement for the ML-1, a significant amount of additional instrumentation was provided. The physical arrangement of the equipment is such that the "prototype" components are easily identified as the:

- 1) Reactor Skid - a 15 ton unit containing the nuclear reactor and associated shielding and controls;
- 2) Power Conversion Skid - a 15 ton unit containing the power conversion equipment; and,
- 3) Control Cab - a 2-1/2 ton unit containing all the instruments and controls for operation of the field plant.

The ML-1 reactor consists of a calandria-type pressure vessel with appropriate inlet and exit gas ducts and plenums. Sixty-one pin-type BeO-UO_2 fuel elements are located in the tubes of the calandria. The demineralized water moderator surrounds the calandria and the six semaphore-type control rods operate in the moderator spaces between the calandria tubes. The entire reactor structure is supported inside a nine-foot diameter tank which contains heavy metal shields to permit relocation of the reactor within 24 hours after shutdown from extended operation, and a drainable (borated water) shield to attenuate radiation during reactor operation.

The plant working fluid (99.5 vol% nitrogen, 0.5 vol% oxygen) enters the reactor at 800°F and approximately 300 psia. The gas is heated to 1200°F in a single pass over the hot surfaces of the fuel elements. The moderator water is maintained at a temperature of 180°F ; energy deposited in the moderator is removed in an water-to-air heat exchanger mounted on top of the power conversion skid. Provision is made for circulation, filtration and demineralization of the moderator water and for circulation and cooling (by exchange with the moderator water) of the shield water.

The hot gas leaving the reactor is expanded in a gas turbine which drives the compressor and alternator. The gas leaving the turbine passes through a regenerative heat exchanger (recuperator), through the system heat sink (air-to-air precooler) and to the compressor suction. The compressor discharges through the recuperator to the reactor inlet, thus completing the closed (modified Brayton) cycle. A lubrication system (including provision for recovery and removal of lubricating oil from the working fluid which leaks past the turbine compressor seals), the electrical switch gear, and miscellaneous power conversion hardware are mounted on the power conversion skid. An a-c, two-speed motor is coupled to the turbine compressor shaft to provide starting power to the set.

The following auxiliary systems are provided for the ML-1:

- 1) A deoxygenation system which removes dissolved oxygen from a bypass stream to maintain the moderator system oxygen content below 0.7 ppm.
- 2) An emergency cooling system which automatically injects a supply of coolant gas into the reactor in the event of a complete stoppage of working fluid flow.
- 3) A working fluid makeup system to compensate for normal leakage and to provide for initial charging of the system.
- 4) Waste gas storage facilities to accommodate the charge of radioactive gas in the loop in the event of an emergency.

C. BACKGROUND BIBLIOGRAPHY

The following bibliography provides information on sources of additional background to the material presented in this report. These documents trace the technical evolution of the AGCRSP from inception but do not, in general, document programmatic decisions. Such activity may be inferred from the technical approaches pursued and from the general background information presented in the reports.

The following reports were published by Aerojet-General Nucleonics, San Ramon, California under the Army Gas-Cooled Reactor Systems Program.

<u>DOCUMENT NO.</u>	<u>TITLE</u>	<u>CLASSIFICATION</u>
IDO-28505	<u>GCRE Semiannual Report, 1 November 1956 Through 30 June 1957, 20 February 1958</u>	CRD
IDO-28506	<u>GCRE-I Hazards Summary Report, December 1958, with three addenda, March 1959, February 1960, May 1960</u>	U
IDO-28519	<u>GCRE Semiannual Progress Report, 1 July Through 31 December 1957, 26 June 1958</u>	CRD
IDO-28526	<u>GCRE Semiannual Progress Report, 1 January Through 30 June 1958, 17 October 1958</u>	CRD

<u>DOCUMENT NO.</u>	<u>TITLE</u>	<u>CLASSIFICATION</u>
IDO-28533	<u>AGCRSP Semiannual Progress Report, 1 July Through 31 December 1958, 28 February 1959</u>	CRD
IDO-28537	<u>Preliminary Hazards Summary Report for the ML-1 Nuclear Power Plant, 22 April 1959</u>	U
IDO-28542	<u>AGCRSP Semiannual Progress Report, 1 January Through 30 June 1958, July 1958</u>	U
IDO-28549	<u>AGCRSP Semiannual Progress Report, 1 July Through 31 December 1959, 22 December 1959</u>	U
IDO-28550	<u>The ML-1 Design Report, 16 May 1960</u>	U
IDO-28555	<u>ML-1 Transportability Studies, 23 March 1960</u>	U
IDO-28558	<u>AGCRSP Semiannual Progress Report, 1 January Through 30 June 1960, 11 July 1960</u>	U
IDO-28560	<u>Final Hazards Summary Report for the ML-1 Nuclear Power Plant, with four supplements, 5 August 1960</u>	U
IDO-28567	<u>AGCRSP Semiannual Progress Report, 1 July Through 31 December 1960, 17 December 1960</u>	U
IDO-28573	<u>AGCRSP Semiannual Progress Report, 1 January Through 30 June 1961, 10 August 1961</u>	U
IDO-28581	<u>AGCRSP Semiannual Progress Report, 1 July Through 31 December 1961, 31 January 1962</u>	U
IDO-28590	<u>AGCRSP Semiannual Progress Report, 1 January Through 30 June 1962, 24 August 1962</u>	U
IDO-28597	<u>AGCRSP, Study of the GCRE Tube Bundle Failure, 14 December 1962</u>	U
IDO-28602	<u>AGCRSP Semiannual Progress Report, 1 July Through 31 December 1962, 22 February 1963</u>	U
IDO-28607	<u>AGCRSP Quarterly Progress Report, 1 January Through 31 March 1963, 15 May 1963</u>	U
IDO-28612	<u>AGCRSP Quarterly Progress Report, 1 April Through 30 June 1963, 15 August 1963</u>	U
IDO-28617	<u>AGCRSP Quarterly Progress Report, 1 July Through 30 September 1963, 15 November 1963</u>	U

<u>DOCUMENT NO.</u>	<u>TITLE</u>	<u>CLASSIFICATION</u>
IDO-28621	<u>AGCRSP Quarterly Progress Report, 1 October</u> <u>Through 31 December 1963, 27 January 1964</u>	U
IDO-28626	<u>AGCRSP Quarterly Progress Report, 1 January</u> <u>Through 31 March 1964, 15 May 1964</u>	U
IDO-28632	<u>AGCRSP Quarterly Progress Report, 1 April</u> <u>Through 30 June 1964, 15 August 1964</u>	U

APPENDIX BML-1 PLANT CHARACTERISTICS

Note: Items marked with a single asterisk (*) indicate changes made since 31 March 1964. Items marked with a double asterisk (**) indicate entries added since 31 March 1964.

1. GENERAL

Design performance at 100°F

Gross electrical output	420 kw*
Net electrical output	350 kw*
Reactor thermal power	2.98 Mw to gas; 3.41* Mw total

Cycle efficiency	$\left(\frac{\text{Thermal output}}{\text{Power to gas}}\right)$	17.2%*
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Plant thermal efficiency	$\left(\frac{\text{Gross elect. pwr}}{\text{Total reactor pwr}}\right)$	13.2%*
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Net plant efficiency	$\left(\frac{\text{Net elect. output}}{\text{Total reactor pwr}}\right)$	10.3%**
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Coolant flow (compressor inlet)	92,500*
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Dose rate at control cab @ 500-ft during full power operation	5 mr/hr (with expedient shielding as needed)
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Dose rate at 25 ft, 24 hr after shutdown (direction of transport vehicle driver with P-C skid in place)	15 mr/hr
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Overall plant dimensions	279 x 113 x 93 in. high
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Overall plant weight and dimensions	Weight	Dimensions (in.)
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Reactor package	30,000 lb	111 x 110 x 93 high (plus ion exchange column on end)
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Power-conversion package	30,000 lb	168 x 113 x 93 high
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Control cab	6500 lb	145 x 82 x 81 high
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Auxiliary equipment	15,000 lb	- - - - -
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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	140,000 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	1.41
Radial	1.27
Maximum fuel center temperature	2160°F (BeO-UO ₂)
(including hot spot factors)	2650°F (UO ₂)
Maximum moderator temperature	190°F
Maximum surface temperature of fuel cladding (nominal, average)	1500°F
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1650°F

3. REACTOR NUCLEAR CHARACTERISTICS

Average thermal neutron flux (fuel)	1.9×10^{12} neut/cm ² -sec
Average fast neutron flux (fuel)	1.7×10^{13} neut/cm ² -sec
Maximum to average thermal flux ratio	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

Without shims	1.54
With shims	1.47
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	1.018
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, $\Delta k/k$ -°C	
at 0°C	$+0.3 \times 10^{-6}$
at 90°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°F (max.)
Wall thicknesses	Tubes 0.020 in.; plenum 2.12 in. min
Source tube	0.020 in. wall thickness; 6.500 in. OD

5. REFLECTOR

Composition, top	2 in. H ₂ O; 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° segment 4 in. Pb; 180° 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 (2 wt% boric acid)*
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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	<u>Volume %</u>
UO ₂	4.3
BeO	3.3
Stainless steel	3.6
Hastelloy X	7.0
H ₂ O	58.6
Insulation	7.0
Gas void	<u>16.2</u>
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 wt% BeO-UO ₂ ; 6 wt% 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	<u>0.004</u> $\Delta k/k$
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 (100°F ambient temp)*	
Net power, kw	350*
Reactor inlet, °F	781*
Turbine inlet, °F	1193*
Compressor inlet, °F	133*
Compressor inlet, psia	116*
Compressor outlet, psia	321*
Reactor inlet, psia	314*

13. TURBINE-COMPRESSOR SET

	<u>Stratos T-C Set</u>	<u>Clark T-C Set</u>
Speed, rpm	18,338	22,000
Turbine stages	2	2
Turbine rotor material	Incoloy 901	A-286 (first stage)* AISI 422 (second stage)*
Turbine blade material	Inco 713	M-252*
Turbine stator blade material	Inconel	N 155 or 19-9 DL
Expansion ratio	2.38	2.42*
Compressor stages	2	11
Compressor material	AL 355 T71	403 stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compressor ratio	2.72	2.765*
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 pressure area)
Support	Overhung turbine	Turbine and compressor supported between bearings

14. ALTERNATOR

Output	
Rating	750* KVA 3 ϕ , 60 cycle
Voltage	2400/4160 V
Rotor shaft speed	1800*
Diameter, maximum	36 in.*
Length	54 in.*
Weight	5000 lb**

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	78.4*
Pressure loss	
High pressure $\Delta P/P$	2.1%*
Low pressure $\Delta P/P$	1.25%*
Type	Shell and tube regenerator
Tubes	4 passes x 840 tubes
Shell	1 pass
Surface	External fins
Materials	300 series stainless steel

16. PRECOOLER, MODERATOR COOLER AND OIL COOLER ASSEMBLY

Dimensions:

Length, overall	166 15/16 in.
Precooler	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

Precooler:

Header, inlet	One, 14 in.
Header, outlet	One, 10 in.
Effectiveness	92.2%*
Total $\Delta P/P$	1.69%*
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
Air flow	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

30 September 1964

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AEROJET-GENERAL NUCLEONICS