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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

Final Test Report
Initial Full Power and Limited Endurance Tests
of the
ML-1 NUCLEAR POWER PLANT
(ANSOP 16625)

July 1963

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AEROJET-GENERAL NUCLEONICS
SAN RAMON, CALIFORNIA

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FINAL TEST REPORT
INITIAL FULL POWER AND LIMITED ENDURANCE TESTS
OF THE
ML-1 NUCLEAR POWER PLANT
(ANSOP 16625)

by
N. Kattchee

Published July 1963

Approved by:

R. H. Chesworth
for R. H. Chesworth
Supervising Representative
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AEROJET-GENERAL NUCLEONICS
A SUBSIDIARY OF AEROJET-GENERAL CORPORATION

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM
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ABSTRACT

The evaluation of the data generated during the full power (ANSOP 16625) and limited endurance tests of the ML-1 mobile nuclear power plant indicates that the reactor performs in accordance with the design specifications. The performance of the power plant as a whole was essentially as observed in earlier testing, although several unresolved anomalies exist in the performance data which require further testing and evaluation.

During the test period from 27 February to 4 March 1963, the reactor attained a maximum power of 3.44 Mw(t) and 247 kw(e) was measured at the output shaft of the turbine-compressor set. No operating limits were exceeded during these tests and all systems performed satisfactorily. Except for the known performance deficiency of the turbine-compressor set, which prevented the attainment of design output power, no operational, stability or control problems were encountered. All test objectives were achieved and the tests were considered completely successful.

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TABLE IV-1
ML-1 SYSTEM PERFORMANCE
CLARK TURBINE-COMPRESSOR SET

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GAS LOOP		ML-1 DESIGN PERFORMANCE (REF 5)					ML-1 PERFORMANCE INITIAL SELF SUSTAINED OPERATION (ANSOP 16615)					ML-1 PERFORMANCE, INITIAL FULL POWER RUN (ANSOP 16625)					ML-1 PERFORMANCE, INITIAL FULL POWER RUN (ANSOP 16625)					ML-1 LIMITED ENDURANCE TEST (100 HOURS)				
		100% NET POWER			PRESSURE DROPS		21 SEPTEMBER 1963			PRESSURE DROPS		0530, 28 FEBRUARY 1963			PRESSURE DROPS		0638, 4 MARCH 1963			PRESSURE DROPS		TYPICAL RUN, 4 MARCH 1963			PRESSURE DROPS	
		°F	PSIA	BTU/LB	EQUIP'T	PIPING	°F	PSIA	BTU/LB	EQUIP'T	PIPING	°F	PSIA	BTU/LB	EQUIP'T	PIPING	°F	PSIA	BTU/LB	EQUIP'T	PIPING	°F	PSIA	BTU/LB	EQUIP'T	PIPING
COMPRESSOR	IN	132.9	116.2	147.2	0.3	0.7	92.0	59.8	137.0	0.7	0.7	103	120.7	139.48	0.2	0.2	64.0	94.05	129.8	0.2	0.2	72	80.4	131.79	0.2	0.2
	OUT	369.7	321.3	206.0			310.0	138.0	190.0			309	280.2	191.23			269.0	240.0	180.77			275	196.0	182.27		
RECUPERATOR HIGH PRESSURE SIDE	IN	369.7	321.0	206.0	6.7	0.7	310.0	137.3	190.0	4.5	0.2 (EST)	309	280	191.23	6.9	0.6 (EST)	269.0	239.8	180.77	5.7	0.6 (EST)	275	195.8	182.27	5.5	0.4 (EST)
	OUT	784.9	314.3	313.0			752.0	133.8	304.0			758	273.1	305.12			748.0	234.1	302.51			720	190.3	295.23		
REACTOR	IN	784.9	314.3	312.2	22.5	0.7	750.0	133.6	303.7	7.3	0.2 (EST)	756	272.5	304.6	15.2	0.6 (EST)	746.0	233.5	301.99	13.7	0.6 (EST)	718	189.9	294.71	13.7	0.4 (EST)
	OUT	1200.0	291.1	423.6			1149.0	126.3	409.0			1192	257.3	421.35			1199.5	219.8	423.4			1134	176.2	405.47		
TURBINE	IN	1193.5	290.4	422.0	0.1	0.1	1144.0	126.1	408.5	0.5	NEGL	1189	256.7	419.98	1.1	0.1	1194.5	219.2	422.04	1.1	0.1	1129	175.8	404.12	1.0	0.1
	OUT	899.2	120.0	341.0			922.0	61.2	350.0			955	125.1	357.13			958.5	100.5	358.07			907	84.0	344.34		
RECUPERATOR LOW PRESSURE SIDE	IN	899.2	119.9	341.0	1.4	0.1	922.0	61.2	350.0	0.5	NEGL	955	125.0	357.13	1.1	0.1	958.5	100.4	358.07	1.1	0.1	907	83.9	344.34	1.0	0.1
	OUT	488.6	118.5	236.2			396.0	60.7	213.0			411	123.9	216.32			382.0	99.3	209.04			374	82.8	207.03		
PRECOOLER	IN	486.3	118.4	236.1	2.0	0.2	395.5	60.7	212.9	0.83	0.07 (EST)	410	123.8	216.07	2.9	0.2	381.0	99.2	208.78	2.95	0.2	373	82.9	206.78	2.3	0.2
	OUT	132.9	116.4	147.2			92.0	59.87	137.0			103	120.9	139.48			64.0	96.25	129.8			72	80.6	131.79		
		ΔP, PSI			32.6	2.1	ΔP, PSI			12.13	1.17	ΔP, PSI			26.1	1.8	ΔP, PSI			23.45	1.8	ΔP, PSI			22.5	1.4
					TOTAL ΔP 34.7					TOTAL ΔP 13.3					TOTAL ΔP 27.9					TOTAL ΔP 25.25					TOTAL ΔP 22.9	
NET POWER (AT THE BUSS)	KW(E)	338.1					48.17					189.0					247.0					130.0				
REACTOR POWER (TO GAS)	MW(T)	2.9620 (NET)					1.4330					3.2077					2.9392					2.2550				
COMPRESSOR FLOW	LB/HR	92,524.0					47,855.6					94,068.0					81,612					69,840				
TURBINE FLOW	LB/HR	90,673.0					47,667.6					93,868.0					81,432					68,364				
CONTROL BYPASS	LB/HR	925.0					0					0					0					0				
COMPRESSOR EFFICIENCY	%	83.9					68.42					79.6					76.5					75.8				
RECUPERATOR EFFECT. (LP/HP) %		78.4/78.4					85.9/73.3					84.4/69.5					82.8/69.4					84.3/69.6				
TURBINE EFFICIENCY	%	86.0					80.0					78.62					82.9					75.7				
PRECOOLER EFFECTIVENESS	%	92.2					93.5					78.8					86.7					88.0				
AMBIENT TEMPERATURE		100°F					90°F					40°F					15.5°F					31°F				

IV-3

"EST" INDICATES CALCULATED VALUES FOR ΔP IN UNINSTRUMENTED PIPING

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FINAL TEST REPORT

INITIAL FULL POWER AND LIMITED ENDURANCE TESTS OF THE
ML-1 NUCLEAR POWER PLANT (ANSOP 16625)

I. INTRODUCTION

The ML-1 mobile nuclear power plant (shown schematically in Figure I-1), developed under the Army Gas-Cooled Reactor Systems Program, consists of a high-temperature gas-cooled, water-moderated reactor coupled to compact power conversion equipment. The closed-cycle, gas-turbine power plant has a design generating capacity from 300 to 500 kw of electrical power. The ML-1 is a demonstration unit; field plants (ML-1A) designed to furnish electrical power at remote military installations will ultimately be based on this design. Additional information concerning the AGCRSP and the ML-1 is presented in Appendix A. The design characteristics of the plant are tabulated in Appendix B.

All components required for an initial, limited evaluation of the performance of the plant were available at the test site at NRTS in late June 1962. Following a detailed checkout of all components, systems and controls, the initial self-sustained operation of the plant was accomplished in September 1962 (ANSOP 16615). During this test, the plant produced 50 kw of power; the maximum reactor power attained was 1.6 Mw. (1)* In the period between the completion of ANSOP 16615 and the initiation of the tests reported herein, several modifications were made to the plant and, following a detailed checkout, ANSOP 16625, the initial full power test, was undertaken. The purpose of this experiment was to demonstrate that the reactor would operate at design levels without exceeding any design limits, and to determine the maximum shaft output power available from the present (known deficient) turbine-compressor set. In view of the very satisfactory performance of the plant, a 100-hour endurance run was added to the test objectives after plant startup had been achieved.

*Numbered references are listed at the end of this report.

FIGURE I-1. SIMPLIFIED FLOW DIAGRAM FOR THE ML-1

A comprehensive report of the conduct of the tests and the preliminary analysis of test data has been published.⁽²⁾ The report presented herein reviews and summarizes the evaluation of the performance of the plant and expands, where appropriate, on the information presented in the earlier report. The evaluation is, unfortunately, somewhat inconclusive in several areas because the principal mission of the ML-1 is to demonstrate the operation of a gas-cooled nuclear power plant and both the design of the plant and the complement of installed instrumentation make fully detailed component and plant performance evaluation impossible.

II. SUMMARY

The ML-1 power plant operated essentially according to predictions during the initial full power test and the limited endurance test. A total of 101 hours of self-sustained operation was accumulated. The maximum reactor power attained was 3.44 Mw and the maximum turbine-compressor shaft output measured by the dynamometer was 247 kw. These maxima did not occur under the same plant operating conditions. The reactor tube sheet heating problem, which was observed during earlier test operation, was apparently eliminated by the fuel element seating modification completed prior to these tests; no other operational problems were apparent during the tests.

A. TEST CHRONOLOGY

Following a detailed pre-operational checkout, the ML-1 plant was brought to self-sustaining conditions. At this point, the reactor power was approximately 1.1 Mw, the mass flow rate was 7.1 lb/sec, the turbine inlet temperature was about 1150°F and the turbine-compressor (t-c) set speed was 11,000 rpm. The t-c unit was accelerated to full speed by alternately increasing the mass flow rate and the reactor power (turbine inlet temperature).

The reactor was brought to full power (actually 3.44 Mw, as compared with the design power of 3.3 Mw) on 28 February at 0530 hours. At this time, the measured t-c set shaft output was 189 kw, the mass flow rate was about 26 lb/sec, and the ambient temperature was 40°F. No design or operating limit was exceeded during this phase of the test and the plant was operated in this condition long enough to achieve approximate thermal equilibrium and to obtain a set of data and gas samples for analysis.

Subsequent to the above run, the reactor power level was reduced to about 2.4 Mw (130 kw shaft output power, mass flow rate approximately 19.5 lb/sec) and the plant was operated at steady state conditions for 97 hours. Several data points were taken during this phase of the test.

On 4 March, with a turbine inlet temperature of 1200°F and a compressor inlet pressure of 94 psia, 247 kw was measured at the dynamometer. The reactor power at this time was 2.9 Mw, the mass flow was 22.7 lb/sec, and the ambient temperature was 15.5°F. Although the t-c set power output was lower than the design value, because of a known mismatch between the turbine and compressor, the value is essentially as predicted by earlier testing.

B. RESULTS

The significant results of the evaluation of the test data are summarized below:

- 1) The system pressure drop at full flow and full power is approximately 19% below the design prediction; the majority of the difference is in the reactor pressure drop.
- 2) The effectiveness of the precooler is significantly lower than the design value, although this deficiency and that discussed in 3) below may both be explained by a faulty precooler inlet temperature instrument.
- 3) A discrepancy exists between the effectiveness of the high pressure side of the recuperator and that of the low pressure side, as calculated from the ANSOP 16625 data, although the general performance of the unit seems satisfactory. This discrepancy also may be due to error in the precooler inlet temperature readings.
- 4) The compressor operated at lower efficiency and pressure ratio than specified and the turbine at a lower than specified expansion ratio as a result of the predicted excess turbine flow area. This mismatch was aggravated by the lower-than-design system pressure drop.
- 5) The tube sheet temperature did not approach the operating limit and remained well below values observed in earlier testing. Although the predicted effect on reactor pressure drop and fuel element temperatures was not observed, it seems clear that the fuel element seating modification reduced the fuel element bypass flow and the associated tube sheet temperature.
- 6) The analysis of neutron flux noise traces indicates that no instability exists in the ML-1 reactor.
- 7) Both the operational and shutdown shielding perform essentially as predicted.
- 8) The use of the compressor map to establish system flow rates was confirmed as an acceptable method for flow rates near the design point.

III. SIGNIFICANT PLANT MODIFICATIONS

During the period between the initial self-sustained operation of the power plant (ANSOP 16615) and the tests reported herein, the following significant changes were made in the ML-1 plant equipment:

- 1) The fuel element seating concept was modified to eliminate bypass flow.
- 2) Equipment was installed to record and analyze the reactor neutron flux traces to evaluate the stability characteristics of the reactor.
- 3) A dynamometer was installed to absorb and measure plant power output.

These changes are discussed in detail below:

A. FUEL ELEMENT SEATING MODIFICATION

Evaluation of the results of the initial self-sustained operation indicated that the fuel elements were not properly seated in the top tube sheet, thus permitting excessive flow of reactor coolant in the annulus between the fuel element outside diameter and the pressure tube inside diameter. This condition resulted in high tube sheet temperatures, lower than anticipated reactor pressure drop, and higher than predicted fuel element temperatures. The analysis indicated that the observed conditions could be accounted for by a 6 to 8% bypass flow.

A program was initiated to determine the cause of the bypass flow and to develop a corrective modification to eliminate the problem. It was determined that bypass flow resulted from two conditions:

- 1) Improper initial seating of the fuel elements resulting from non-perpendicularity between the lip and the centerline of the reactivity shims and non-perpendicularity between the fuel element seating surface and the axis of the fuel element.
- 2) "Lift-off" of seated fuel elements during operation as a result of differential thermal expansion between the fuel element outer liner and

the cooler pressure tube when the frictional forces between the fuel element, the reactivity shim and the pressure tube exceed the weight of the fuel element plus the force exerted by the downward flowing coolant.

The corrective modifications (Figures III-1 and III-2) involved the installation of unpressurized metal "O" rings at the fuel element seating surface (to accommodate non-perpendicularity and surface imperfections with a minimum of heat transfer from the hot fuel element to the tube sheet) and a suitable spring assembly to prevent lift-off of a seated element by thermal ratcheting during operation.^(3,4) The spring is designed to exert a force in excess of 50 lb on the top of the fuel element during reactor operation.

B. REACTOR STABILITY ANALYSIS EQUIPMENT

Inasmuch as a nuclear reactor had never before operated in a closed, gas-cooled, power-producing loop at the temperatures predicted for the ML-1, it was decided to make provisions for monitoring reactor power to detect incipient instability, if such existed, during the initial ascension to full power. A device marketed by Milletron, Inc. was selected and installed for this purpose. The equipment records the output of a precision neutron detector on magnetic tape and automatically plays back the tape through band pass filters to produce a plot of the reactor power density spectrum in the form of a Bode plot (system gain and phase shift versus frequency). This diagram can be analyzed immediately to detect peaks in the spectrum and the amplitude of such peaks can be monitored at successively higher reactor power levels to determine if an incipient instability exists.

C. DYNAMOMETER

During the performance of the initial self-sustained operation of the ML-1, a non-prototype, three-speed start motor was used to apply a 50 kw load to the turbine-compressor set. This unit does not have sufficient capacity to absorb power output in the range anticipated for the full power test. Prior to ANSOP 16625, a 500 hp General Electric water-cooled induction dynamometer was installed and connected to the t-c set output shaft. In addition to absorbing and measuring the plant power output, this unit could be used to control t-c set speed by activation of the provided automatic speed control system (variable control of excitation current).

Calculations indicated that the dynamometer-start motor assembly had natural torsional frequencies at about 1040 and 3690 cpm, within the normal operating speed range of the unit. A Torsiograph was attached to the outboard end of the dynamometer shaft to monitor vibration in this unit and provision was made to read out the Torsiograph output (as well as that of the vibration instruments on the t-c set) on an eight channel recorder, oscilloscope or panoramic analyzer.

FIGURE III-1. ML-1 FUEL ELEMENT HOLD-DOWN MECHANISM

FIGURE III-2. ENLARGED VIEW OF HOLD-DOWN MECHANISM

IV. CONDUCT OF EXPERIMENT

A. PREPARATION

The significant preparations made for these tests included the following:

- 1) The temperature probes in the system were replaced with new, calibrated ceramic type thermocouple probes. In sensitive locations, additional probes were installed to provide duplicate temperature data.
- 2) Essentially all temperature, pressure, etc., sensors, transmitters and recorders were recalibrated prior to the initiation of ANSOP 16625.
- 3) The dynamometer instrument and control systems were calibrated in a 75-hour endurance run of the dynamometer-start motor system. The vibration instrumentation was calibrated and checked out.
- 4) Operation of the turbine-compressor set and closely associated subsystems was demonstrated by cold rotation prior to the initiation of ANSOP 16625.
- 5) The gas analysis equipment and the main loop and precooler fission product monitoring systems were checked out and calibrated.
- 6) The reactor stability analysis equipment was calibrated and base line noise spectra were recorded with the reactor operating at zero power and with various support systems in the operating and shutdown conditions.
- 7) The moderator, shield water, deoxygenation, make-up gas, emergency power and radiation monitoring systems were all checked out prior to the start of the test.
- 8) A reference position grid was laid out on the test building floor to permit reproducible determinations of radiation levels and recalibration of the portable gamma and fast neutron survey instruments against standard sources was completed.

B. CONDUCT OF EXPERIMENT

The power plant was started up on 26 February 1963 in accordance with the procedure specified in ANSOP 16625 (see Appendix C). In summary, the start-up was accomplished as follows:

- 1) The reactor was started up and brought to a power level of approximately 100 watts.
- 2) The start motor was energized and the t-c set was accelerated to 25% of rated speed.
- 3) The compressor inlet pressure was increased to compensate for the anticipated decrease during acceleration and the t-c set was accelerated to 50% rated speed with the start motor.
- 4) The reactor power and the coolant mass flow were alternately increased until the reactor outlet temperature reached 1150°F, at which point the t-c set was self-sustaining (reactor power at this point was 1.1 Mw and the system mass flow was 7.1 lb/sec.)
- 5) The start motor was turned off and the system mass flow and reactor power were increased until significant power was being absorbed by the dynamometer at a speed slightly in excess of the self-sustaining condition. The t-c set speed was controlled by the automatic speed control system (excitation control) of the dynamometer.
- 6) The system mass flow and the reactor power were increased alternately until the t-c set reached design speed of 22,000 rpm and the reactor reached design power. At this point, the reactor was operating at 3.44 Mw (3.2 Mw to gas), the mass flow rate was 26.1 lb/sec and the output to the dynamometer was 189 kw. The turbine inlet temperature was about 1190°F and the compressor inlet pressure was 120 psia. The speed of the t-c set was controlled throughout this sequence by the dynamometer automatic speed control system.
- 7) The reactor power was reduced to 2.4 Mw (130 kw shaft output at 80 psia compressor inlet pressure and 19.5 lb/sec mass flow) and operated at this level for approximately 97 hours.
- 8) On 4 March 1963, at an ambient temperature of ~15°F (25°F lower than the 28 February test), the reactor power was increased until the limit of 1200°F at the reactor outlet was reached. Under these conditions, the measured power output was 247 kw. The reactor was operating at 2.9 Mw (to gas), the mass flow was 22.7 lb/sec, and the compressor inlet pressure was 94 psia.
- 9) Following Step 8, the power plant was shut down in accordance with the procedure specified in ANSOP 16625 (Appendix C).

At appropriate times during the experiment, the power plant was allowed to stabilize and a complete set of operating and radiation level data was recorded. The operating condition of the plant at the time full reactor power and maximum shaft output power were recorded is shown in Table IV-1, along with typical conditions during the endurance run.

V. EVALUATION OF TEST RESULTS

A. POWER PLANT PERFORMANCE

1. Plant Energy Balance

The overall power plant energy balances for the maximum reactor power condition, the maximum shaft output power condition, and a typical condition during the limited endurance run are tabulated in Table V-1. This table also compares the results obtained during the ANSOP 16625 tests with those obtained during earlier testing (ANSOP 16615) and with the design plant energy balance.

The large amount of energy indicated as "unaccounted" in Table V-1 forces the conclusion that actual plant operating conditions must have been significantly different from those indicated by the instrumentation. This is especially true of the indicated value for precooler energy rejection; the experimental values indicate that approximately 60% of the total reactor power was rejected to atmosphere by the precooler, while cycle analysis and precooler design analysis require that about 70% of the energy be rejected at the precooler. Such a discrepancy can be the result of faulty precooler temperature instrumentation and can account for a large portion of the "unaccounted" value.

The experimentally determined moderator and shield water heating loads are presented in Table V-2. The experimental values for the lubricating system heating are less than half of those predicted by design calculations (see Table V-3).

It is not conceivable that the ML-1 power plant could achieve self-sustaining conditions with a discrepancy in the energy balance as large as that indicated in Table V-1. The fact that the "unaccounted" energy increases with increasing mass flow rate (see Tables IV-1 and V-1) while the temperature differences across the recuperator remain relatively unchanged permits the conclusion that the temperature measured at the inlet to the precooler must include a significant error. Calculations show that if this temperature is 50°F higher than indicated, the "unaccounted" energy can be virtually eliminated. In addition, such assumption would result in calculated precooler heating rejection loads which are close to the design value and an associated increase in the precooler effectiveness. At the same time, the energy transfer

TABLE V-1 - ML-1 ENERGY BALANCE

IN KILOWATTS

	ANSOP 16625 <u>2/28/63</u>	ANSOP 16625 <u>3/4/63</u>	Limited Endurance Run, Typical <u>3/4/63</u>	ANSOP 16615 <u>Ref. (2)</u>	Design (338 kw(e)) <u>Ref. (5)</u>
Total Reactor Output	3,443	3,230	2,349	1,762	3,455
1. Shield & Moderator Water Heating	239	294	226	365	451
2. Piping Heat Losses	67	69	52	57	68
3. Precooler Rejection	2,039	1,812	1,441	1,065	2,409
4. Lubrication System Heating	29	41	39	24	91
5. Electrical Losses	--	--	--	8	28
6. Auxiliary Load	--	--	--	--	70
7. Useful Output	189	247	130	40	338
8. Unaccounted	870	767	461	203	0

IN PERCENT

Total Reactor Output	100	100	100	100	100
1. Shield & Moderator Water Heating	6.9	9.1	9.6	20.7	13.1
2. Piping Heat Losses	2.0	2.1	2.2	3.2	1.9
3. Precooler Rejection	59.4	56.1	61.4	60.5	69.8
4. Lubrication System Heating	0.9	1.3	1.7	1.4	2.6
5. Electrical Losses	--	--	--	0.5	0.8
6. Auxiliary Load	--	--	--	--	2.0
7. Useful Output	5.5	7.6	5.5	2.2	9.8
8. Unaccounted	25.3	23.8	19.6	11.5	0

V-2

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TABLE V-2 - SHIELD AND MODERATOR ENERGY TRANSFER (IN KILOWATTS)

	ANSOP 16625 <u>2/28/63</u>	ANSOP 16625 <u>3/4/63</u>	Limited Endurance Run, Typical <u>3/4/63</u>	ANSOP 16615	Design (338 kw(e))
<u>Energy Input:</u>					
1. Inlet Duct & Plenum to Shield Water	*	*	*	*	10.5
2. Outlet Duct & Plenum to Shield Water	*	*	*	*	22.8
3. Fuel Elements & Tube Sheets to Moderator H ₂ O	*	*	*	*	79.1
4. Nuclear Heating of Moderator & Shield Water	*	*	*	*	342.6
5. Circulating Pumps & Water Heaters	38.6 ⁺	38.6 ⁺	38.6 ⁺	38.6 ⁺	---
Total Input**	278.0 _{±95.0}	332.9 _{±116.0}	261.4 _{±105.0}	368.1 _{±70.0}	455.0
<u>Energy Output:</u>					
1. Shield Tank to Ambient	3.7	3.7	3.6	3.5	3.7
2. Cooler to Ambient	235.7 _{±95.0}	290.6 _{±116.0}	222.8 _{±105.0}	326.0 _{±70.0}	451.3
Chargeable to Plant Energy Balance ⁺	239.4**	294.3**	226.4**	329.5**	455.0

* Not measured

+ Best estimate

** Based on measured energy rejection from moderator cooler to ambient assuming a "standard" thermocouple error of $\pm 2^{\circ}\text{F}$

TABLE V-3 - LUBRICATION SYSTEM LOSSES (IN KILOWATTS)

	ANSOP 16625 <u>2/28/63</u>	ANSOP 16625 <u>3/4/63</u>	Limited Endurance Run, Typical <u>3/4/63</u>	ANSOP 16615	Design (338 kw(e))
<u>Energy Input:</u>					
1. Turbine Bearings	3.90	3.76	3.12	2.65	} 10.0
2. Compressor Bearings	0.20	0.78	0.70	0.74	
3. Turbine Cooling Jacket	9.32	8.01	6.52	5.65	17.8
4. Thrust Bearing	8.03	16.07	15.94	10.28	26.0
5. Gear Box	3.50	6.88	6.79	4.22	26.0
6. Alternator Bearings (Start Motor and Dynamometer)	6.82	8.45	7.47	0.84*	2.0*
7. Oil Seal and Leakage	**	**	**	**	6.9
8. Pump Power	1.14	0.80	0.59	5.58	1.9
Total Input:	32.88	44.75	41.13	29.95	90.6
<u>Energy Output:</u>					
1. Sump and Piping to Ambient	1.8	1.8	1.7	1.5	1.8
2. Cooler Rejection Load	23.49	35.67	35.84	18.32 ⁺⁺	92.4
Chargeable to Plant Energy Balance	29.08	41.11	39.33	24.88	91.5
$\left(\frac{\text{Input} + \text{Output}}{2} \right)$					

* Does not include the dynamometer bearing losses (6.16 kw)

** Unknown

⁺⁺ Measured at the cooler

across the recuperator would approach a balanced condition and the calculated effectiveness of the two passes would be essentially equal.

The performance of the ML-1 power plant during ANSOP 16625 is inconsistent with the energy balance developed from the experimental data. An analysis of the energy balance indicates clearly that the precooler temperature instrumentation must be improved if meaningful results are to be obtained from further experiments.

2. System Pressure Drop

The performance of the ML-1 power plant is particularly sensitive to system pressure drop. As a consequence, special attention has been devoted throughout the test series to the determination of pressures at various points in the system. The instrumentation provided for this purpose is listed in Table V-4. The experimental pressure drops observed during ANSOP 16625 are compared with the ANSOP 16615 results and the design values in Table IV-1. As indicated in this table, the experimentally determined system pressure drop at full power and rated system flow rate is 19% lower than predicted by design calculations.

The two major contributors to the system pressure drop are the reactor and the high pressure pass of the recuperator (see Table IV-1). The configuration of the reactor has been altered significantly during the test series (bypass flow modification, etc.) so that direct comparisons of the indicated reactor pressure drop are not possible. On the other hand, the recuperator and associated pressure instrumentation have remained unchanged throughout closed cycle power conversion skid testing at Azusa and in the experimental operation at NRTS. As shown in Figure V-1, the Azusa and NRTS test data correlate quite well to a straight line which passes through the calculated design point and exhibits the anticipated 1.8 slope, characteristic of turbulent flow in pipes. It can be concluded that the lower-than-design system pressure drop is associated to a large degree with the reactor. This subject is discussed in Section V-B-3.

B. REACTOR PERFORMANCE

1. Tube Sheet Temperatures

During ANSOP 16615, unacceptably high temperatures (up to 550°F) were observed in the upper tube sheet of the reactor. This condition was subsequently attributed to the energy deposition in the tube sheet from 800°F coolant which was bypassing the fuel elements in the annulus between the fuel element outer liner and the pressure tube. Prior to ANSOP 16625, modifications were made (as discussed in Section III-A and shown in Figure III-2) to minimize the bypass flow.

The analysis of ANSOP 16615 data, adjusted to include the anticipated effect of the bypass flow modification, indicated that the following significant changes should be observed as a result of the modification:

TABLE V-4 - ML-1 PRIMARY GAS COOLANT SYSTEM PRESSURE INSTRUMENTATION

Instrument Identification No.	Readout Range			Installation Point (2)
	psia	mv	Scale Division	
<u>Control Cab</u>				
PI-101-A	0-450	--	10	1
PI-101-B	0-450	--	10	2
PI-101-A-1	0-300	--	6	1
<u>Analysis Racks</u>				
PXR-103-1	0-300	30	0.5; 0.05 ⁽³⁾	7
PXR-103-2	0-300	30	0.5; 0.05	8
PXR-103-6	0-300	30	0.5; 0.05	1
PdX-106	0-5	45	- ; 0.05	11 - 12
PdX-107	0-50	40	- ; 0.05	5 - 6
PdX-108	0-10	20	- ; 0.05	9 - 10
PdX-109	0-25	45	- ; 0.05	3 - 4
<u>Gauge Board</u>				
PI-120	0-150	--	1	1
PI-121	0-350	--	5	2
PI-123	0-350	--	5	4
PI-124	0-350	--	5	6
PI-125	0-150	--	1	8
PdI-130	0-200	--	0.5	1 - 2
PdI-131	0-50	--	0.5	3 - 4
PdI-132	0-50	--	0.5	5 - 6
PdI-133	0-10	--	0.1	11 - 12
PdI-135	0-50	--	0.5	3 - 6
PdI-136	0-10	--	0.1	9 - 12

(1) P = pressure; I = indicator (gauge); X = non-prototype; R = recorder;
d = differential pressure instrument.

(2) Refers to state points shown in Figure I-1.

(3) Values indicate minimum mv sensitivity of the recorder and potentiometer, respectively.

FIGURE V-1. PRESSURE DROP THROUGH ML-1 RECUPERATOR
HIGH PRESSURE SIDE

- 1) The indicated upper tube sheet temperature should be reduced by approximately 40°F.
- 2) The average temperature of the nine instrumented fuel elements should be decreased by approximately 25°F at a given turbine inlet temperature and mass flow rate.
- 3) The pressure drop in the reactor core should be increased by about 15%.

The anticipated reduction in tube sheet temperature was realized after the bypass flow modification. In fact, the reduction was significantly larger than predicted (see Table V-5); a reduction in excess of 100°F was observed at comparable system conditions. The anticipated changes in fuel element temperatures and reactor pressure drop were not observed; these points are discussed in the following sections.

TABLE V-5 - SAMPLE TUBE SHEET TEMPERATURE DATA

	<u>Upper Tube Sheet Temperature, °F</u>	<u>Reactor Flow Rate, lb/sec</u>	<u>Reactor Inlet Temperature, °F</u>	<u>Reactor Power, Mw(t)</u>
ANSOP 16625 28 Feb. 1963 @ 0530 Hr	443	26.1	758	3.444
ANSOP 16625 4 March 1963 @ 0638 Hr	427	22.7	748	3.230
Limited Endur. Run 3 March 1963 @ 2230 Hr	400	18.55	715	2.405
ANSOP 16625 28 Feb. 1963 @ 0054 Hr	377	13.86	701	1.539
ANSOP 16615 21 Sept. 1962 @ 1509 Hr	512	12.85	701	1.538

2. Fuel Element Temperatures

As indicated earlier, it was anticipated that the average temperature of the 9 instrumented fuel elements in the ML-1-I core would be decreased by approximately 25°F (at a given turbine inlet temperature and mass flow rate) by the modification to eliminate bypass flow. The instrumented elements were installed in the core positions shown in Figure V-2.

Predictions were made of the anticipated temperature of each of the 9 instrumented fuel elements during ANSOP 16625. These predictions were based on the data accumulated during ANSOP 16615 and appropriate

FIGURE V-2. LOCATION OF INSTRUMENTED FUEL ELEMENTS IN ML-1 CORE

corrections were applied to compensate for the anticipated elimination of bypass flow and the flow redistribution in the core resulting from the installation of holddown spring guides in the upper plenum. The predicted temperatures and the actual temperatures observed during full power operation are shown in Table V-6. As indicated in this table, the predicted temperature decrease is not apparent although experimental inaccuracies and the significant scatter of the data may be sufficient to mask the effect. The same conclusion can be drawn from the data shown in Figure V-3 where the difference between the reactor outlet temperature and the turbine inlet temperature is plotted against mass flow rate.

**TABLE V-6 - COMPARISON OF PREDICTED AND INDICATED
FUEL ELEMENT TEMPERATURES***

Position	Indicated Temp., °F	Predicted Temp., °F	Indicated Temp., °F		
	ANSOP 16615		ANSOP 16625		
	21 September 1962		28 February 1963		
	1623 Hr	ANSOP 16625**	0418 Hr	0440 Hr	0530 Hr
5E	1372	1364	1360	1364	1362
5F	1354	1342	1355	1357	1360
3C	1285	1266	1293	1286	1246
3E	1290	1272	1282	1278	1284
5B	1248	1214	1223	1217	1222
8E	1290	1253	1266	1266	1273
2H	1244	1211	1270	1270	1276
1E	1136	1133	1131	1198	1133
7G	1176	1097	1193	1188	1192
Average	1263	1238	1263	1271	1263

*Normalized to 791°F reactor inlet temperature

**Including correction for elimination of 8% bypass flow and flow redistribution in upper plenum.

3. Reactor Pressure Drop

The analysis of data generated during ANSOP 16615 indicated that the reactor package pressure drop was approximately 20% less than predicted by computation based on flow tests of prototype fuel elements, experiments conducted with quarter-scale mock-ups of the plenum and baffles, and theoretical analyses. It was anticipated that the pressure drop would be higher during ANSOP 16625 as a result of the bypass flow modification. This modification was expected to increase the core pressure drop by about 15% as the result of the elimination of bypass flow and by an additional 5 to 10% as a result of the installation of the holddown springs and guides in the upper plenum.

FIGURE V-3. TEMPERATURE DIFFERENCE BETWEEN REACTOR OUTLET AND TURBINE INLET

The density-corrected reactor pressure drop based on data generated during ANSOP 16615 and ANSOP 16625 is plotted in Figure V-4. As indicated in this figure, the core pressure drop did not increase as expected in ANSOP 16625. The data scatter in the low-flow region is attributed to the characteristics of the pressure sensing instrumentation. No explanation is available at this time for the difference between the predicted and observed core pressure drop performance, other than that the judgement factors used in the prediction were overly conservative.

4. Reactor Stability

The reactor noise spectrum from 0.01 to 640 cps was recorded and plotted by the Milletron equipment prior to the initiation of ANSOP 16625 and at each stable power level during the conduct of the experiment. The examination of the Bode diagrams generated by the Milletron results in the conclusion that the ML-1 reactor is stable throughout design operating range and, with a high degree of probability, at power levels far in excess of the design value. No significant resonances of an unexplainable nature were observed.

The data obtained by the Milletron equipment were submitted for analysis to Dr. J. Thie (consultant to Milletron, Inc. and control systems specialist). The conclusions of Dr. Thie's analysis are summarized below:

- 1) No indication of any unstable tendencies were found in the spectra of the reactor operating at various powers up to 2.5 Mw. The absence of any indication of instability threshold at 2.5 Mw indicates that stable operation can be expected at power levels considerably higher than this value.
- 2) The noise observed apparently originated from two sources:
 - a) Low frequency noise from the moderator system which varied with reactor power.
 - b) High frequency noise resulting from the random rate of arrival of neutrons at the detection chambers, which was frequency independent and directly proportional to reactor power.
- 3) Small peaks observed in the spectra at 0.25 and 9.6 cps were independent of reactor power and do not represent instability.

Further information on this experiment has been reported by D. L. Crimmins, et al. ⁽⁶⁾

5. Reactivity

A slight increase in core reactivity occurred between the performance of ANSOP 16615 and ANSOP 16625. This increase was attributed to the slightly higher location of the fuel elements in the core as a result of the installation of "O" ring seals. The reactivity increase was estimated to be approximately 0.002 $\Delta K/K$. This change did not effect reactor performance during ANSOP 16625.

FIGURE V-4. ML-1 REACTOR PRESSURE DROP CORRELATION

C. POWER CONVERSION EQUIPMENT PERFORMANCE

1. Turbine-Compressor Set Performance

The compressor operating map for the Clark CSN-1 compressor, generated during closed-cycle skid testing at Azusa, is shown in Figure V-5. The design point, the ANSOP 16615 operating point, and representative data from ANSOP 16625 are shown on the map. The ANSOP 16625 data correlates fairly well with the ANSOP 16615 point about the 7% $\Delta P/P$ (high pressure side) pressure drop line. The point which falls to the right of this line was obtained at low compressor inlet pressure (80 psia) and turbine inlet temperature (1129°F). The compressor flow functions observed during ANSOP 16625 were, as shown in the figure, in good agreement with the design value although the compressor pressure ratios were significantly lower than design. The compressor efficiencies calculated from the ANSOP 16625 data as well as the non-dimensional speed characteristic ($N/\sqrt{T_7}$) do not agree with the values obtained for the observed flow function during Azusa testing. It is anticipated that the modification of the CSN-1 turbine to reduce the effective flow area will increase the compressor pressure ratio along a constant speed line to a point close to the design point indicated in Figure V-5. The explanation of the anomaly in efficiency and speed line data will require further testing and analysis.

The turbine operating line developed during Azusa testing is shown in Figure V-6 which also presents the operating point as established during ANSOP 16615 and the data developed during ANSOP 16625. The latter data confirm the earlier conclusions that the flow area in the turbine is significantly larger than the design value with the result that the flow function is higher and the expansion ratio is lower than design. The anticipated modification of the CSN-1 turbine should improve this situation significantly.

During the conduct of ANSOP 16625, it was noted that the lubricating oil flow rate to the turbine and compressor journal bearings increased significantly above that observed in earlier operation. Analysis of samples of the lubricating oil revealed significant quantities of tin, indicating abnormally high wear rates in the bearings. It was decided to partially disassemble the turbine compressor set to inspect the bearings at the conclusion of ANSOP 16625.

2. Precooler Performance

Analyses of the data generated during ANSOP 16625 indicate that the precooler effectiveness is approximately 84% at the design nitrogen flow rate of 26 lb/sec. This value is approximately 8% lower than the design value and is consistent with the values obtained during Azusa testing (Figure V-7).

Two conditions existed during ANSOP 16625 testing which affect the accuracy of the effectiveness value quoted above:

- 1) The power plant was operated inside the ML-1 Test Building and, although the large doors in the ends of the building were opened, it was clear that a significant amount of hot air from the precooler exhaust was being recirculated and picked up by the precooler fans.

FIGURE V-5. CSN-1 COMPRESSOR CHARACTERISTICS (NITROGEN)

FIGURE V-6. CLARK CSN-1 TURBINE EXPANSION RATIO VERSUS TURBINE FLOW FUNCTION

FIGURE V-7. ML-1 PRECOOLER EFFECTIVENESS

2) The indicated temperature of the nitrogen at the inlet to the pre-cooler was probably in error by as much as 40 to 60°F. Such an error could result from stratification of the gas in the inlet duct. A reasonable probability can be assigned to the existence of this error since plant energy balance calculations, as well as pre-cooler and recuperator effectiveness calculations, all support the conclusion that such an error must have existed.

3. Recuperator Performance

The recuperator effectiveness as calculated from the ANSOP 16625 data is approximately 84% for the low pressure side and 69% for the high pressure side (see Table IV-1). These values are at variance with the design value of 79% and the Azusa test value of approximately 78%. In addition, the difference between the effectiveness of the high and low pressure sides is a thermodynamic improbability; these two values should be identical within the random experimental error. Several possible explanations exist for these anomalies:

1) Leakage could be occurring between the high and low pressure passes in the recuperator or within the turbine-compressor set. A leakage flow of approximately 10% would be required in the recuperator or 20% in the t-c set to account for the observed difference in effectiveness values. Such leakage would have a drastic effect on system performance (it is doubtful that self-sustained operation of the plant could be achieved under these conditions) and, in the absence of any such observation, it is concluded that the anomaly cannot be ascribed to recuperator or t-c set internal leakage.

2) A large error in the computed value of the turbine outlet temperature (approximately 100°F) would be sufficient to equalize the effectiveness of the high and low pressure sides of the recuperator. However, the resulting effectiveness would be nearly 82% (3% above the design value). Such an assumption would also require impossible turbine behavior (efficiency greater than 100%).

3) If the temperature of the gas at the discharge of the low pressure side of the recuperator (pre-cooler inlet) was approximately 50°F higher than indicated, the effectiveness of the pre-cooler would be raised to near the design value; the difference between the effectiveness of the high and low pressure passes in the recuperator would be reduced to within experimental accuracy; and the large unaccounted energy portion in the plant energy balance would be essentially eliminated. It is considered possible that such a temperature error could exist as the result of flow stratification at the point of temperature measurement. Modified temperature instrumentation and additional testing will be required to establish the validity of such an assumption.

4. Vibration

A comprehensive vibration analysis was performed prior to ANSOP 16625 to evaluate potential vibration problems associated with full power operation of the plant and the recent installation of the dynamometer/start

motor assembly. This analysis indicated that the only potential problem area was associated with the dynamometer/start motor; critical speeds in the operating range of this assembly could result in high torsional vibration at about 1040 and 3690 cpm. On the basis of the analysis, the following torsional vibration limits were established:

- 1) During acceleration with no external load:
 - a) 0.9 degrees peak-to-peak amplitude for the first mode ($\sim$ 1040 cpm).
 - b) 0.075 degrees peak-to-peak for the second mode ($\sim$ 3690 cpm).
- 2) For the full speed condition with external load:
 - a) 0.36 degrees for the first mode.
 - b) 0.04 degrees for the second mode.

Linear vibration limits were established in accordance with the manufacturer's recommendations for the CSN-1 t-c set and dynamometer at 0.0005 and 0.002 in. respectively. Linear vibration limits for the start motor were specified at 0.003 to 0.005 in. depending on the frequency of vibration.

During the cold rotation tests preceding ANSOP 16625, the calculated natural torsional frequencies were observed. It was noted that torsional vibrations were induced in the rotating system whenever a sudden torsional impact (such as that associated with a change in start motor speed) was imposed on the system. Such impulses excited both natural modes but the vibrations were quickly damped out.

During ANSOP 16625, the first mode was slightly excited (about 0.03 degrees peak-to-peak) at 25% speed. There was no evidence of increasing amplitude with time. The first critical speed was passed through without difficulty as the unit was accelerated from 25 to 50% speed. The peak vibration occurred at about 1080 rpm; the maximum peak-to-peak amplitude was about 0.04 degrees. The trace developed by the Torsiograph during this period is shown in Figure V-8a. No other significant torsional vibrations were observed up to full speed with 100 kw load on the plant. Figure V-8b shows a typical Torsiograph trace at 100% speed with a plant output power less than 100 kw. The trace consists of a complex presentation of both the first and second modes with the second mode predominant. The peak-to-peak amplitude is approximately 0.02 degrees.

As plant power output was increased above 100 kw, both modes were identifiable in the Torsiograph trace. Figure V-8c is typical of the trace at approximately 250 kw plant output power. The peak-to-peak amplitude for the first mode is approximately 0.08 degrees and for the second mode is approximately 0.02 degrees.

Linear vibration of the start motor, dynamometer and t-c set were monitored throughout the test and in no case did the values approach the pre-established limits.

TIME → ACCELERATION ON STARTMOTOR FROM 25% SPEED PASSING
THROUGH FIRST CRITICAL SPEED

CHART SPEEDS: 100 mm/second
GAIN: 50 mv/cm

FIGURE V-8. ANSOP 16625 - TORSIONAL VIBRATIONS

5. Hydrocarbon in the Main Process Loop

Continuously operating instrumentation is installed on the ML-1 to monitor the concentration of hydrocarbon in the main gas loop. A limit of 200 ppm has been established to prevent fouling of the fuel element, turbine, and heat exchanger surfaces. The detection instrumentation operated without incident during ANSOP 16625 and the limit was not exceeded at any time during the conduct of the test.

D. SHIELDING PERFORMANCE

The ML-1 shield was designed to attenuate radiation to the levels below:

- 1) Maximum radiation level 24 hours after shutdown (with the aqueous shield drained and the reactor and power conversion skids coupled) at a horizontal distance of 25 feet from the reactor center line in the direction of the power conversion skid - 15 mr/hr.
- 2) Maximum radiation level 24 hours after shutdown at a distance of 25 feet from the reactor center line in any except the power conversion skid direction - 150 mr/hr.
- 3) Maximum radiation level 24 hours after shutdown at a vertical distance of 25 feet over the reactor center line - 1500 mr/hr.
- 4) Maximum radiation level at the control cab (500 feet from the reactor) during full power operation (with expedient shielding as required) - 5 mrem/hr.

Measurements were made during the conduct of ANSOP 16625 and calculations were performed based on these data to evaluate the performance of the shield. The results are discussed below.

1. Shutdown Shield

For purposes of evaluating shutdown radiation levels it was assumed that the reactor had operated for 107 hours at 2.2 Mw (thermal power). This assumption is valid for isotopes with half lives less than 45 days since the reactor had not operated for approximately 5 months and the isotope build-up from previous runs had decayed to essentially zero. The effects of isotopes such as Co^{60} with extremely long half lives (5.2 years) were evaluated by assuming 2.2 Mw operation for 117 hours.

The gamma measurements observed during ANSOP 16625 were extrapolated to the equivalent of 10,000 hours of operation on the basis of the relationship of radioactive manganese (Mn-56) to the predicted contributions from the longer-lived isotopes. The photoneutron levels were adjusted using the relationship (the fission product gamma above 1.6 Mev) between 107 hours of operation at 2.2 Mw(t) and 10,000 hours at full power. The results of the extrapolated calculations are presented in Table V-7.

TABLE V-7 - ML-1 SHUTDOWN SHIELD PERFORMANCE SUMMARY

(Extrapolated from ANSOP 16625 data to yield values after 10,000 hours of operation and 24 hours of decay)

<u>Location</u>	<u>Neutron Levels (mrem/hr)</u>	<u>Gamma Levels (mr/hr)</u>	<u>Total (mrem/hr)</u>	<u>Predicted (mr/hr)</u>
P/C skid direction 25 ft from reactor (P/C in place)	9.6	9.2	18.8	15
Non-P/C skid direction, 25 ft from reactor (maximum)	69	129	198	150
Above reactor, 25 ft (expedient shield installed)	75	400	475	1500

2. Operational Shield

Measurements of the neutron and gamma radiation levels observed during operation of the reactor under ANSOP 16625 were extrapolated to full power conditions by using the ratio of full power (3.3 Mw(t)) to the operating power at the time the data were taken. The extrapolated results in the direction of the power conversion skid and in a direction 90° from the power conversion skid are shown in Figures V-9 and V-10. The summarized performance of the ML-1 operational shield is shown in Table V-8.

TABLE V-8 - ML-1 OPERATIONAL SHIELD PERFORMANCE

(Based on data from ANSOP 16625 extrapolated to 3.3 Mw(t) with wooden expedient shield in place)

<u>Location</u>	<u>Neutron Levels (mrem/hr)</u>	<u>Gamma Levels (mrem/hr)</u>	<u>Total (mrem/hr)</u>
At control cab behind berm at 500 ft	< 2.0	0.9	< 2.9
At 500 ft in P/C skid direction	3.8	4.4	8.2
At 500 ft in non-P/C direction	5.2	26.2	31.4
At 25 ft in P/C skid direction	1150	2000	3150

As indicated in Table V-8, a radiation level of 3.15 rem/hr is predicted for the area behind the power conversion skid 25 feet from the reactor. This level would permit occupancy for approximately 5 minutes (for the purpose of a rapid inspection, if desired) without exceeding the weekly personnel exposure limit of 300 mrem.

The radiation detection instrument located on the reactor tank facing the power conversion skid indicated a level of less than 1,000 r/hr when extrapolated to full power conditions. This corresponds to approximately 250 r/hr at the portions of the power conversion skid nearest the reactor and is well below the design radiation damage limit of 500 r/hr.

FIGURE V-9. OPERATIONAL BIOLOGICAL DOSE RATE FROM ML-1
AT 3.258 Mw TOTAL POWER WITH AXIAL WOOD
EXPEDIENT SHIELD

DISTANCE FROM REACTOR CENTERLINE - feet

FIGURE V-10. OPERATIONAL BIOLOGICAL DOSE RATE FROM
ML-1 AT 3.258 Mw TOTAL POWER WITH AXIAL
WOOD EXPEDIENT SHIELD

As indicated in Table V-8, the expedient wooden shield was in place over the reactor during ANSOP 16625. Calculations were performed to estimate the radiation levels during full power reactor operation with the wooden shield removed. The results of these calculations are shown in Table V-9. The range of values indicated for the control cab position represents two methods of performing the calculation. The higher value assumes that the levels at the cab would be increased by the reciprocal of the attenuation factors of the wooden shield. The lower value is based on a less conservative assumption and represents the most realistic estimate of the level which would be encountered.

TABLE V-9 - OPERATIONAL SHIELD PERFORMANCE

(Based on ANSOP 16625 data extrapolated to 3.3 Mw(t) without expedient wooden shield)

<u>Location</u>	<u>Neutron Levels (mrem/hr)</u>	<u>Gamma Levels (mrem/hr)</u>	<u>Total (mrem/hr)</u>
At control cab behind berm at 500 ft	5.2-13.4	1.8-2.6	7.0-15.5
At 500 ft in P/C skid direction	13.4	6.2	19.6
At 500 ft in non-P/C direction	14.8	28.0	42.8

REFERENCES

1. Final Test Report - Initial Self-Sustained Operation of the ML-1 (ANSOP 16615), AN-AGCR-457, 21 February 1963
2. ML-1 Preliminary Test Report, Full Power Test (ANSOP 16625), AN-AGCR-415 (IDOP-89), 15 March 1963
3. AGCRSP, Semiannual Progress Report, IDO-28602, 22 February 1963
4. AGCRSP, Bypass Flow Reduction Design Report, AN-AGCR-477, 15 March 1963
5. AGCRSP, ML-1 Design Report, IDO-28550, 16 May 1960
6. AGCRSP, ML-1 Stability Tests, AGN TM-403, June 1963

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-UO₂ 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 air-to-water 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 1959</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, 12 January 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 two 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, 7 February 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 1962, 15 May 1963</u>	U

APPENDIX BML-1 PLANT CHARACTERISTICS

(Note: Items marked with an asterisk indicate changes made since April 1963.)

1. GENERAL

Design performance at 100°F

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

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

2. REACTOR THERMAL CHARACTERISTICS

Power density	700 kw/ft ²
Maximum heat flux	140,500 Btu/hr/ft ² *
Average heat flux	78,200 Btu/hr/ft ² *
Heat transfer surface	126.5 ft ²
Maximum to average heat flux ratio	
Axial	1.5
Radial	1.2
Maximum fuel center temperature (including hot spot factors)	2160°F (BeO-UO ₂) * 2650°F (UO ₂) * ²
Maximum moderator temperature	190°F
Maximum surface temperature of fuel cladding (nominal, average)	1520°F
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1750°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	1.54
Neutron lifetime	1.9×10^{-5} sec*
k_{eff} , cold, clean core; no shims or burnable poison	1.067
Operating k_{eff} , cold, clean core, with shims and burnable poison	1.014
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.6% in 10,000 hr
Maximum	6.5%
Prompt temperature coefficient, $\Delta k/k-^{\circ}\text{C}$	
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; 0.500 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 (10 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 w/BeO-UO ₂ ; 6 w/UO ₂ ; 1 empty)
Pin outside diameter	0.241 in.
Pin cladding material	Hastelloy X
Pin cladding wall thickness	0.030 in.
Pin spacer	0.040 in. OD Hastelloy wire
Heat transfer material (pin internal)	He
Pellet diameter	0.176 in. (nominal)
Type burnable poison	Cadmium
Reactivity worth of burnable poison	0.6% at startup

9. CONTROL ELEMENTS

Type	Tapered blades
Location	Moderator
Number: Shim blades	3 pairs (3 actuators)
Safety blades	2 pairs (2 actuators)
Regulating blades	1 pair (1 actuator)
Absorber material: Safety and shim blades	5 wt% Cadmium-
	15 wt% Indium-
	80 wt% Silver
Dimensions (each blade)	4 x 10.5 x 0.25 to 0.62 in.
Regulating blades	Stainless steel
Dimensions (each blade)	4 x 9 x 0.25 to 0.62 in.
Cladding material	none
Reactivity worth of control elements:	
Safety and shim blades	0.058 $\Delta k/k$
Regulating blades	<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 x 10 ⁶ Btu/hr

11. REACTOR WORKING FLUID FLOW

Working fluid	99.5 vol% N ₂ + 0.5 vol% O ₂
Reactor inlet temperature	800°F nominal
Reactor mixed-mean outlet temperature	1200°F max.
Average velocity in core	160 ft/sec
Maximum velocity	180 ft/sec
Inlet pressure	315 psia (max.)
Core ΔP	15 psi
Reactor ΔP	22 psi

12. POWER CYCLE

Type	Brayton cycle with regeneration		
Total volume of working fluid system	120 ft ³		
Total system working fluid inventory full load at 100°F	52 lb		
Working fluid transit time	2.0 sec		
Cycle characteristics:			
Ambient temperature	<u>100°F</u>	<u>0°F</u>	<u>-65°F</u>
Net power, kw	330	330	330
Reactor inlet, °F	791	597	597
Turbine inlet, °F	1200	990	990
Compressor inlet, °F	132	24	24
Compressor inlet, psia	117	93	93
Compressor outlet, psia	320	294	294
Reactor inlet, psia	313	288	288

13. TURBINE-COMPRESSOR SET

	<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	Incoloy 901
Turbine blade material	Inco 713	N 155
Turbine stator blade material	Inconel	N 155 or 19-9DL
Expansion ratio	2.38	2.38
Compressor stages	2	11
Compressor material	A1 355 T71	403 stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compressor ratio	2.72	2.72
Case material	304 stainless steel	304 stainless steel
Seals		
at journals	Buffered labyrinth	Buffered labyrinth
interstage	Plain labyrinth	Plain labyrinth
shaft	Buffered labyrinth	Double "L" ring seal oil buffered
Bearings		
journal	Tilting pad	Plain babbit
thrust	Kingsbury type	Kingsbury type (in low press. area)
Support	Overhung turbine	Turbine and compressor supported between bearings

14. ALTERNATOR

	<u>60 Cycle Operation</u>	<u>50 Cycle Operation</u>
Output		
Rating	500 KVA 3 ϕ	417 KVA 3 ϕ
Voltage	2400/4160 V	2000/3467 V
Rotor shaft speed	3600 rpm	3000 rpm
Case		
Diameter, maximum	40.25 in.*	
Length, without starting motor	30 in.	
Length, with starting motor	35.5 in.*	

Weight, alternator only	5900 lb*
Starting motor	400 lb*
Temperature, operating (hot spot)	300°F internal max.*

15. RECUPERATOR

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

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

Dimensions:

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

Materials

Tubes and fins	Series 1100 aluminum
Headers	Series 2219 aluminum
Weight	6500 lb

Pre-cooler:

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

Moderator cooler:

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

Oil cooler:

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

31 August 1963

APPENDIX C

ANSOP 16625

PROCEDURE FOR FULL POWER TEST OF THE ML-1 POWER PLANT

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STANDARD OPERATING PROCEDURE
MOBILE LOW POWER REACTOR - I

PROCEDURE SECTION

16 EXPERIMENTAL PROCEDURES

TITLE:

FULL POWER TEST

SCOPE

This procedure outlines the steps to be followed for the full power test of the ML-1 Power Plant.

The sequence of steps outlined herein is designed to accomplish the following:

1. Bring the ML-1 power plant to self-sustained condition.
2. Accelerate the turbine-compressor set to rated speed.
3. Apply a load in small increments to determine the maximum permissible gross electrical load that can be applied.

This procedure is the second of a series in initial power tests designed to provide data for the gross evaluation of the power plant. This test will be followed by a limited endurance test, ANSOP 16635, designed to provide a limited endurance run of the power plant early in the test program. Succeeding experiments are described in the test plan for ML-1 Nuclear Power Plant Test Program.

A graphical representation of the manner in which the power plant is taken to full power condition is illustrated on Attachment 5. Ref: AGN Drawing No. 425196 P & I Diagram.

SUPPLEMENTAL PROCEDURES

Supplemental procedures required for reference in implementing this procedure include:

<u>Title</u>	<u>ANSOP Number</u>
Personnel Control Procedure	2302
Lock and Tag Procedure	3150
Power Plant Pre-Startup Checks	14000
Power Plant Post Shutdown Checks	14004
Power Plant Emergency Procedures	14005

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Supplemental Procedures - Cont'd.

<u>Title</u>	<u>ANSOP Number</u>
Power Plant Annunciated Alarms Operator Action	14008
Reactor Pre-Startup Check List	14020
Reactor Startup	14021
Low Power Reactor Operation	14022
Nuclear Instrumentation Pre-Startup Check	14060
Non-Nuclear Scram Circuit Check	14070
Control Rod System Pre-Startup Check	14080
Lube System Startup	14131
Lube System Shutdown	14133
Speed Control System Pre-Startup Check	14210
Moderator System Startup	14251
Moderator System Shutdown	14253
Deoxygenation System Normal Operation	14254
Shield Water System Startup	14271
Shield Water System Shutdown	14273
Electrical Distribution System Pre-Startup Check	14340
Electrical Distribution System Operation	14342
Dynamometer Normal Operation	14345
RAM System Startup	14361
Primary Coolant Monitoring System	14382
Primary Loop Sampling System	14384
Alnor Dew Point Operation	14385
Gas Analysis Equipment Operation	14422
Analysis Instrumentation Operation	14522

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ML-1 OPERATING LIMITS FOR THIS TEST

Operational limits for the ML-1 Power Plant, as established for operations covered by this procedure, are set forth below. The following limits shall be strictly adhered to during the performance of this procedure. Should a limit specified be reached, the ML-1 General Supervisor shall be notified and appropriate action shall be taken at his direction to maintain the given parameter within the specified operating range of this test.

	<u>Limit</u>	<u>Readout</u>
1. Reactor Power	3.0 mw to Gas Max.	Calc. per ANSOL 16625A
2. Compressor Inlet Temperature	150°F Max.	TXR-102-2
3. Compressor Inlet Pressure	130 psia Max. 50 psia Min.	PI-120
4. Compressor Discharge Pressure	345 psia Max.	PI-121
5. Fast Pressure Loss $\Delta P / \Delta T$	45 psi/10 sec. and 40 psi total press. loss. Max. $\frac{dp}{dt}$	YH-102
6. High Pressure Recuperator Outlet (Reactor Inlet) Temperature	825°F Max.	TX-109
7. Reactor Outlet Temperature	1200°F Max.	TXR-101-2,3
8. Turbine Exhaust Temperature	1050°F Max.	TX-110-1
9. Precooler Inlet Temperature	510°F Max.	TX-112
10. Reactor Inlet Pressure	330 psia Max.	PI-123
11. Reactor ΔT	450°F Max.	TXR-101-2,3 - TX-109-1
12. Moderator Water Outlet Temperature from Reactor	190°F Max.	TI-202
13. Moderator Water Reactor Inlet Temp.	180°F Max.	TI-201
14. Moderator Water Level	-8 In. Max.	LI-201b

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ML-1 Operating Limits - Cont'd.

		<u>Limit</u>	<u>Readout</u>
15.	Moderator Water Conductivity	2 micromhos Max.	CI-201a
16.	Shield Water Level	-4 In. Max.	LI-201a
17.	Shield Water Boric Acid Concentration	$10 \pm \frac{1}{2}$ wt. %	
18.	Shield Water Temperature	130°F Min.	TI-203
19.	Moderator Water Low Flow (Low ΔP)	80% of full flow (ΔP) Min.	FYL-201
20.	Fuel Element Thermocouple Temp.	1400°F Max.	TX-221 - TX-230
21.	Tube Sheet Temperatures	533°F Max.	TX-216
22.	Inner Radial Shield Temp.	375°F Max.	TX-211
23.	Reactor Lower End Cone Temp. (Lead)	375°F Max.	TX-212
24.	Shield Water Upper Cone Temp. (Water)	210°F Max.	TX-213
25.	Shield Water at Heat Exchanger Discharge Temperature	210°F Max.	TX-214
26.	Bearing Temperature Thrust & Gear Radial	170°F Max. 225°F Max. 220°F Max.	TI-602 e.f.; TX-614 TI-602c-d TSR-612
27.	Turbine Bearing ΔP	75 psi Max.	PdAL-602
28.	Lube Oil Supply Temperature	150°F Max. 120°F Min.	TR-619-3
29.	Auxiliary Lube Oil Pump Start ΔP	50 psi Min.	PdI-621; PdI-622
30.	Lubrication Oil Filter Pressure Drop	35 psi Max.	PdI-620
31.	Lubrication Oil Sump Level - no detectable variation during operation		LI-601; LI-602

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<u>ML-1 Operating Limits - Cont'd.</u>		<u>Limit</u>	<u>Readout</u>
32.	Lubrication Oil Sump Level (Pre-rotational)	25 gallon Min.	LI-601; LI-602
33.	Lubrication Oil Sump Pressure	45 psia Max.	PI-603
34.	Alternator Case to Lube Oil Sump Δ P	10 In. H ₂ O Min.	PdI-626
35.	Seal Pressure Δ P	0.2 psid Min.	Pdx-611; Pdx-612
36.	Start Motor Power - slow speed (Continuous) (Short time up to 1 min.) Start Motor Power - medium speed (Continuous) (Short time up to 2 min.) Start Motor Power - fast speed (Continuous) (Short time up to 1 min.)	42 kw Max. 64 kw Max. 82 kw Max. 123 kw Max. 86 kw Max. 129 kw Max.	WI-940 WI-940
37.	Start Motor Current Per Phase - slow speed: (Continuous) (Short time up to 1 min.) Start Motor Current Per Phase - medium speed: (Continuous) (Short time up to 1 min.) Start Motor Current Per Phase - fast speed: (Continuous) (Short time up to 1 min.)	76 amps Max. 114 amps Max. 111 amps Max. 166 amps Max. 115 amps Max. 172 amps Max.	II-920 II-920 II-920
38.	T-C Set Speed	22,500 rpm Max.	SIC-102
39.	Positive Reactor Period	10 sec. Min.	NPI 73 & 74
40.	High Level Channels 5, 6 & 7	3.3 mw Max.	NI 75, 76 & 77
41.	Control Cab Area Radiation	15 mrem/hr. Max.	RAM Chan. 1 & fast neutron Inst. in cab
42.	Skid Area Radiation	1000 R/hr. Max.	RAM Chan. 2
43.	Loop Oxygen Concentration	0.4 V/O Min. 3.0 V/O Max.	Direct Sample

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ML-1 Operating Limits - Cont'd.

	<u>Limit</u>	<u>Readout</u>
44. Loop Hydrocarbon Concentration	200 ppm by vol. Max.	ANSOL 14522
45. Carbon Trap Activity	Increase of 1 microcurie of fission products between successive sam- ples 10 microcuries Max.	ANSOL 14384
46. Moderator O ₂ Concentration	0.5 cc/L Max.	
47. Dynamometer Output	370 KW Max.	
48. Fuel Element Temperature Hot Spot Limit	1750°F	
Calculate by following formula:		
$T(\text{TIC-101}) + 420 \left(\frac{\% \text{ power}}{\% \text{ flow}} \right) + 0.8 (\% \text{ power}) < 1735^{\circ}\text{F.}$		
NOTE: 100% power = 3.0 mw to gas 100% flow = 26 lb./sec.		
49. Pressure Vessel Stress Limit:	36,900 psi	
Operating limits shall not exceed the envelope shown on Attachment 7.		

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PROCEDURE

NOTES:

I. SUPERVISION

Execution of this procedure shall be closely monitored by:

1. ML-1 General Supervisor
2. Health and Safety Supervisor
3. Technical Support Section Head

Execution of this procedure shall be under the direction of ML-1 Power Plant Supervisor.

II. FACILITY CONDITION

At the time of initiation of this procedure, the power conversion skid will be coupled to the reactor skid. The power plant package will be located in the test building. The following non-prototype systems will be utilized.

- a. Coolant Gas Supply System - A supply of nitrogen will be stored in high pressure storage cylinders.
- b. Start System - A 100 H.P., 3 speed start motor will be coupled to the stub shaft extension.
- c. ML-1 Non-Prototype Emergency Cooling System
- d. Non-Prototype Instrumentation
- e. Dynamometer - Coupled to the outboard end of the 3-speed start motor will be utilized as a power absorption device.
- f. Deoxygenation System - To provide deoxygenation of the moderator water.

III. REACTOR SCRAM

If a reactor scram occurs at any time during this procedure execute applicable portions of ANSOP 14005, Power Plant Emergency Procedures. Consult the ML-1 General Supervisor for instructions regarding power plant re-startup.

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IV. PERSONNEL CONTROL IN RADIATION AREAS

1. During the course of this experiment, no one shall be permitted to enter a radiation field which yields a combined dose rate greater than 200 mrem/hr.
2. The maximum accumulated dose allowable for the duration of this experiment to any one individual shall be 900 mrem, per ANSOP 2100.
3. Anyone who goes to the reactor (inside the ML-1 perimeter fence) on an SWP when the reactor is operating, must be accompanied by one other person who will be equipped with portable two-way communication equipment and a survey meter. The second person will serve as communicator and radiation monitor and shall at all times be in communication with the analysis rack radio communications operator.

A. PREPARATION

Check

1. Test Crew Briefing

The ML-1 General Supervisor will brief the operating test crews prior to the initiation of this procedure. He shall insure that all crew members are familiar with ANSOP 14005, Power Plant Emergency Procedures, ANSOP 14008, Power Plant Annunciated Alarms - Operator Action, and ANSOP 3950, Master Emergency Plan.

2. Visually inspect the power conversion, reactor, and auxiliary skids in the test building area to insure that conditions are acceptable for a power plant startup.
3. Insert an indium foil into the lucite normalizer holder on the reactor per Experiment 16003.

a. Complete the appropriate portions of ANSOL 16003.

4. Complete ANSOP 14000, Power Plant Pre-Startup Check List, through step 31.f.

NOTE: After step 17., Shield Water System Filling, of ANSOP 14000, has been completed the shield and moderator water temperatures will be maintained at 175°F.

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5. Install two film badges on each survey marking stake at the following locations: (See Attachment 3.)

<u>Diagonal</u>	<u>Distance from Reactor</u>
0°	50', 100', 150', 200', 300', 400'
225°	Same as 0°
290°	Same as 0°

6. Complete the analysis run on each of the two milletron system detectors.

NOTE: Milletron personnel will perform this analysis. The Milletron Noise Analysis System is a self-contained unit, utilizing its own detectors, amplifiers, cables and analysis equipment. This system may be operated at any time during this procedure with no effect on reactor operation.

- a. Record the moderator and shield water temperatures on ANSOL 14522.

- 1) TI-202
- 2) TI-203

7. Complete the remaining portion of ANSOP 14000.

8. Remove the nuclear accident dosimeter from the test building, and store the dosimeter in the ML-1 General Supervisor's office.

B. REACTOR STARTUP

1. Insure that all personnel are at their assigned stations. (See Attachment 1.)
2. Check that ANSOP 14020, Reactor Pre-Startup Check, has been completed within the preceding four hours.
3. Complete ANSOP 14021, Reactor Startup. Rod withdrawal pattern shall be Pattern No. 1. Stabilize power at 1.2×10^7 nv (approximately 100 watts).

NOTE: All references to reactor power during the performance of this procedure shall use as the readout instrument the Channel 3 Log N recorder, unless otherwise noted.

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4. Stabilize and maintain reactor power level at 1.2×10^5 nv.
Record the control rod positions in the console log.

CAUTION: IF, AT ANY TIME, DURING STABILIZED REACTOR OPERATION, THE CONTROL ROD POSITIONS VARY DETECTABLY FROM PREVIOUS STABILIZED POSITIONS, REACTOR POWER SHALL NOT BE INCREASED UNTIL AFTER CONSULTING WITH THE ML-1 GENERAL SUPERVISOR.

NOTE: The ML-1 General Supervisor shall satisfy himself that all data and instrumentation readings indicate that the power plant is ready for startup.

5. Check that the static seals are vented.
6. Press "SLOW" start button to energize start motor.
7. Allow T-C set to stabilize at "SLOW" start motor speed (~ 25% speed) 5500 rpm.
8. Stabilize and maintain the reactor power level for ~10 minutes and record the control rod positions in the console log.

CAUTION: OBSERVE START MOTOR POWER AND CURRENT. IF THE MOTOR DRAWS MORE THAN 42 KW OR 76 AMPS CONTINUOUSLY, OR 64 KW OR 114 AMPS FOR PERIODS MORE THAN ONE MINUTE, PRESS THE START MOTOR "STOP" BUTTON.

9. Data Point No. 1

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
- b. Time mark all recorder charts.
- c. Compare the data obtained with the predicted data on Attachment 2.
- d. Complete the analysis run on each of the two milletron system detectors.
- e. Complete ANSOL 14384, Primary Loop Sampling System.
- f. Obtain a gas sample for oxygen analysis.
- g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.

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Check

10. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.
11. Obtain permission from the ML-1 General Supervisor to proceed to the next step.
12. Withdraw a shim rod to increase the reactor power level to approximately 2 KW (2.4×10^6 nv).
13. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.
14. Data Point No. 2

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
 - b. Time mark all recorder charts.
 - c. Compare the data obtained with the predicted data on Attachment 2.
 - d. Complete the analysis run on each of the two milletron system detectors.
 - e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
15. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.
 16. Obtain permission from the ML-1 General Supervisor to proceed to the next step.
 17. Withdraw a shim rod to increase the reactor power level to approximately 50 KW (6.0×10^7 nv).

CAUTION: IF THE REACTOR ΔT EXCEEDS 100°F , CHECK WITH THE ML-1 GENERAL SUPERVISOR BEFORE PROCEEDING.

18. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.

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19. Data Point No. 3

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
- b. Time mark all recorder charts.
- c. Compare the data obtained with the predicted data on Attachment 2.
- d. Complete the analysis run on each of the two milletron system detectors.
- e. Complete ANSOL 14384, Primary Loop Sampling System.
- f. Obtain a gas sample for oxygen analysis.
- g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
- h. Calculate the thermodynamic power per ANSOL 16625A.

20. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.

21. Obtain permission from the ML-1 General Supervisor to proceed to the next step.

22. Withdraw a shim rod to increase the reactor power level to approximately 200 KW (2.5×10^8 nv).

CAUTION: DO NOT EXCEED 800°F REACTOR OUTLET TEMPERATURE.

23. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.

24. Data Point No. 4

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
- b. Time mark all recorder charts.
- c. Compare the data obtained with the predicted data on Attachment 2.
- d. Complete the analysis run on each of the two milletron system detectors.

Check

- e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
 - h. Calculate the thermodynamic power per ANSOL 16625A.
25. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.
26. Complete an area radiation survey on the 290° diagonal in the following manner:

NOTE: At least 2 personnel are required for this survey. One person shall maintain contact with the analysis rack radio communications operator at all times.

- a. Proceed to the 290° diagonal (see Attachment 3) on the north side of the earth berm.
- b. Move along the 290° diagonal toward the test building until the gamma radiation level is ~100 mr/hr.

CAUTION: DO NOT ENTER A RADIATION FIELD WHICH YIELDS A COMBINED DOSE RATE GREATER THAN 200 MREM/HR.

- c. Obtain a radiation survey at the survey marker stake (see Attachment 3) at which the gamma radiation is ~100 mr/hr.
27. Complete Section B. of Experiment 16003 to retrieve the reactor normalizer foil.
28. Adjust the compressor inlet pressure to 65 psia.
29. Obtain permission from the ML-1 General Supervisor to proceed to the next step.
30. Press the start motor "MEDIUM" speed button and accelerate the turbine compressor to 50% speed.

CAUTIONS: A. MAINTAIN THE REACTOR POWER CONSTANT, USING A SHIM ROD, AS A POSITIVE REACTIVITY SHIFT WILL OCCUR DUE TO THE NEGATIVE TEMPERATURE COEFFICIENT OF THE FUEL ELEMENTS.

- B. IF THE START MOTOR POWER EXCEEDS 82 KW (OR 111 AMPS) CONTINUOUSLY, OR 123 KW (OR 166 AMPS) FOR MORE THAN 1 MINUTE, OR IF ANY OF THE LIMITS ON PAGES 3, 4, 5 AND 6 ARE EXCEEDED, PRESS THE START MOTOR "SLOW" BUTTON. ANALYZE THE POWER PLANT OPERATING CONDITIONS.

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Check

31. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.
32. Check that the start motor power does not exceed 82 KW or 111 amps.
33. Adjust the compressor inlet pressure to 60 psia.
34. Data Point No. 5
Perform the following actions:
 - a. Record a complete set of power plant data per ANSOL 14001 and 14522.
 - b. Time mark all recorder charts.
 - c. Compare the data obtained with the predicted data on Attachment 2.
 - d. Complete the analysis run on each of the two milletron system detectors.
 - e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
 - h. Calculate the thermodynamic power per ANSOL 16625A.
35. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.
36. Obtain permission from the ML-1 General Supervisor to proceed to the next step.
37. Attain virtual self-run conditions in the following manner:
 - a. Withdraw a shim rod to increase the reactor power level by 50 KW.
 - b. Stabilize and maintain the reactor power level until the reactor outlet temperature has stabilized.
 - c. Repeat step B.37.a. and b. until self-run is virtually attained (start motor power drops to 5-10 KW).

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38. Stabilize and maintain the reactor power level for ~ 10 minutes and record control rod positions in the console log.
39. Data Point No. 6
Perform the following actions:
 - a. Record a complete set of power plant data per ANSOL 14001 and 14522.
 - b. Time mark all recorder charts.
 - c. Compare the data obtained with the predicted data on Attachment 2.
 - d. Complete the analysis run on each of the two milletron system detectors.
 - e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
 - h. Calculate the thermodynamic power per ANSOL 16625A.
40. Complete an area radiation survey per step B.26.
41. Increase compressor inlet pressure to 65 psia.
42. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.
43. Obtain permission from the ML-1 General Supervisor before proceeding to the next step.
44. Open the speed control bypass valve until the start motor power requirement is increased by 10 KW (— 15 - 20 KW total) or until the speed control bypass valve is 10% open, whichever occurs first.
45. Withdraw a shim rod to increase the reactor outlet temperature until the start motor power requirement decreases to less than 2 KW.

CAUTION: DO NOT EXCEED 1200°F REACTOR OUTLET TEMPERATURE.

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Check

46. Stabilize and maintain the reactor power level for ~ 10 minutes and record the control rod positions in the console log.
47. Check that the dynamometer automatic speed control is set to limit the T.C. set speed at approximately 13,000 rpm.
48. Turn ON the dynamometer excitation current.
49. Obtain permission from the ML-1 General Supervisor to proceed to the next step.
50. Press the start motor "STOP" button and close the speed control bypass valve.

NOTE: The T.C. set will accelerate until the speed is limited by the dynamometer. The dynamometer output as read from the torque - KW curve, Attachment 6, should be approximately 10 KW.

CAUTION: CONTINUOUSLY MONITOR THE TURBINE-COMPRESSOR SET VIBRATION LEVEL DURING THIS ACCELERATION FOR ANY INDICATION OF A RESONANCE VIBRATION AREA.

IF A VIBRATION AREA IS ENCOUNTERED IMMEDIATELY OPEN THE SPEED CONTROL BYPASS VALVE APPROXIMATELY 15%. WHEN THE T-C SET HAS DECELERATED TO 50% SPEED, PRESS THE START MOTOR MEDIUM BUTTON. CONSULT WITH THE ML-1 GENERAL SUPERVISOR BEFORE PROCEEDING.

51. Stabilize and maintain the power plant operation conditions for. ~ 10 minutes.
52. Obtain permission from the ML-1 General Supervisor before proceeding to the next step.
53. Increase the dynamometer load as follows:
 - a. Withdraw a shim rod to increase the reactor outlet temperature until the dynamometer output reaches 30 KW.
 - b. Increase compressor inlet pressure if 1200°F is reached in step 53.a., maintaining 1200°F reactor outlet temperature until the dynamometer output reaches 30 KW.

CAUTION: DO NOT EXCEED 1200°F REACTOR OUTLET TEMPERATURE OR 100 PSIA COMPRESSOR INLET PRESSURE.

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Check

54. Adjust the dynamometer automatic speed control to allow the T-C set to accelerate to approximately 15,000 rpm, or until the dynamometer output decreases to 10 KW.

CAUTION: CONTINUOUSLY MONITOR THE TURBINE-COMPRESSOR SET VIBRATION LEVEL DURING THIS ACCELERATION FOR ANY INDICATION OF A RESONANCE VIBRATION AREA.

IF A VIBRATION AREA IS ENCOUNTERED IMMEDIATELY STOP THE ACCELERATION AND ADJUST THE DYNAMOMETER SPEED CONTROL TO ITS ORIGINAL SETTING. CONSULT WITH THE ML-1 GENERAL SUPERVISOR BEFORE PROCEEDING.

55. Stabilize and maintain the power plant operating conditions for ~ 10 minutes.
- a. Observe all power plant readout instruments to verify that normal operating parameters are not being exceeded.
- b. Time mark all recorder charts.
56. Obtain permission from the ML-1 General Supervisor before proceeding to the next step.
57. Increase the dynamometer load to ~30 KW, per step 53.
58. Adjust the dynamometer automatic speed control to allow the T-C set to accelerate to approximately 16,500 rpm (75% speed) or until the dynamometer output decreases to 10 KW.

CAUTION: CONTINUOUSLY MONITOR THE TURBINE-COMPRESSOR SET VIBRATION LEVEL DURING THIS ACCELERATION FOR ANY INDICATION OF A RESONANCE VIBRATION AREA.

IF A VIBRATION AREA IS ENCOUNTERED IMMEDIATELY STOP THE ACCELERATION AND ADJUST THE DYNAMOMETER SPEED CONTROL TO ITS ORIGINAL SETTING. CONSULT WITH THE ML-1 GENERAL SUPERVISOR BEFORE PROCEEDING.

59. Stabilize and maintain the power plant operating conditions for ~ 10 minutes.

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60. Data Point No. 7

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
- b. Time mark all recorder charts.
- c. Compare the data obtained with the predicted data on Attachment 2.
- d. Complete the analysis run on each of the two milletron system detectors.
- e. Complete ANSOL 14384, Primary Loop Sampling System.
- f. Obtain a gas sample for oxygen analysis.
- g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
- h. Calculate the thermodynamic power per ANSOL 16625A.

61. Check the operation of the overspeed valve as follows:

- a. Manually trip the overspeed valve (SAV-101) and observe that it has OPENED by observing an immediate decrease in the dynamometer output.
- b. Immediately reset the overspeed trip valve.

CAUTION: IF THE OVERSPEED TRIP VALVE CANNOT BE RESET IMMEDIATELY SCRAM THE REACTOR AND PRESS THE START MOTOR SLOW BUTTON WHEN THE T-C SET HAS DECELERATED TO 25% SPEED (5500 RPM) AND PROCEED WITH ANSOP 14005, POWER PLANT EMERGENCY PROCEDURE.

- 62. Check that the ML-1 operating limits on pages 3, 4, 5 and 6 are not being exceeded.
- 63. Complete an area radiation survey per step B.26.
- 64. Repeat steps B.52. through B.55. to accelerate the T-C set to 18,000 rpm.
- 65. Repeat steps B.52. through B.55. to accelerate the T-C set to 20,000 rpm.

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66. Repeat steps B.52 through B.55. to accelerate the T-C set to 22,000 rpm.
67. Obtain permission from the ML-1 General Supervisor before proceeding to the next step.
68. Increase the dynamometer load to ~50 KW per step B.53.
69. Stabilize and maintain the power plant operating conditions for ~10 minutes.
70. Data Point No. 8
Perform the following actions:
 - a. Record a complete set of power plant data per ANSOL 14001 and 14522.
 - b. Time mark all recorder charts.
 - c. Compare the data obtained with the predicted data on Attachment 2.
 - d. Complete the analysis run on each of the two milletron system detectors.
 - e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
 - h. Calculate the thermodynamic power per ANSOL 16625A.
71. Check that the ML-1 Operating Limits on pages 3, 4, 5 and 6 are not being exceeded.
72. Complete an area radiation survey per step B.26.
73. Obtain permission of the ML-1 General Supervisor before proceeding to the next step.
74. Increase the dynamometer load as follows:

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- a. Withdraw a shim rod to increase the reactor outlet temperature until the dynamometer output increases by 50 KW.

CAUTION: DO NOT EXCEED 1200°F REACTOR OUTLET TEMPERATURE.

- b. Increase compressor inlet pressure if 1200°F is reached in step 74.a., maintaining 1200°F reactor outlet temperature until the dynamometer output increases by 50 KW.

75. Stabilize and maintain the power plant operating conditions for ~10 minutes.

- a. Observe all power plant readout instruments to verify that normal operating parameters are not being exceeded.
- b. Time mark all recorder charts.
- c. Calculate the thermodynamic power per ANSOL 16625A.

CAUTION: DO NOT EXCEED 1200°F REACTOR OUTLET TEMPERATURE.

76. Repeat steps B.73. through B.75. to increase the dynamometer load in 50 KW increments until one of the following conditions occur:

- a. The reactor power level reaches 3.0 MW to gas.
- b. One of the ML-1 Operating Limits is reached.

77. Stabilize and maintain the power plant operating conditions for ~10 minutes.

78. Data Point No. 9

Perform the following actions:

- a. Record a complete set of power plant data per ANSOL 14001 and 14522.
- b. Time mark all recorder charts.
- c. Compare the data obtained with the predicted data on Attachment 2.

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Check

- d. Complete the analysis run on each of the two milletron system detectors.
 - e. Complete ANSOL 14384, Primary Loop Sampling System.
 - f. Obtain a gas sample for oxygen analysis.
 - g. Complete ANSOP 14385, Operation of the Alnor Dew Point Analyzer.
 - h. Calculate the thermodynamic power per ANSOL 16625A.
79. Complete an area radiation survey per step B.26.
80. Maintain the power plant operating conditions until directed by the ML-1 General Supervisor to proceed to the next step.
81. Reduce the reactor power and decrease system mass until a stabilized reactor outlet temperature of 1150°F at 80 psia compressor inlet pressure is attained.
82. Maintain the power plant operating conditions until directed by the ML-1 General Supervisor to proceed to the next step.
83. Insert a shim rod to reduce the reactor power level until the load on the dynamometer reaches approximately 10 KW.
- CAUTION: DO NOT DECREASE REACTOR OUTLET TEMPERATURE AT A RATE GREATER THAN 100°F/MINUTE.
84. Decrease the dynamometer speed control setting until the load on the dynamometer is increased to approximately 50 KW.
- CAUTION: CONTINUOUSLY MONITOR THE TURBINE-COMPRESSOR SET VIBRATION LEVEL DURING THIS ACCELERATION FOR ANY INDICATION OF A RESONANCE VIBRATION AREA.
- IF A VIBRATION AREA IS ENCOUNTERED IMMEDIATELY STOP THE ACCELERATION AND ADJUST THE DYNAMOMETER SPEED CONTROL TO ITS ORIGINAL SETTING. CONSULT WITH THE ML-1 GENERAL SUPERVISOR BEFORE PROCEEDING.
85. Repeat steps 83. and 84. until the turbine compressor speed reaches 50% speed.

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- NOTES: I. Adjust the loop pressure as required to maintain the compressor inlet pressure between 60 and 100 psia.
- II. Observe that the auxiliary lube oil pump and the startup compressor are operating when the turbine compressor speed reaches 80%.
86. Reduce the reactor power until the load on the dynamometer reaches ZERO and the turbine speed drops below 50% speed.
87. Turn OFF the dynamometer excitation.
88. Energize the start motor in "MEDIUM" speed.
89. Decrease the reactor power level until the reactor outlet temperature reaches 400°F with a compressor inlet pressure of 60 psia.

CAUTION: DO NOT DECREASE REACTOR OUTLET TEMPERATURE AT A RATE GREATER THAN 100°F/MINUTE.

90. Scram the reactor.
91. Press the start motor "STOP" button.
92. When the T/C set reaches 25% speed (5500 rpm) energize the start motor in "SLOW" speed.
93. Continue to rotate the T-C set until the reactor outlet temperature is stable at a temperature below 175°F.
94. Press the start motor "STOP" button and measure the time required for the T-C set to decelerate to a stop.
95. Monitor and record shutdown radiation levels in accordance with Experiment 16004, Shutdown Shielding Evaluation.
96. Shut down the power plant in accordance with ANSOP 14004.
- NOTE: The main moderator pump shall be left operating.
97. Reinstall the nuclear accident dosimeter in the test building.
98. Record the fuel element temperature once each hour until the maximum fuel element temperature has decreased to ~150°F.

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Attachment 1

ASSIGNED PERSONNEL STATIONS

<u>RACK 0</u>	<u>RACK 1</u>	<u>RACK 2</u>	<u>RACK 3</u>	<u>RACK 4</u>	<u>RACK 5</u>	<u>RACK 6</u>	<u>RACK 7</u>	<u>RACK 8</u>	<u>RACK 9</u>
Milletron Analysis	Radiation Monitor DVM Seal Δ P	Transducer Cal. & Gas Analysis	TV System Radio & Patch Panel Radio	Power Supplies Transducer Amplifier	LCR Channel 2 & Intercom	Fuel Temp. Recorder Effluent Monitor	Rx Out. Temp. Turbine Speed Sonic Analyzer	Hi-Level Chan. 5 Chan. 3 or 4	LCR Chan. 1-Period Bypass Valve Recorder
OBSERVER A Racks 1 & 2		OBSERVER B Racks 3, 4 & 5		OBSERVER C Racks 6 & 7		OBSERVER D Racks 8, 9 & 10		OBSERVER E Racks 11 & 12	

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RACK 10	RACK 11	RACK 12
Chan. 6 & 7 Start Motor Pwr. Primary Loop Temp. Recorder	Loop Press. TV System Dyna. Control	Secondary Annun. Temp. Recorder Deoxy. Control

C-24

General Supervisor _____

Date _____

Remarks:

Power Plant Supervisor _____

Shift _____

ANSOP _____

Observers:

A _____
B _____
C _____
D _____
E _____
F _____
G _____

Survey Personnel:

1. _____
2. _____
3. _____

PREDICTED PERFORMANCE DATA

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Attachment 2
Page 1

<u>Page</u>	<u>Step</u>	<u>Data Point</u>	<u>Descriptive Condition</u>	<u>Log N[*] Power nv</u>	<u>Thermo-^{**} dynamic Power, kw</u>	<u>Compressor Inlet Pressure, psia</u>	<u>Reactor Outlet Temp. °F</u>	<u>Reactor Delta T °F</u>
9	A.6.		Plant shutdown, milletron	0	0	60		
9	B.3.		Reactor only, 100 watts	1.2×10^5	0.100	60	150	
10	B.9.	1	Reactor 100 watts, 1/4 speed, milletron	1.2×10^5	0.100	60	150	
11	B.14.	2	Reactor 2 kw, 1/4 speed, milletron	2.4×10^6	2.	60	175	1
12	B.19.	3	Reactor 50 kw, 1/4 speed, milletron	6.1×10^7	50.	60	450	69
12	B.24.	4	Reactor 200 kw, 1/4 speed, milletron, retrieve indium foil	2.4×10^8	200	60	800	275
14	B.34.	5	Reactor 200 kw, 1/2 speed, milletron, radiation survey	2.4×10^8	200	60	505	126
15	B.39.	6	Start motor power 5-10 kw, 1/2 speed, milletron	6.6×10^8	540	60	1140	345
19	B.60.	7	16,500 rpm, Dynamometer 10+ kw, milletron, radiation survey	9.1×10^8	970	60	1150	375
20	B.70.	8	22,000 rpm, dynamometer 50 kw, milletron	1.6×10^9	1700	60	1150	410
21	B.78.	9	22,000 rpm, dynamometer max. kw, 1200 F, milletron, radiation survey	3.1×10^9	3300	120	1200	450

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Predicted Performance Data

<u>Page</u>	<u>Step</u>	<u>Data Point</u>	<u>Descriptive Condition</u>	***		<u>Shim Rod Position (Reg. 30 deg.) (175° F. Mod. Temp.)</u>
				<u>Skid Rad- iation RAM No. 2 Rem/hr</u>	<u>Start Motor (-) kw, Dyna- mometer (+) kw</u>	
9	A.6.		Plant shutdown, milletron		0	
9	B.3.		Reactor only, 100 watts		-18	49.5 deg.
10	B.9.	1	Reactor 100 watts, 1/4 speed, milletron		-18	
11	B.14.	2	Reactor 2 kw, 1/4 speed, milletron	1	-17	
12	B.19.	3	Reactor 50 kw, 1/4 speed, milletron	50	-14	
C-26 12	B.24.	4	Reactor 250 kw, 1/4 speed, milletron, retrieve indium foil	90	-10	
14	B.34.	5	Reactor 250 kw, 1/2 speed, milletron, radiation survey	90	-42	
15	B.39.	6	Start motor power 5-10 kw, 1/2 speed, milletron	140	-5	
19	B.60.	7	16,500 rpm, Dynamometer 10+ kw, milletron, radiation survey	190	+10	
20	B.70.	8	22,000 rpm, dynamometer 50 kw, milletron	240	+50	
21	B.78.	9	22,000 rpm, dynamometer max. kw, 1200 F, milletron, radiation survey	460	+290 (Ambient Temp. 20° F.)	

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NOTES:

- * Channel 3 and 4 corrected to "Test Position" values.
- ** Includes thermodynamic power to moderator system.
- *** Located at 240 deg., 4 ft. above reactor centerline on outside of shield tank (ANSOP 16615 position).

ML-1 SITE SURVEY MAP

- - Film Badges
- - Film Badges & Survey Point

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2-1-63

LOG N vs. REACTOR POWER

ANSOP 16625
Attachment 4
Page 1

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LOG N vs. REACTOR POWER

ANSOP 16625
Attachment 4
Page 2

Log N Power Level, nv
(Corrected to Channel Test Positions)
(ANSOP 14060)

R. D. Peak
1-18-63
ANSOP-C-138b

TURBINE SPEED vs. REACTOR POWER

ANSOP 16625
Attachment 5

AGN TM-402

LOAD CELL READOUT vs. DYNAMOMETER POWER

ANSOP 16625
Attachment 6

J. M. Filant
2-1-83
ANSOP-C-140

ANSOP 16625
Attachment 7

ML-1 OPERATING LIMITS BASED ON TUBE
BUNDLE STRESS INTENSITIES

NOTE: To determine operating limits, read up from moderator temperature to the applicable power line. Read left to maximum TX-216 temperature.

1-24-63
G. S. Braun
ANSOP-C-141