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Report No. IDO-28560
Volume II (Supplement I)
of Two Volumes

MASTER

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

FINAL HAZARDS SUMMARY REPORT

FOR THE

ML-1 NUCLEAR POWER PLANT

NOVEMBER 1960

SECOND PRINTING, NOVEMBER 1962

Aerojet-General CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY
THE GENERAL TIRE

Report No. IDO-28560
Supplement I

L E G A L   N O T I C E

The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

Report No. IDO-28560
AEC Research and Development Report
UC-80: Reactor Technology
TID-4500 (18th Edition)
Contract AT(10-1)-880

ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

FINAL HAZARDS SUMMARY REPORT
for the
ML-1 NUCLEAR POWER PLANT

SUPPLEMENT I

Approved by:

R. H. Chesworth
Supervising Representative

September 1961
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ERRATA

Page 29, Section E - Deoxygenation of Moderator Water

Substitute the following for the text shown under the above heading:

> "The ML-1 moderator water will be deoxygenated to an oxygen concentration below 0.5 cc/liter when the plant is operated at power for significant periods of time. Deoxygenation will be accomplished by passing a 20 gpm bypass stream from the main moderator circulating pump discharge through an oxygen absorbing resin column. This treatment will be standard for ML-1 operation until the results of tube bundle mock-up tests and subsequent metallurgical evaluations of the condition of the mock-ups are available. At this time, if the evidence warrants such action, deoxygenation of ML-1 moderator may be discontinued".

ABSTRACT

This document supplements the ML-1 Hazards Summary Report, No. IDO-28560, originally published in November 1960. The material presented in the Supplement amplifies and revises various sections of the original publication, in order to up-date it and to satisfy the requirements pertinent to power operation of the entire ML-1 plant.

The text, with illustrations and graphs, is arranged in five sections and two appendixes: 1) a summary that includes an up-to-date tabulation of power plant characteristics; 2) descriptions of significant changes to certain ML-1 components - fuel element, leak-detection and refueling equipment, stainless steel uses, control blade locking mechanisms, and moderator deoxygenation; 3) operation of the plant with air as the coolant; 4) the Phase II Test Program under which the combined reactor and power-conversion packages will be operated; and 5) examples of detailed operating procedures for the test program. The appendixes contain: 1) discussions of recommendations made by the U.S. AEC concerning ML-1 operations, and 2) a list of errata in the original report.

The work reported herein was carried out under U. S. AEC Contract No. AT(10-1)-880.

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I. SUMMARY

In order to present a more complete description of the ML-1 power plant, the summary section of Report No. IDO-28560 is repeated in this supplemental document. The tabulation of power plant characteristics, Paragraph I.B., below, has been revised to accord with the latest experimental information. The accident analyses summarized in Paragraph I.C., below, have also been revised to incorporate accidents associated with air operation of the ML-1.

A. GENERAL

The ML-1 power plant will be tested at the National Reactor Testing Station, Idaho, at a facility specifically constructed for this purpose. Although the ML-1 is designed for field operation independent of any permanent facility or installation, the facility at NRTS is provided as a shelter for the supplemental instrumentation required for test operations and performance evaluation. The facility will provide a weather-tight and radioactively "warm" maintenance enclosure for the reactor. Approximately 500 ft away, adjacent to the control cab, a building is provided for office space and special analysis instrumentation.

The ML-1 reactor and power conversion equipment are readily transportable on standard Army trailers, railroad flatcar, barge, ship or large transport aircraft. For such transport, the power plant may be divided into separate packages (skids) holding: the reactor, the power conversion equipment, and the auxiliary equipment. The criteria for mobility have necessitated compact designs of high structural integrity for all components. The reactor design was governed by stringent requirements for shutdown radiation dose rate and overall package weight. A water-moderated reactor concept was selected to minimize core size, shielding weight, and fuel inventory.

The reactor core consists of 61 fuel elements through which the nitrogen or air coolant flows at 300 psig and is heated from 800° to 1200°F. The elements are contained in pressure tubes that are surrounded by slightly pressurized, demineralized water and are enclosed in a heavy metal reflector/shield. Each fuel element contains 18 pins that have 22-in. long sections fueled with ceramic pellets. In six of the pins, the pellets are highly enriched UO_2; in the other twelve, UO_2 diluted with BeO. The pins are clad in Hastelloy X tubing (0.241 in. OD), and contained within an insulated, stainless steel jacket. The 61 stainless steel pressure tubes that separate the nitrogen coolant from the moderator water are arranged in a triangular lattice between stainless steel tube-sheets. The reactor is controlled by six pairs of "semaphore" type, tapered, absorbing blades that operate in the water spaces between fuel elements. This core assembly is surrounded by a gamma shield and submerged in an aluminum tank which, during operation, is filled with a boric acid solution to provide neutron shielding.

The power conversion equipment in the primary circulating system includes a 60-cycle generator driven by a turbine-compressor set, a regenerative gas-to-gas heat exchanger (recuperator) to improve the thermodynamic cycle efficiency, and a gas-to-air heat exchanger (precooler) to dissipate the cycle waste heat to the atmosphere. A starting motor, coupled through the alternator to the t-c set, provides the capability for startup and controlled shutdown of the power plant. Afterheat generation following an emergency reactor scram is accommodated by the coast-down of the t-c set and the heat removal capacity of the moderator water system. During ML-1 operation, the only radioactive waste product released from the plant is gaseous coolant leaking through imperfect seals and piping joints. This gaseous release, monitored by standard instruments, will be maintained at a minimum level by curtailing plant operations (if necessary) to prevent undue radiological hazards in the area. Following a reactor shutdown, the other waste products include the activated moderator water, shielding water, and lubricating oil. The disposal of such liquid wastes will be controlled according to the regulations specified by the U.S. AEC, Idaho Operations Office.

To assure reliability and ruggedness, the power plant controls and instrumentation utilize transistors and military quality relays and meters. All reactor control blade circuits are interlocked to provide safe control sequences during checkout and operation. During startup and operation, eleven separate instrument circuits (which monitor the plant operation) can initiate a reactor scram in the event of an abnormal condition. Twenty-eight additional circuits warn of non-standard operation conditions so that the operator can initiate corrective action.

The operation of the ML-1 will be regulated by strictly administered, detailed procedures covering all phases and conditions of the power plant operation and maintenance. Conformance of these procedures is required; operating personnel are to be qualified by advance training.

Each individual system of the power plant has been investigated to determine the hazards associated with various equipment or component failures, either individually or in combination. These hazards are discussed in Paragraph I.C, below.

Two situations are defined that have significant radiological consequences:

An incident is postulated to occur as the result of an act of sabotage in which the control blade withdraw circuit is deliberately altered to permit simultaneous withdrawal of all blades. In addition, it is assumed that the reactor safety circuit is disabled so that an automatic period or power level scram is not possible. The simultaneous withdrawal of all blades will result in a reactivity input of 0.0807% $\Delta k/k$ sec. Continuing this reactivity addition rate will result in vaporization within the core region and an explosive disassembly of the reactor pressure vessel.

In this event, the whole body equivalent dose at the nearest off-site populated area (Atomic City,approximately six miles southeast) during strong inversion weather conditions is calculated to be about 6 rem,with a corresponding thyroid gland dose of about 150 rem. Such maximum exposures are considered to be within the acceptable limits for emergency conditions. Winds from the ML-1 site are in this direction about 1 - 2% of the time.

The security system provides the primary safeguard against sabotage. Normal access to the area is controlled at the GCRE facility. A gate, installed across the roadway, will either be locked or be under continual surveillance. Administrative and supervisory personnel located at the ML-1 facility act as an additional safeguard against sabotage.

The second situation that has significant radiological consequences is defined as the "maximum credible accident" (see Paragraph 2,below). This accident results from a gross failure of the primary coolant system, causing a sudden loss of primary coolant to the atmosphere. In addition, the safety circuitry provided for such an emergency fails to function, and the reactor power continues at the normal level until changes occur, due to melting within the core. Because little or no cooling is provided to the fuel elements,the cladding also melts. As cladding begins to drain out of the core, an increase in reactivity results. The subsequent increase in power hastens the melting of the uranium dioxide fuel, which drains out of the core and terminates the excursion. Calculations show that about 50% of the fuel will melt as a result of such an accident. The fission products released by the molten and unmolten fuel will be discharged to the atmosphere through the break in the primary coolant system,as natural convective forces cause coolant flow through the reactor core.

Under the most adverse weather condition, an incident cloud gamma dose of 7 rem will be received by a person in the auxiliary control building. The incident cloud gamma dose received by a person at the hearest off-site populated location (Atomic City) is 0.24 rem; the comparable thyroid gland dose is 3.1 rem.

The hazards associated with transporting the reactor package have been investigated. An accident is postulated in which a collision occurs during transit, causing the reactor shielding and pressure vessel to be ruptured and allowing exposure of the basic reactor core. Furthermore it is assumed that the core contains a high fission product inventory and that the core structure is highly activated. The consequences of such an accident were discussed in Appendix E to the original report.

In situations involving transportation of the ML-1 within the NRTS, this accident is not considered to be credible, inasmuch as all traffic is controlled by the U. S. AEC; travel may be restricted, as necessary, on roads being used for ML-1 movements. Hazards arising from the actions of aircraft flying over the NRTS are virtually eliminated, because the Station is a restricted area and is off-limits for all civilian and commercial aircraft. In general, transporting the ML-1 should be no more hazardous than moving irradiated fuel elements in a transport cask. The ML-1 radial shield and pressure vessel are fabricated to very high structural standards in order to satisfy the requirements of mobility.

A careful, detailed design, based on all available knowledge and supplemented by performance tests of critical components, has produced a safe power plant. This plant, coupled with an effective and efficient operating organization, should demonstrate that the ML-1 has the useful characteristics demanded in military applications.

B. TABULATION OF POWER PLANT CHARACTERISTICS

1. Site

a. Location - National Reactor Testing Station, Idaho

b. Exclusion distance - security fence 500 ft from reactor

c. Prevailing wind direction - from southwest during day, from northeast during night

d. Population direction, name, and distance -
Southeast, GCRE, 0.45 mile
Southeast, Atomic City, 6 miles

2. Operating Data

	Operating Data	Rated Value for 100°F Ambient Air Temperature
a.	Reactor thermal power	3.3 Mw (2.9 Mw into gas coolant, 0.4 Mw into moderator water)
b.	Net electrical power output	330 kw
c.	Reactor power density	700 kw/cu ft
d.	Reactor inlet gas pressure	313 psia

e.	Reactor outlet gas pressure	289 psia
f.	Reactor inlet gas temperature	$791^{o}F$
g.	Reactor outlet gas temperature	$1200^{o}F$
h.	Maximum fuel temperature for hot spot pin	
	1) Cladding surface	$1750^{o}F$
	2) Fuel center line	$2160^{o}F$ (UO_2-BeO pins) $2650^{o}F$ (UO_2 pins)
i.	Core operating lifetime	
	1) Initial	3,000 hr
	2) Ultimate, design	10,000 hr

3. <u>Reactor Core</u>

a.	Approximate dimensions of fueled volume	22 in. dia by 22 in. long
b.	Number of fuel elements	61
c.	Element configuration	Cluster of 19 pins (18 fueled)
d.	Number of control assemblies	6 total, all types
e.	Control assemblies design	Pair of tapered absorbing blades, rotated into core
f.	Moderator	Demineralized water
g.	Reflector	
	1) Top	2 in. water, 4.5 in. stainless steel, 1.5 in. tungsten
	2) Bottom	3 in. stainless steel, 3 in. tungsten
	3) Radial (toward power conversion equipment)	1.8 in. lead, 2 in. tungsten
	4) Radial (rear)	4 in. lead
h.	Core volume composition	<u>Volume Percent</u>
	UO_2 fuel	4.3
	BeO fuel diluent	2.8
	Hastelloy X fuel cladding	7.0
	Gas void, coolant passage	16.2
	Insulation & center pin void	7.5
	Stainless steel liners, tubes, etc.	3.6
	Water moderator	58.6

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i.	Heat capacity of fuel elements	
	1) Ceramic fuel only	45.1 kw sec/^{o}C
	2) Fuel and cladding	80.6 kw sec/^{o}C

4. Reactor Nuclear Data

a.	Neutron flux	
	1) Average thermal flux	1.9×10^{12} neuts/cm^2 sec
	2) Average fast flux	1.7×10^{13} neuts/cm^2 sec
	3) Maximum-to-average thermal flux ratio	3.9
b.	Critical mass, cold, clean, no fixed poisons	34 kg U^{235}
c.	Total core loading	49 kg U^{235}
d.	Hydrogen-to-U^{235} atom ratio	36
e.	Neutron lifetime	2.4×10^{-5} sec
f.	Temperature coefficients of reactivity	
	1) Fuel coefficient*	$+ 0.6 \times 10^{-6}$ Δk/k ^{o}C
	2) Moderator coefficient at 80^{o}C**	$+ 5 \times 10^{-5}$ Δk/k ^{o}C
	3) Moderator coefficient at 35^{o}C**	$+ 1.3 \times 10^{-4}$ Δk/k ^{o}C
g.	Moderator void coefficient	
	1) Reflector surface***	$- 1 \times 10^{-6}$ Δk/k cm^3
	2) Core average	$- 0.8 \times 10^{-6}$ Δk/k cm^3
h.	Effective reactivity, k_{eff}, cold, clean core	
	1) No shim liners	1.056
	2) With shim liners (operating core configuration)	1.015

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* Measured at GCRE
** Measured at ML-1
*** Measured at Battelle Memorial Institute Critical Facility

i.	Excess reactivity requirements for 10,000 hr operation		
	1)	Fuel depletion	+ 0.8% Δ k/k
	2)	Fission products, including samarium	+ 1.4% Δ k/k
	3)	Xenon fission product	+ 1.1% Δ k/k
	4)	Xenon override	+ 0.1% Δ k/k
	5)	Moderator temperature changes**	- 0.6% Δ k/k
	6)	Coolant gas pressure changes**	+ 0.1% Δ k/k
	7)	Control allowance for power changes	+ 0.3% Δ k/k
	8)	Total excess required	+ 3.2% Δ k/k
j.	Reactivity control available throughout 10,000 hr operation		
	1)	Burnable poison	2.20% Δ k/k
	2)	All control rods**	6.25% Δ k/k
	3)	Total available	8.45% Δ k/k
k.	Reactivity worth of single fuel element		
	1)	At core periphery **	0.45% Δ k/k
	2)	At core center	2.2% Δ k/k
# l.	Epithermal fissions, fraction		0.33
# m.	Thermal fissions, fraction		0.67
# n.	Neutron utilization, f		0.82
# o.	Thermal diffusion length, L		1.6 cm
# p.	Fermi age		92 cm^2
# q.	Buckling, B^2		0.0053 cm^2
# r.	U^{235} burnup in 10,000 hr		3.6%

5. <u>Fuel Element Assemblies</u>

a.	Fuel material	93.1% enriched U^{235} as UO_2
b.	Fuel weight, each element	800 gm U^{235} in 980 gm UO_2
c.	Overall dimensions of element	1.72 in. OD, by 32 in. long
d.	Number of pins, each element	19
e.	Fuel pellet density	96% theoretical density

** Measured at ML-1

Average value for non-uniform core

f.	Fuel pellet compositions	
	1) Center pin	No fuel, void
	2) Inner 6 pins	100 vol% UO_2
	3) Outer 12 pins	39.5 vol% UO_2,60.5 vol% BeO
g.	Heat transfer media inside pin	Helium
h.	Fuel pin cladding material	Hastelloy-X
i.	Pin cladding dimensions	0.241 in. OD,with 0.030 in. wall
j.	Burnable poison	Cadmium alloy tube
k.	Shim liner	Silver-plated stainless steel tube
l.	Equivalent diameter for coolant flow	0.0112 ft
m.	Coolant flow area through element	0.00492 sq ft
n.	Heat transfer surface area, each element	2.08 sq ft

6. Control Blade Assemblies

a.	Control assembly type	Two tapered absorbing blades operating in vertical arcs similar to a semaphore signal
b.	Number of control assemblies	
	1) Shim-scram assemblies	Five
	2) Regulating assembly	One
c.	Control blade materials	
	1) Shim-scram assemblies	Cadmium-indium-silver alloy (5-15-80 wt%,m.p. 1200°F)
	2) Regulating assembly	Stainless steel,AISI Type 202
d.	Blade dimensions	
	1) Shim-scram	10 in. long, 4 in. wide; tapered; 1/4 in. thick at tip, 5/8 in. thick at base
	2) Regulating	9 in. long, 4 in. wide tapered to 3.5 in.; 1/4 in. thick at tip; 5/8 in. thick at base

		Each, $\Delta k/k$	Total, $\Delta k/k$
e.	Reactivity worth of control assemblies		
	1) Shim-scram assemblies	1.48%*	5.84%
	2) Regulating assembly	0.44%*	0.41%
	Total		6.25%*

*Measured at ML-1

f.	Average reactivity insertion rates	Δ k/k sec
	1) Safety-shim assembly*	0.0066%
	2) Regulating assembly*	0.034%
g.	Maximum possible reactivity insertion rates	Δ k/k sec
	1) Single safety-shim assembly	0.0082%
	2) Regulating assembly	0.051%
	3) One shim-scram plus regulating	0.059%
h.	Scram times for shim-scram assemblies	
	1) Electronics delay	0.040 sec
	2) Breakaway lag	0.030 sec
	3) Insertion time	0.280 sec
	Total	0.350 sec

7. Reactor Pressure Vessel

a.	Overall dimensions	80 in. high, 31 in. dia
b.	General configuration	Two gas plenums connected by 61 pressure tubes
c.	Design pressures and temperatures	330 psia gas pressure; 800°F inlet and 1200°F outlet pressure; 30 psia water pressure, 190°F water temperature; effectively 300 psig and 400°F wall temperature
d.	Construction materials	
	1) Gas ducts, plenums and baffle supports	Stainless steels, Types 304-L and 321
	2) Tube-sheets	Stainless steel, Type 304-L
	3) Pressure tubes	Stainless steel, Type 321
e.	Miscellaneous dimensions	
	1) Gas ducts	10 in., Schedule 40 pipe
	2) Plenums	1.25 in. minimum wall thickness
	3) Pressure tube length	24 in. between inside surfaces of tube-sheets
	4) Pressure tubes	1.796 in. OD, with 0.020 in. wall

* Measured at ML-1

f.	Internal heat insulation		
	1)	Gas ducts and plenums	Three 0.015-in.-thick radiation shields uniformly spaced between the 0.090-in.-thick duct liner and vessel walls
	2)	Tube-sheet	Refrasil insulation blanket
	3)	Pressure tubes	0.1-in.-thick Thermoflex insulation liner in fuel elements
g.	Relief valve		
	1)	Number	One
	2)	Pressure	330 psig
	3)	Size	2-in.

8. <u>Primary Coolant System</u>

a.	Coolant		Nitrogen (99.5% N_2,0.5% O_2) or air
b.	Number of loops		One
c.	Number of coolant passes through core		One
d.	Total volume of primary system		120 cu ft
e.	Heat transfer area of core		127 sq ft
f.	Heat flux		
	1)	Maximum	137,500 Btu/hr sq ft
	2)	Average	80,500 Btu/hr sq ft
g.	Coolant flow rate through reactor		25.5 lb/sec
h.	Average velocity in coolant passages		160 ft/sec
i.	Pressure		
	1)	Inlet	313 psia
	2)	Outlet	289 psia
j.	Temperature		
	1)	Inlet	791°F
	2)	Outlet	1200°F
k.	Maximum fuel surface temperature		1750°F

l.	Compressor	
	1) Number	One
	2) Flow rate	26.1 lb/sec
m.	Heat sink	Direct to atmosphere, through a forced convection gas-to-air heat exchanger

9. Moderator Water System

a.	Type of water	Demineralized water
b.	Type of flow circulation	Forced convection
c.	Temperatures during reactor operation	
	1) Inlet to reactor	180°F
	2) Outlet from reactor	190°F
d.	Design heat load	1,500,000 Btu/hr
e.	Pumps	
	1) For reactor operation	One, pumping at 300 gpm
	2) For reactor shutdown	One, pumping at 15 gpm
f.	Miscellaneous	
	1) Volume capacity of system	375 gal
	2) Pressure on reactor vessel	19 psig

C. SUMMARY OF ACCIDENT ANALYSES

1. Miscellaneous Accidents

a. Reactor Control System

A withdrawal of any combination of control blades, starting from a subcritical condition, will not result in an accident provided the power rise is terminated by either the period safety circuit or the 110% power scram circuit.

b. Power Failure

ML-1 operations at NRTS will normally be accomplished with dual power sources. Substation power will be supplemented by an auxiliary diesel generator. Because the power plant is designed for field operation, a battery inverter system is provided to supply power to critical components during shutdown when no other auxiliary power source is available. If all power sources fail, no hazard will result until the moderator water is boiled out of the core, due to afterheat. If the water is not replenished, subsequent meltdown of the lead reflector may occur.

c. Water System Failure

No hazards result from failures of the water systems, as long as the core moderator passages remain filled. Failure of the main moderator pump will automatically scram the reactor. If the gas piping is ruptured within the tank,the core will be flooded with the borated shield water. Numerous safety devices, in addition to the large decrease in reactivity caused by flooding the core with borated water, will shut down the power plant. Flooding the gas passage with fresh water will not result in a critical condition as long as no more than a single pair of control blades fails to scram.

d. Fuel Addition

Inadvertent fuel element addition is not possible during normal operation of the power plant, due to the inaccessibility of the core region. Strict administrative and procedural controls will be exercised over all experiments that include addition of fuel to the core. Fuel loading will always be undertaken with at least one pair of scram blades in the cocked position.

e. Coolant Loss Accident Accompanied by Reactor Scram

A rupture in the primary coolant system is a significant hazard. The consequences of such an accident depend on the duration of reactor operation after the onset of coolant loss. Normally the reactor will scram immediately. This accident is expected to release a portion of the gaseous fission products to the atmosphere, in the form of a small cloud vented from the break in the coolant system.

f. Turbine-Compressor Set Operations Hazards

The primary hazard associated with a failure in the turbine-compressor set is the possibility that such a failure will subsequently cause a large rupture in the primary coolant loop. The loss (throwing) of a turbine blade is not expected to rupture the turbine housing. On the other hand, the disintegration of a turbine wheel will probably destroy the housing, resulting in loss of the primary coolant. The safety circuitry will automatically shut down the power plant if such a sudden loss of the coolant gas occurs.

g. External Physical Damage and Transportation Hazards

A transportation accident is not considered to be credible at the NRTS, inasmuch as ground and air traffic can be controlled to eliminate the possibility of a collision during transport.

h. Sabotage

An accident is postulated in which the control blade interlocks and the scram system are altered to permit simultaneous withdrawal of all blades. The power rise is terminated by core vaporization, resulting in an explosive disassembly of the reactor vessel.

i. Hydrocarbon Explosion With Air Coolant

In normal operation the concentration of hydrocarbons in the loop is maintained at a level below 1 ppm by utilizing air buffers on the turbine-compressor bearings and by continuously cleaning up the loop. The hydrocarbon level is continuously monitored to permit the operator to take action before any dangerous condition is approached. However, multiple mechanical failures could permit gross amounts of lubrication oil to be introduced into the loop without corrective action being taken. Under these conditions inflamation or detonation could occur, causing rupture of the main gas loop and resulting in a coolant loss accident as described in paragraph e above.

2. Maximum Credible Accident

a. Description of Accident

The maximum credible accident is considered to be the result of a sudden loss of the primary coolant gas to the atmosphere, accompanied by failure of the scram system to shut down the reactor. Following loss of coolant gas, the reactor will continue to operate at a constant power level; this will cause the Hastelloy fuel pin cladding to melt within the core. As the cladding begins to drain out of the central regions of the core, the reactor is placed on a positive period. This, subsequently, results in melting of the ceramic fuel, which drains out of the core and terminates the excursion. Radioactivity is released as the fission products escape from the system at the location of the failure.

The presence of air coolant in the loop during this accident will result in partial oxidation of the melted cladding material. The energy release from this reaction is small, and there is no appreciable change in the radiological consequences of the accident as compared to those associated with nitrogen coolant.

b. Resultant Radiological Hazards

A gross radioactivity release of approximately 1.6×10^6 curies results from this accident. Personnel within the control building will receive an external cloud gamma dose of 7 rem. Personnel at the nearest off-site populated area will receive an external cloud gamma dose of 0.24 rem and a thyroid gland dose of 3.1 rem. These dosages are applicable for inversion weather conditions.

II. DESIGN AND OPERATIONAL CHANGES

This section of the report describes significant design and operational changes made to the ML-1 power plant since publication of the Hazards Summary Report in November 1960. Included are discussions of: the fuel element, refueling and leak-detection procedures, uses of 17-4 PH stainless steel, control blade locking mechanisms, moderator deoxygenation, and modifications to the primary systems piping and instrumentation.

A. FUEL ELEMENT

No major changes have been made to the ML-1 fuel elements; however, based on operational experience with the IB-2L core in the GCRE reactor, modifications have been made to the slip joint in the vicinity of the insulation.

Although miscellaneous failures occurred in the IB-2L core that did not pertain directly to design inadequacies, the major difficulties are believed to be explained by the following hypotheses: 1) The slip joint in the IB-2L elements, between the inner and outer liners, became restrained in many cases; 2) the thermal expansion of the inner liner subsequently sheared the upper roll pins and pressed the hangers out of the bells at the top of the elements; and 3) the thermal expansion caused the points of the fuel pins to come out of the lower spider in several cases.

During the last reactor operating cycle, there were no signs of fuel element difficulties. Therefore, there is evidence that the failures did not hamper operations and had no adverse effects on reactivity or nuclear safety.

Tests were made to determine the need for modifications to the ML-1 elements; the procedure was as follows: A mockup of the fuel element shell (inner liner, outer liner, insulation, poison assembly and expansion joint) was placed in a tensile testing machine and cycled through 0.250 in., the anticipated amount of relative motion between the inner and outer liners during reactor heat-up and cool-down. In two cycles, the force required to affect the relative motion exceeded 1100 lb and broke the test fixture. This force was far in excess of the 600 lb necessary to shear the pins and to cause the kind of separation that is evident in the IB-2L fuel elements. Examination of the mockup disclosed that the Thermoflex insulation had become tightly wedged between the poison assembly and the liners. As a result, the insulation acted as a friction clutch between the liners to prevent the expansion joint from moving; the inner liner could move only in an upward direction,thus causing the pins to shear and the element to separate.

Therefore, it was decided to modify the shell assembly as follows: Slots were fabricated in the nose piece, and the Thermoflex insulation was stripped back a distance of 1/2 in. past the expansion joint to eliminate any possibility of jamming. A mockup of this assembly was tested by immersing it in water and then drying it to duplicate actual operating conditions. The mockup was cycled 50 times to generate experimental data on which to base the modified design. At this time, all ML-1 fuel elements have been modified to the configuration of the test model.

It is not anticipated that the ML-1 fuel elements will separate as did the IB-2L elements, for two reasons: 1) The poison package in the ML-1 elements takes up less room (0.012 in. versus 0.032 in. in thickness), and 2) the insulation in the ML-1 elements is not as tightly packed. If any deposition should occur on the expansion joint, it is expected that the slots in the nose piece will expand to prevent the type of seizure that occurred in the original design.

B. REFUELING AND LEAK-DETECTION PROCEDURES

1. Refueling

The ML-1 reactor must be shut down when fuel elements leak fission products because these products will, in time, seriously contaminate the power conversion package and make direct maintenance very troublesome. The replacement of "failed" fuel elements follows the same procedure as that utilized for refueling the whole core; the only significant difference is in the number of elements handled.

In general, the procedure for refueling the ML-1 is similar to that for all swimming pool reactors. Essentially the same in both cases are extension tools for unbolting the shielding parts and reactor flanges, the gripper tools for handling the fuel elements, and the coffins for the elements. The proposed method is applicable both to refueling in the test building at NRTS and to refueling under military field conditions. However, there are differences in the equipment requirements of the two situations, as outlined in Table 1, on the following page.

Refueling operations begin after the reactor has been shut down long enough to permit access to the surrounding work areas. During the waiting period, the coolant is pumped out of the primary circulating system to reduce the gaseous activity as much as possible. The procedure is based on the following assumptions:

1 Approximately 45 kw of standby electrical power is available in part for the refueling operation.

2 Radiation levels at personnel bridge over tank will not expose personnel to dose rates above 7-1/2 mr/hr, for a total of 300 mr/week.

3 For maintenance at temperatures below 40°F ambient, an environmental shelter is to be used. (It is recommended that an environmental shelter be used under all field conditions to prevent contamination of the shield water by atmospheric dust and dirt.)

4 For operations under field conditions, at least one 6 x 6 military truck with a power winch is available.

5 Standard military 600- or 1200-gph water treatment equipment is available.

6 During transfer of fuel to the transportation cask, an exclusion area is required around the standpipe.

7 For operations under field conditions, the reactor package is placed on temporary shoring and leveled to distribute the increased load due to the auxiliary shielding water.

8 No provisions are made for disposing of the shielding water if it is contaminated with fission products.

TABLE 1

EQUIPMENT REQUIREMENTS FOR REFUELING OPERATIONS

Under Military Field Conditions:	At Test Building (NRTS):
Temporary shoring	Personnel bridge
Upper removeable shield bolt tool	Fuel element handling tool (short)
Two hoists (1- and 2-ton)	Reactivity shim handling tool
	Instrument cutters

In Both Situations:

Auxiliary shield tank (5600 gal)
Scaffolding
Upper removeable shield sling
Plenum cap sling
Plenum cap bolting tool
Upper gas duct seal bolting tool
Cask positioner
Transportation cask (19-element capacity)
Fuel hold-down plate tool
Fuel element handling tool (long)
Neutron source tool
Expedient shielding
Core flooding and venting flanges
Graylok seal removal tools
Core after-cooling equipment

Refueling is undertaken as outlined in the following steps (see Figure 1):

1 Shut down reactor.

2 Disconnect reactor from power-conversion skid and move to prepared refueling site.

3 Install vent flange on upper gas duct.

4 Install core flooding flange on lower gas duct.

5 Erect scaffold towers and guy to ground.

6 Erect personnel bridge and install hoists.

7 Drain 10-in. shield tank extension.

8 Remove reactor tank cover and shield tank extenstion.

9 Erect 11-ft auxiliary shield tank rubber liner and seal ring; secure seal ring to reactor tank by means of the lid latches.

10 Inflate the pneumatic seal.

11 Drain the borated shield water from the reactor tank.

12 Flush the shield tank with demineralized water to remove boric acid.

13 Fill reactor tank and auxiliary shield tank with demineralized water.

14 Place transportation cask positioner in place below standpipe discharge.

15 Pull transportation cask up positioner ramp by means of the winch, and raise ramp section up until it is horizontal.

16 Remove pressure seal,radiation plug,and storage rack from cask.

17 Position cask beneath standpipe opening,and by rotating turnbuckles lower the discharge pipe flange into contact with the cask flange.

18 Attach the Graylok clamp manually and tighten in place.

19 Open the bypass valve and flood the cask with water. Check the cask drain valve to be sure it is closed.

20 Loosen the captive bolts that attach the removable upper shield to the permanent shield, with the shield bolting tool.

21 Lower the removable shield sling into the tank with the 1-ton hoist, and engage the lifting eyes on the shield.

22 Hoist the shield clear of the tank and place on the floor alongside the reactor skid.

(1) Disengage the hoist, leaving the sling attached to the shield.

(2) Monitor area around shield and rope off if necessary.

REFUELING EQUIPMENT

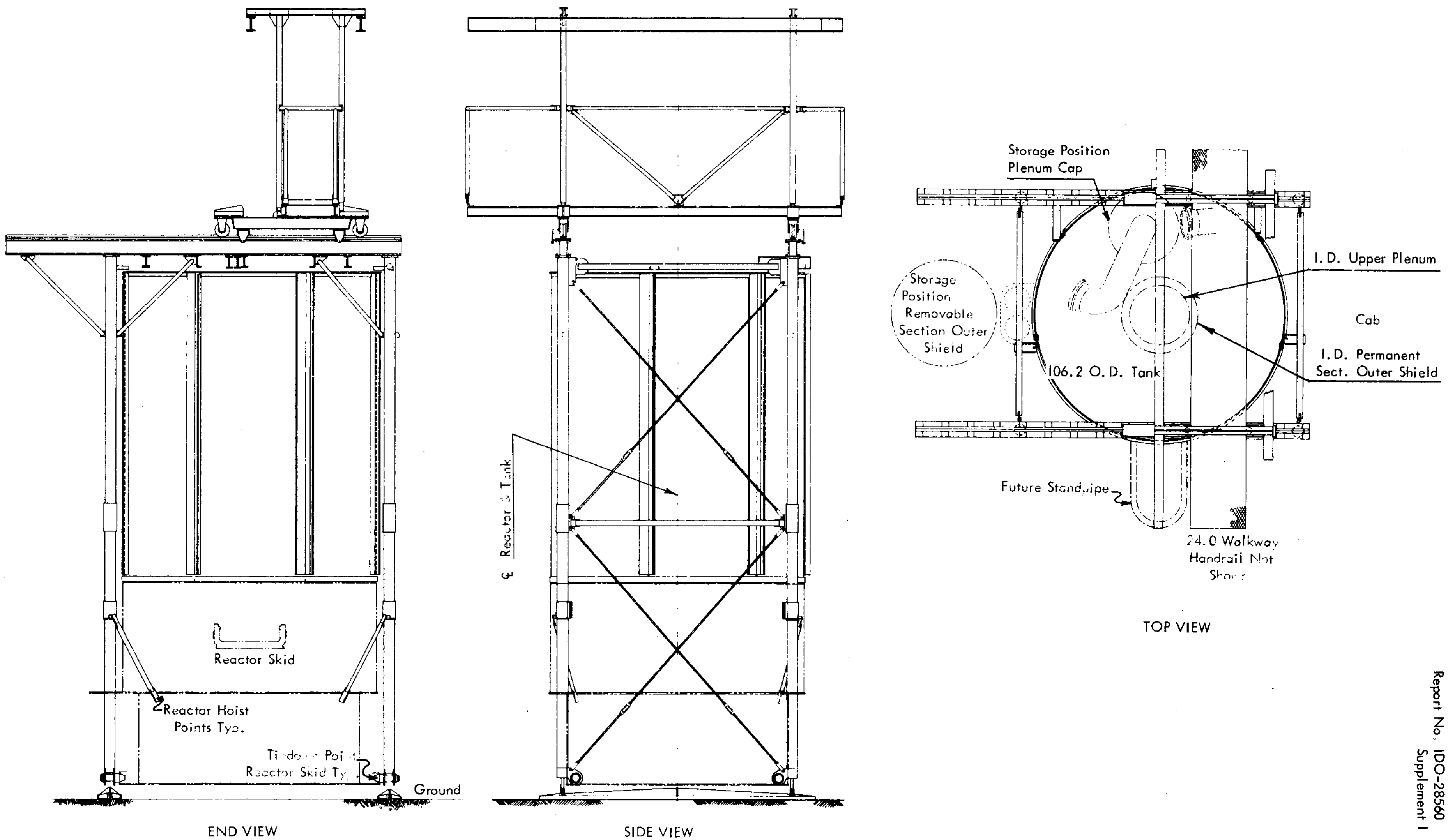


FIGURE 1

23 Attach after-cooling hose from the p-c skid to the lower gas duct flange and motor the turbine-compressor to circulate cooling gas through reactor core.

(1) Disconnect the after-cooling hose and connect the flooding hose to the lower gas duct flange.

(2) Introduce demineralized water into the core. Open the core vent valve and check for steam formation; when water comes out of vent, stop flooding operation and close vent valve.

24 Raise 4 sections of expedient shield into place with the 1-ton hoist and secure shielding to the scaffold.

25 Unbolt the upper gas duct Graylok seal by screwing the clamp holding tube into the clamp;support this from the 1-ton hoist.

(1) Engage the clamp bolt with the universal joint bolting tool and move the tool to the vertical position.

(2) Attach a wrench to the square drive-shank on the tool and loosen the clamp bolt completely.

(3) Slide the clamp assembly down onto the fixed end of the gas duct,keeping the bolting tool engaged if possible.

(4) Loosen the gas duct stub from the outside of the shield tank and retract the duct at least 1-in., compressing the bellows seal as much as possible.

(5) Check visually to be sure that the Graylok seal lip has cleared the flange of the duct which is to be removed.

26 Lower the plenum cap sling into place above the exposed plenum cap with the 2-ton hoist.

(1) Align the sling so that the cross-bar of the T straddles the gas duct.

(2) With the extension bolting tool screw the 3 captive bolts on the fixture into the holes tapped in the plenum cap.

(3) Raise the hoist sufficiently to tighten the load cable slightly.

27 Remove each nut individually and bring it to the nut storage rack by using the plenum cap bolting tool with a 7/8-in. standard socket attached.

(1) Use the special crows-foot extension to remove the 2 nuts partially hidden under the gas duct and place the nuts in the nut storage rack.

(2) Inventory nuts to be sure that they have all been removed from the plenum studs.

28 Raise the hoist slowly and remove the plenum cap.

(1) Observe the gas duct seal to be sure that the insulation liner has not fouled on the lip of the Graylok seal.

(2) Hold the plenum cap so that it does not swing around until it is clear of the plenum.

29 Raise the plenum cap until it is at the same level as the external shield, and move the hoist along the rail until the plenum cap is as close to the extension tank wall as possible and well behind the shield.

(1) Health physics personnel will survey the area outside the expedient shield to be certain that the cap is properly positioned.

30 Engage the hook in the eye of the standpipe outlet cover with the 1-ton hoist; raise the cover to the surface and store outside the tank.

31 Lower the fuel hold-down plate tool over the center fuel hole.

(1) Press down on the tool and rotate counter-clockwise until the 3 forks are engaged under the lifting buttons on the hold-down plate.

(2) Raise the hold-down plate from the core and store it in the same area as the plenum cap.

32 Lower the fuel element storage rack into the shield tank by using the 1-ton hoist.

(1) Place the rack as close to the core opening as possible without obstructing the view of the core face.

33 Lower the fuel handling tool into the core area.

(1) Ascertain that the gripping jaws are open, and lower the tool over the desired element.

(2) Allow the tool to rest on the element, and flip the lever handle over to close the jaws on the fuel element.

(3) Raise the fuel element from the pressure tube slowly, being careful not to exert any side forces on it.

(4) Place the fuel element in one of the holes on the inner circle of the storage rack.

34 Repeat step 33 until the inner circle of the storage rack is filled with elements. Then load the holes on the outer circle of the rack, until 19 fuel elements have been inserted in the rack.

35 Clear the exclusion area around the cask and the standpipe of all personnel.

(1) Health physics personnel will monitor this area during the loading operation.

36 Move the storage rack to the transfer opening in the shield tank wall.

(1) Transfer the loaded rack through the opening to the standpipe area.

37 Lower the loaded rack, by means of the hoist, through the manhole into the transportation cask.

(1) Disengage the hoist and remove from the standpipe area.

38 Lower the cask plug into the standpipe by means of the 1-ton hoist, dropping the plug through the manhole into place on the cask.

(1) Disengage the hoist from the plug lifting eye.

39 Lower the manhole cover into the standpipe, in place over the manhole outlet.

(1) Monitor the cask and surrounding area for radiation before allowing personnel in the vicinity.

40 Manually open the drain valve on the bottom of the cask.

(1) If water is contaminated it must be collected in a suitable container.

41 Manually loosen the Graylok clamp securing the cask to the standpipe, and allow the clamp to lie on top of the cask.

(1) Rotate all turnbuckles on the tank flange to raise the seal clear of the cask flange.

(2) Place the blank seal cover over the cask flange and replace the Graylok clamp.

(3) Tighten the Graylok clamp after all water has drained from the cask.

(4) Close the cask drain and bolt on the safety cover.

42 Lower the ramp jacks.

(1) Disconnect all positioning screws from the cask base.

(2) Turn the winch handle thus allowing the cask to move down the ramp to the ground level.

(The loaded cask is now ready for transportation to the processing area.) Remove the remaining 42 fuel elements by repeating steps 16 through 19 and 32 through 42. To refuel the core with used fuel elements that have too high a radioactivity level for manual contact, follow the above procedure in reverse order.

Refuel the core with new "cold" fuel elements by using the following procedures:

43 Remove new fuel element from the transport container and attach to fuel element tool.

(1) Lower the fuel element into the core hole using visual alignment.

(2) Release the gripping fingers and remove the tool.

44 Repeat step 43 until the core is loaded.

45 Move the hold-down plate tool with the plate attached over the core and lower the plate into place.

46 Ascertain that orientation is correct and that all fuel elements are properly engaged in the holes in the plate.

(1) Push down slightly on tool and rotate clockwise to remove it.

47 Move the hoist holding the plenum cap back over the center of the reactor.

(1) Lower the plenum cap down into place being careful to engage the 2 guide dowels through the proper bolt holes.

(2) Lower the cap while noting the clearance between the plenum cap gas duct and the fixed gas duct stub.

48 Pick up a 7/8-in. nut from the nut storage rack, with the plenum bolting tool, and screw the nut down over the plenum stud.

(1) Repeat this operation for all nuts except the 2 under the gas duct which require the use of the special crowsfoot wrench.

49 After all nuts are hand-tight attach the torque wrench to the extension handle and tighten all bolts uniformly to 300 ft-lb.

50 Release the upper gas duct bellows from the cask exterior and allow the gas duct stub end to re-engage the plenum gas duct.

(1) Slide the clamp up over the joint, using the Graylok clamp tool.

(2) Tighten the clamp screw by using the extension bolting tool.

(3) Attach the torque wrench and tighten the Graylok to 600 ft-lb minimum; remove all tools.

51 Open the vent valve on the upper gas duct blank flange.

52 Open the drain valve on the lower gas duct blank flange and allow the core water to drain out. NOTE: If the water is contaminated it will require special handling and disposal.

53 Close all vents and drains after the water has been emptied from the core and connect a source of clean dry air or nitrogen at 400 psig to the core.

(1) Pressurize the core and check both the plenum seal and the upper gas duct seal for leakage.

(2) Re-tighten bolts where necessary.

(3) Release pressure and vent to atmosphere.

54 Lower the upper removable shield into place over the locating dowels. Unhook the sling and remove it from the tank.

(1) Tighten the captive bolts to 150 ft-lb, using the extension bolting tool and torque wrench.

55 Drain the auxiliary shield tank. NOTE: If the water is contaminated it will require special handling.

56 Remove the personnel bridge and the auxiliary shield tank.

57 Re-install the 10-in. tank extension and lid on the reactor tank.

58 Remove the hoists and scaffold towers.

59 Drain the demineralized water from the main shield tank.

60 Remove the upper and lower gas duct blanking flanges.

61 Move the reactor package to the power-conversion skid and reconnect all lines.

62 Refill the main shield tank with borated water solution.

63 Drain the borated water from the moderator system and flush thoroughly.

64 Refill the moderator system with demineralized water. (System is now ready for startup.)

Replacement charging of new fuel elements may necessitate carrying out critical experiment procedures; this will depend on the number and positions of the elements being replaced.

2. Fuel Element Leak Detection

The system for locating a defective fuel element has been changed from that proposed originally (which required open-cycle air flow through the reactor at low reactor powers). The new system operates with the reactor shut down and the core fully flooded, and is based on the phenomenon that the level of radioactive iodine in a stagnant pool increases sharply if a defective fuel element is submerged in the pool.(*) "Soaking" periods of 10 to 30 minutes have resulted in factors of from 4 to 10 increase in the iodine level.

After the ML-1 reactor is flooded, the individual columns of water contained in the pressure tubes are to be sampled. The water samples will be analyzed for iodine-131 content and compared to a water sample representative of the core flooding water. The failed fuel element detection equipment is shown in Figures 2 and 3. Figure 2 shows a single sample bottle connected to a single fuel element; Figure 3 shows the entire assembly being lowered into a test tank.

The detection procedure is to be carried out as follows: The upper cap and fuel element hold-down plate are removed, and the core is flooded. A support plate containing 61 sample bottles, arranged in the same pattern as are the ML-1 fuel elements, is positioned over the core. Each fuel element is sealed to a sample bottle by an O-ring bonded to the bottle cap. Each bottle is connected to a vacuum tank through a solenoid valve (normally closed), a distribution header, and Tygon tubing. Prior to lowering the assembly into the reactor, the vacuum tank is

(*) "Locating Failed Fuel in Water Reactors," R.N. Osborne, Nucleonics July 1961 pressurized to approximately 2 psi; and each of the 61 spring ball check-valves is manually opened to collapse the corresponding sample bottle accumulator. The vacuum tank is then evacuated (to 30 in. Hg - gauge) with both the solenoid valve and the manual shut-off valves closed. The assembly is lowered into the reactor core and bolted in place in the upper plenum by three captive nut plates.

After the prescribed soaking period has elapsed (approximately 30 minutes), the solenoid valve is opened. This creates a vacuum in each sample bottle, thereby opening the ball check-valve and allowing water from each fuel element to fill the corresponding bottle. When the bottle is full, the ball check-valve closes. Each sample bottle contains 150 - 200 cc water.

The equipment is removed from the reactor and disassembled. Each water sample undergoes examination by means of a pulse-height analyzer to determine iodine content.

Handling the sampling equipment after immersion in the reactor core does not appear to present any significant radiological hazards. Surface dose rates are calculated to be 2 - 4 mr/hr for a single sample bottle containing radioactive products from one defective fuel element. A multiple number of defective pins would cause proprotionately higher dose rates. The sampling equipment is to be monitored after removal from the reactor; and, depending on the level of radioactivity, appropriate action will be taken.

A preliminary feasibility test of the detection method has been carried out with an AGN 201 reactor, under the following conditions:

Reactor power	5 watts
Pin power	.05 watts
Irradiation time	2.75 hours
Time of immersion	20 hours after irradiation
Period of immersion	2 hours
Time of pulse-height analysis	44 hours after irradiation
Pin defect size	18-mil diameter

Iodine-131 and -133 were identified on a pulse-height analyzer.

A more sophisticated test (OETP-632, Failed Fuel Element Detection Experiment) with a full-size IB-2L fuel pin containing a 5-mil-diameter defect will be carried out at the GCRE in the near future. The test will establish the length of the soaking period and the sensitivity of the detection equipment at low-power operation.

FAILED FUEL ELEMENT DETECTION EQUIPMENT

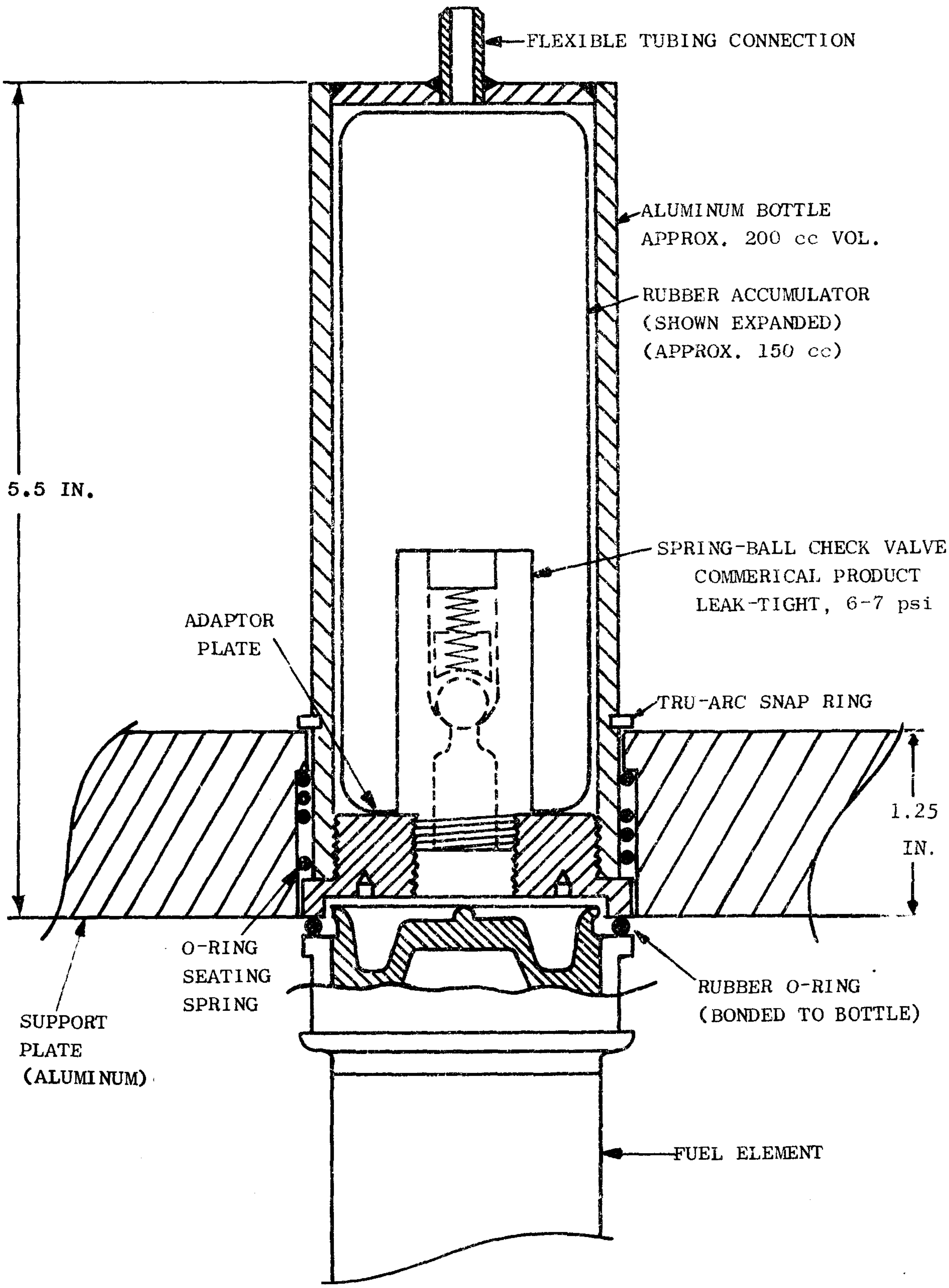


FIGURE 2

FAILED FUEL ELEMENT DETECTION EQUIPMENT

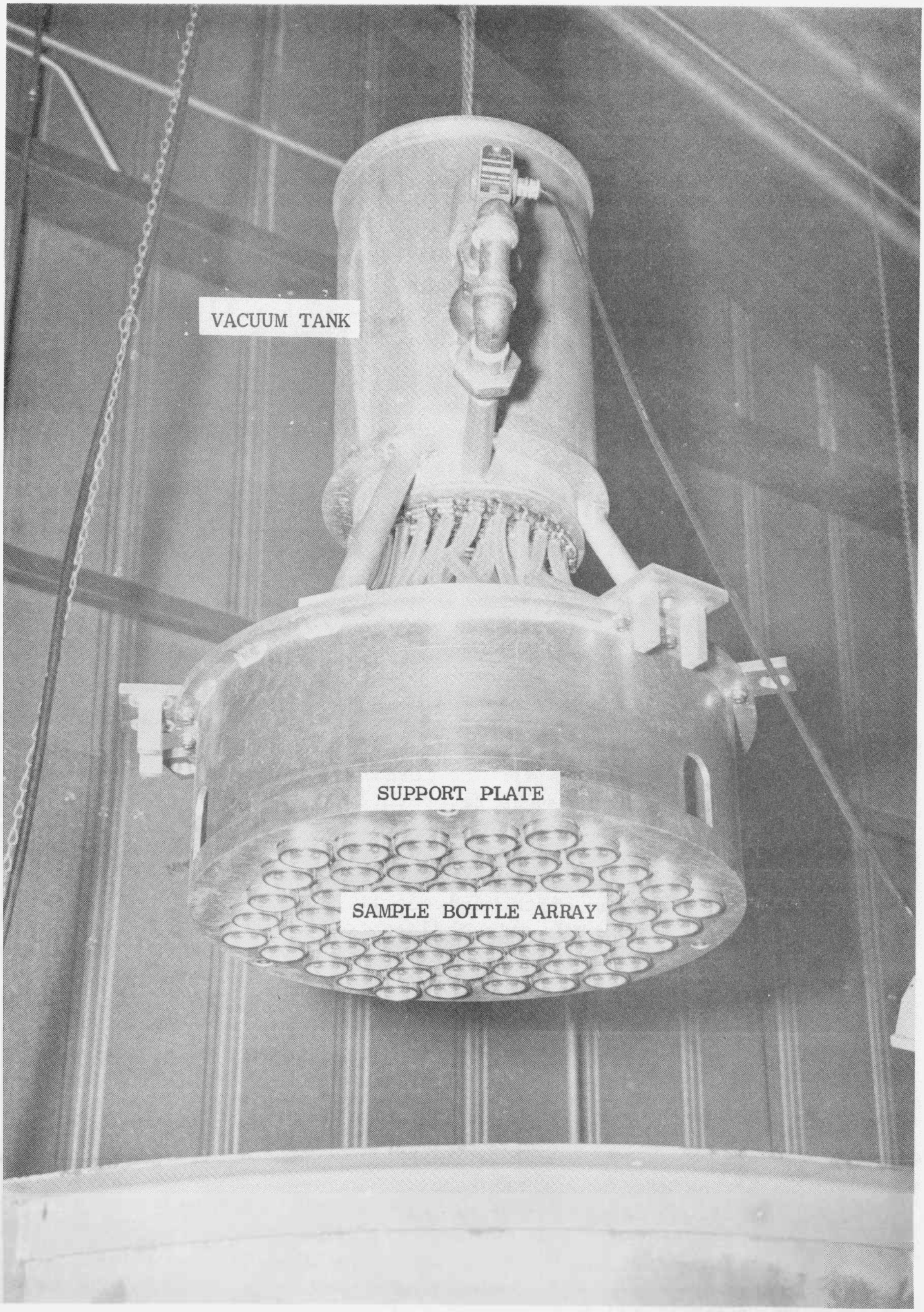


FIGURE 3

C. USES OF 17-4 PH STAINLESS STEEL

Table 1 on pages 30 and 31 lists ML-1 components containing 17-4 PH stainless steel. The 17-4 PH material heat-treated to a temperature of 900°F is used in:

1. The bolts that secure the radial shield structure to the upper and lower plenums

2. The studs that secure the pressure vessel cap to the upper plenum

3. The bolts that secure the reflector and blade mount shield to the upper and lower plenums

The maximum temperature expected in these locations is 190°F.

Because of possible hazards associated with failure of the pressure vessel, the studs securing the pressure vessel cap to the upper plenum (item 2) will be replaced with 17-4 PH stainless steel heat-treated to 1050°F. After careful reviews of stresses and temperatures involved, it is concluded that in all other applications, 17-4 PH stainless steel as used is a reliable material and failures will not result in any hazardous conditions.

D. CONTROL BLADE LOCKING MECHANISMS

There are two mechanisms for locking the control blades in the reactor core:

The first mechanism consists of a spring-loaded pin that locks the limit switch arm of the actuator in position with the limit switch support (see Figure 4). By forcing the clutch to slip, the mechanism will override any attempts to operate the actuator electrically.

The second mechanism is used when an actuator is removed. Immediately after removal of an actuator, the driveshaft locking fixture is placed over the tang of the driveshaft and flat on the actuator support structure. The spring pin chained to the fixture is inserted through holes in the fixture and in the support structure, locking the fixture to the structure. Figure 5 illustrates the method of locking the shaft.

The existing clock-type holding spring exerts a torque of approximately 30 in.-lb to hold the blades in the scrammed position. This torque is sufficient to require a wrench on the tang of the driveshaft to override the spring intentionally and cause the blades to open.

The blades are unbalanced; the upper blade is heavier than the lower blade. The blades weigh approximately 6.2 and 5.4 lb, respectively. The center of gravity of each blade is approximately 5.8 in. from the axis of the drive shaft. Consequently, shock loads in a downward direction will tend to close the blades.

Shock loads in an upward direction produce approximately: (6.2 - 5.4) lb x 5.8 in., or 3.5 in.-lb/g. Therefore, a shock load equivalent to 30 in.-lb / 3.5 in.-lb-g, or approximately 8-1/2 g is required to equalize the closing torque.

During horizontal shock loads, one set of control blades will be subjected to a maximum opening force; two other sets will receive lesser opening forces; and three sets will receive closing forces. The center of gravity of the blades is approximately on a line passing through the axis of the drive gears at 5° from horizontal. Shock loads produce approximately: $(6.2 + 5.4) \times 5.8 \sin 5^{\circ}$, or 5.9 in.-lb/g. Therefore, a horizontal shock load of 30 in.-lb / 5.9 in.-lb-g or 5.1 g is required to equalize the closing torque.

When the reactor is being transported, either the actuators or the drive shaft locking fixtures will be in place (as described in Paragraph D_3 above) to augment the action of the holding spring in maintaining the blades in the scrammed position.

During maintenance, it is possible to remove the dashpot assembly in addition to the actuator mechanism, although this will be done only infrequently. With the dashpot removed, the blades are held in the core by gravity (due to the weight inbalance between the upper and lower blades) and friction. In this condition, it is relatively easy to actuate the blades out of the core. However, maintenance will be performed on only one blade at a time, and the actuator housings are locked to prevent inadvertent manipulation. The reactor will remain subcritical under all conditions even if any two pairs of blades are withdrawn. Therefore, no credible hazardous situation will occur due to unlocked blades. The blades will be positively locked during all transport.

E. DEOXYGENATION OF MODERATOR WATER

The ML-1 moderator water will be deoxygenated to an oxygen concentration below 0.1 cc/ml, in order to minimize crevice corrosion of the stainless steel pressure tubes. Techniques based on mechanical deaerators and deoxygenating ion-exchange resin columns are being evaluated for application in the ML-1 system.

F. PRIMARY SYSTEMS

An up-dated piping and instrumentation diagram for the ML-1 primary systems is shown as Figure 6. Changes made to the diagram since November 1960 include the following:

1 Moderator water drain lines modified
2 Neutron detector relocated
3 Reactor tube sheet temperatures added
4 Fuel element temperatures added
5 Precooler louver control removed
6 Coolant bypass piping changed
7 Lubricating oil piping re-routed
8 Alternator cooling lines added

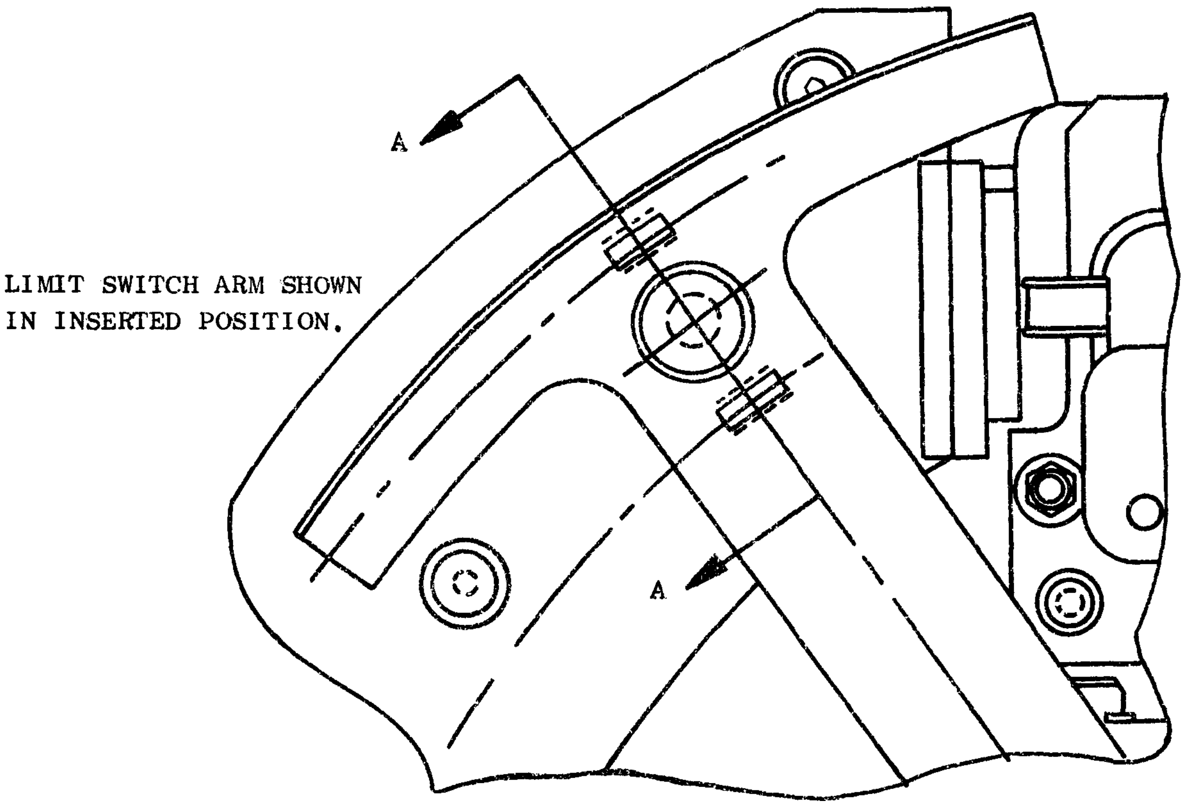
TABLE 2: USES OF 17-4 PH STAINLESS

PART DESCRIPTION	DRAWING NO.	POSITION IN THE REACTOR	SPECIFICATION PROCUREMENT OF MAT'L	MANUFACTURING PROCESS
CONTROL BLADE SUPPORT	1-408731	IN MODERATOR WATER ON SHELL SIDE OF CORE TUBE BUNDLE 185°F OPERATING WATER TEMP. 220°F MAX. WATER TEMPERATURE	AERONAUTICAL MATERIAL SPEC. AMS 5355	PRECISION CAST, WELDED, STRESS RELIEVED, MACHINED & INSPECTED (WELDED TO 1-408734)
BEARING BLOCKS	1-408734	SAME AS ABOVE	AMS 5355	PRECISION CAST, WELDED, STRESS RELIEVED, MACHINED & INSPECTED
SPACER BLOCK	1-408740	SAME AS ABOVE	AMS 5643	MACHINED, HARDENED, & INSPECTED
CONTROL BLADE GEARS	1-408654	SAME AS ABOVE	AMS 5643	VENDOR: ADVANCE GEAR & MACHINE CO. LOS ANGELES SOLN. TREATED, ROUGH MACHINED, AGED, MAGNAFLUXED FINISHED BY GRINDING, INSPECTED (MAGNAFLUX)
SPLINE, CONTROL BLADE SHAFT	1-408715	SAME AS ABOVE	AMS 5643	VENDOR: ADVANCE GEAR & MACHINE CO. LOS ANGELES SOLN. TREATED, ROUGH MACHINED, AGED, MAGNAFLUXED, FINISHED BY GRINDING, INSPECTED (MAGNAFLUX)
SHAFT, CONTROL BLADE	1-408724	SAME AS ABOVE	AMS 5643	ROUGH MACHINED, AGED, FINISHED MACHINED, AND INSPECTED
BUSHING, BEARING HOUSING	1-408739	SAME AS ABOVE	AMS 5643	ROUGH MACHINED, AGED, CHROME PLATED, FINISHED BY HONING CHROME PLATE, INSPECT
BOLTS, RADIAL SHIELD	1-408968-28	SECURE RADIAL SHIELD STRUCTURE TO UPPER AND LOWER PLENUMS IN 3" SHIELD WATER ANNULUS	AMS 5643	ROUGH MACHINED, AGED, FINISHED BY GRINDING & INSPECTED
STUDS	1-423972	SECURE PRESSURE VESSEL CAP TO UPPER PLENUM	AMS 5643	ROUGH MACHINED, AGED, THREADS FINISHED BY GRINDING, AND INSPECTED
NUTS	1-423969	SECURE PRESSURE VESSEL CAP TO UPPER PLENUM	AMS 5643	ROUGH MACHINE, GRIND THREADS, INSPECT
GRAYLOC SCREW	--	UPPER GAS DUCT CLAMP SCREW FOR 10" GRAYLOC FLANGE	AMS 5643	AGED, FINISH MACHINED, AND INSPECTED
BOLTS, RELFECTORS & BLADE MOUNT SHIELDS	1-423444	SECURE SUPPORT FEET TO UPPER & LOWER PLENUMS MODERATOR SIDE OF PRESSURE VESSEL	AMS 5643	ROUGH MACHINED, AGED, SHANK GROUND, THREADS ROLLED, PASSIVATED & INSPECTED.

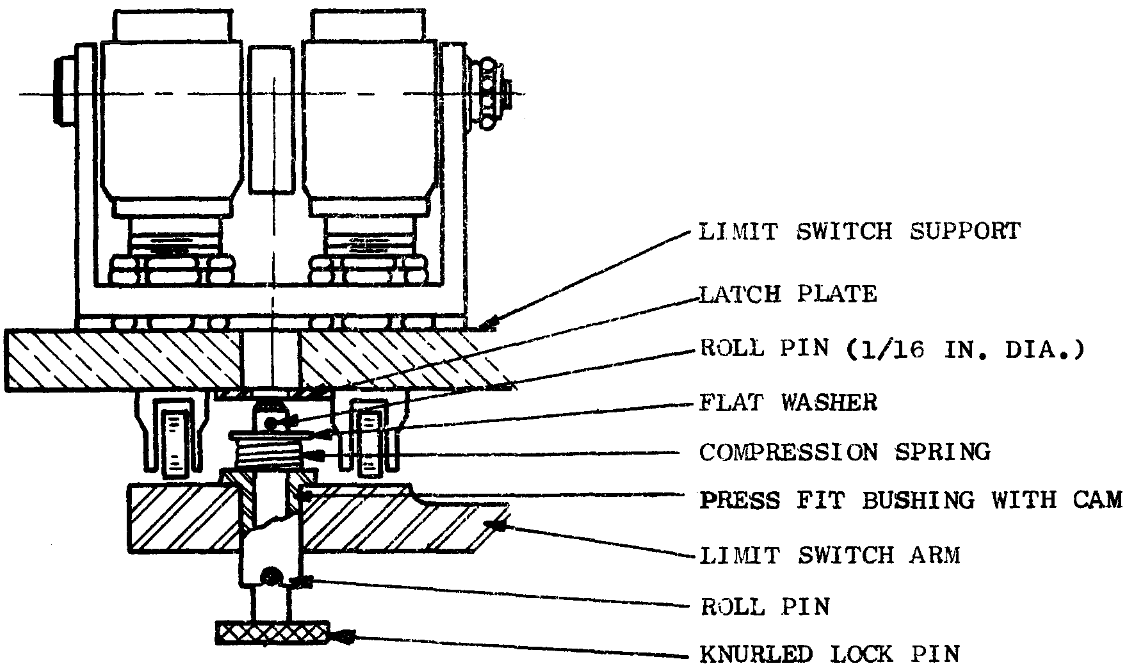
STEEL IN ML-I REACTOR PACKAGE

HEAT TREATMENT TEMP., TIME	METHOD OF COOLING	HARDNESS SPECIFIED	HARDNESS OBTAINED	NON-DESTRUCTIVE TESTS	PLATING	COLD WORK AFTER SOLN. TREATMENT
1900°F 15 MIN.	AIR COOL	NONE	--	X-RAY OF CASTING AT HIGH STRESS AREA ONLY	NONE	NONE
1900°F 15 MIN.	AIR COOL	NONE	--	NONE	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 1100° 3 HRS.	AIR COOL	Rc 32-36	Rc 38-39	NONE	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 1130°F 90 MIN.	AIR COOL	Rc 32 MINIMUM	Rc 37-39	MAGNETIC PARTICLE INSPECT PER MIL-I-6868	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 1130°F 90 MIN.	AIR COOL	Rc 32 MINIMUM	Rc 34-35	MAGNETIC PARTICLE INSPECT PER MIL-I-6868	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 1000°F 60 MIN.	AIR COOL	Rc 32-36	Rc 36-38	NONE	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 1100°F 2 HRS.	AIR COOL	Rc 32-36	Rc 32-36	THICKNESS OF CHROME PLATE CHECKED BY MAGNAGAUGE	.001" THICK CHROME PLATE PER QQ-C-320 CLASS 2 TYPE II	NONE
SOLN. TREAT PER AMS 5643 AGE: 900°F 75 MIN.	AIR COOL	Rc 38-45	Rc 38-45	NONE	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 900°F 60 MIN.	AIR COOL	Rc 41-45	Rc 41-47	NONE	NONE	NONE
SOLN. TREAT PER 5643 NOT AGED	NOT APPL	NONE	28-32	NONE	NONE	NONE
SOLN. TREAT PER 5643 AGE: 1150°F	AIR COOL	NONE	Rc 32	NONE	NONE	NONE
SOLN. TREAT PER AMS 5643 AGE: 900°F	AIR COOL	NONE	Rc40-45	MAGNETIC PARTICLE INSPECTION	NONE	NONE

MECHANICAL STOP ON ML-1 ACTUATOR



TO LOCK: TURN PIN 90° & RELEASE SPRING TO DRIVE PIN INTO HOLE IN LATCH PLATE.



SECTION A-A

FIGURE 4

DRIVESHAFT SAFETY LOCK FOR ML-1

METHOD OF LOCKING: INSTALL LOCKING FIXTURE OVER TANG OF DRIVESHAFT AND INSERT SPRING LOCK PIN.

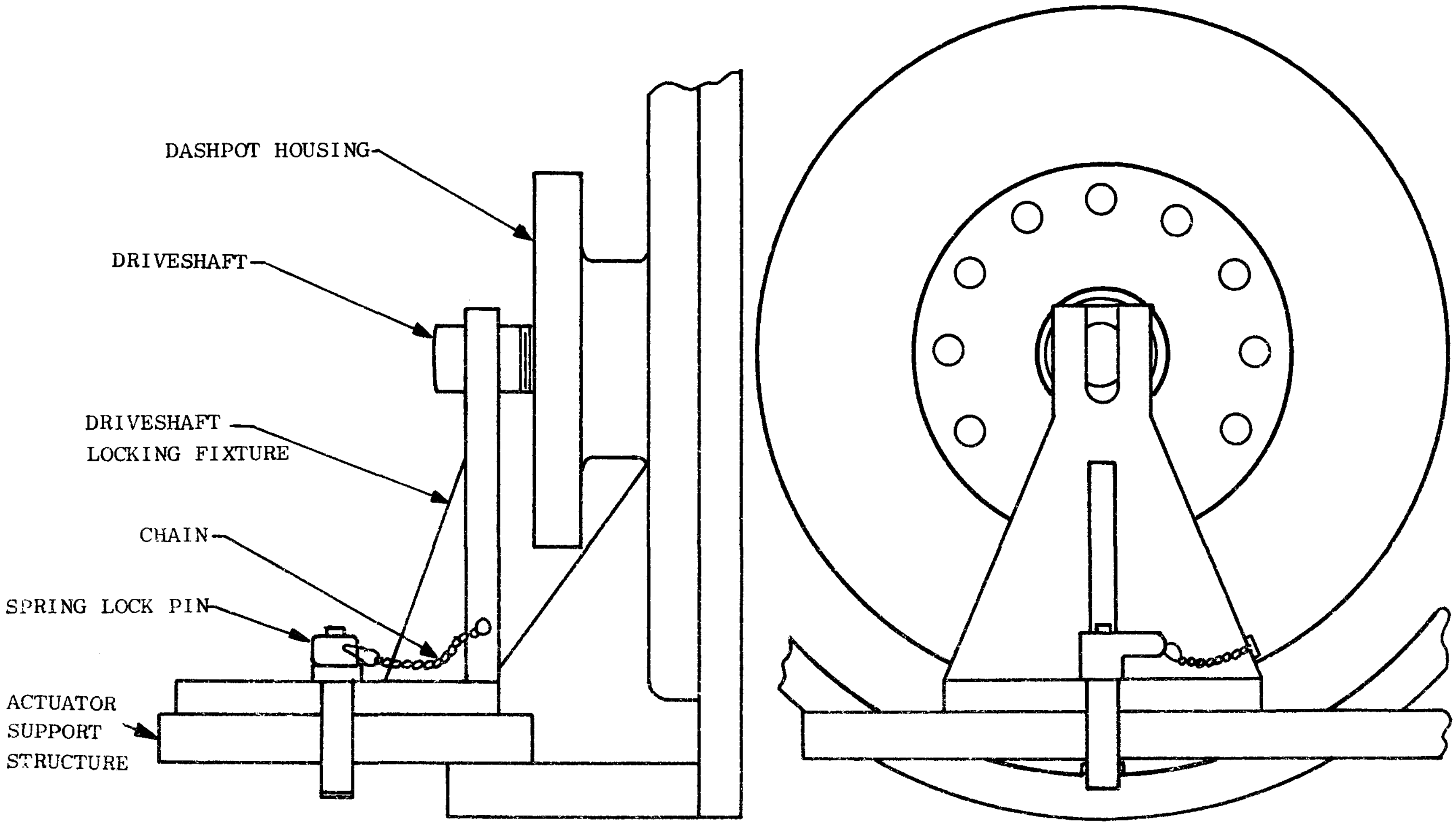


FIGURE 5

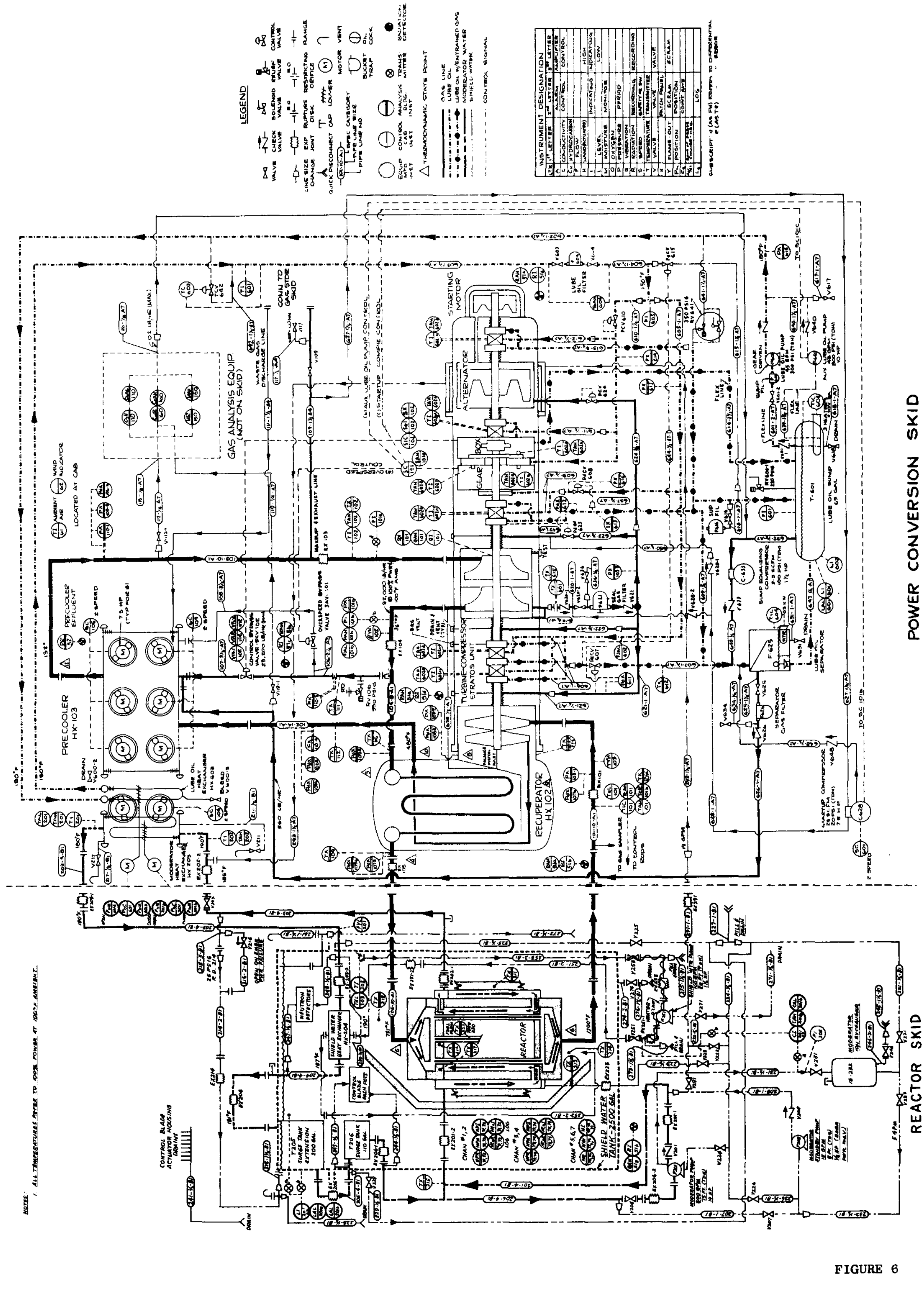

LEGEND
INSTRUMENT DESIGNATION
POWER CONVERSION SKID
REACTOR SKID
PRECOOLER HX-103
RECUPERATOR HX-102
TURBINE-COMPRESSOR STRATOS UNIT
ALTERNATOR
STARTING MOTOR
GEAR BOX
GAS ANALYSIS EQUIP. (NOT ON SKID)
REACTOR
SHIELD WATER TANK-2500 GAL

FIGURE 6

III. AIR OPERATION OF THE ML-1 POWER PLANT

It is planned to operate with air as the coolant gas following operation with the reference gas. Operation with air will be preceeded, where possible, by testing experience in the GCRE, in the Gas Turbine Test Facility, and in laboratories.

A. CORROSION CONSIDERATIONS

Corrosion tests of the fuel element cladding material (Hastelloy X containing 1.8% cobalt) have been run at 1750°F and 300 psi for 10,000 hr, both in the reference gas (99.5% N_2 + 0.5% O_2) and in air. Air was slightly more corrosive than the reference gas, but not prohibitively so, as shown in Table 3 below:

TABLE 3

CORROSIVE EFFECTS OF AIR AND OF THE REFERENCE GAS

	Penetration (in.)	
Time (hr)	Air	Reference Gas
1,000	0.0009	0.0007
5,000	0.0017	0.0015
10,000	0.0020	0.0020

The effects on room-temperature physical properties of Hastelloy X of long-term exposure at 300 psia and 1750°F in the both media are shown in Table 4 on the following page.

Turbine materials have been corrosion-tested in air for 5000 hr at a temperature of 1200°F. Although complete metallurgical evaluations of the materials specimens have not been completed, no visible detrimental effects were noted.

TABLE 4

HASTELLOY X AFTER EXPOSURE TO AIR AND TO REFERENCE GAS

	Ultimate Tensile Strength (psi)		0.2% Offset Yield Strength (psi)		Percent Elongation	
Time (hr)	Air	Reference Gas	Air	Reference Gas	Air	Reference Gas
0(as received)	(117,000)		(66,000)		(41)	
2,500	98,000	100,000	49,000	40,000	31	25
5,000	105,000	112,000	51,000	51,000	23	29
10,000	94,000	92,000	45,000	44,000	20	14

B. RADIOLOGICAL CONSIDERATIONS

During operation of the ML-1, both the coolant gas and the reactor structure will become activated from neutron radiation. Principle activities after 10,000 hr operation in air and in the reference gas are listed in Table 5:

TABLE 5

PRINCIPLE RADIOACTIVE ISOTOPES

	Half Life	Principle Reaction	Quantity (curies) Air Coolant	Quantity (curies) Reference Gas Coolant
Nitrogen-16	7.35 sec	$O^{16}(n,p)N^{16}$	0.18	0.004
Carbon-14	5600 yr	$N^{14}(n,p)C^{14}$	0.80	1.02
Argon-41	1.85 hr	$A^{40}(n,\gamma)A^{41}$	2.10	0.11

The increase in the argon-41 level does not significantly raise the dose rate at the control cab during reactor operation; the radioactivity contribution of argon-41 is calculated to be 0.06 mr/hr. Similarly, the argon-41 does not contribute appreciably to the dose rate 25 feet from the reactor 24 hr after shutdown; the activity due to argon-41 at that time is 0.02 mr/hr.

No radiological problems are foreseen in the case of either media during operation at the expected ML-1 plant leakage rates. Twenty-four hours after shutdown, the short-lived, gamma-emitting nitrogen-16 and argon-41 will have decayed to insignificant amounts, leaving only carbon-14 as the principle radioactive isotope. Because carbon-14 is a beta-emitter only, there is no radiation hazard to personnel approaching the shutdown plant. Furthermore, face masks and protective clothing will be worn to prevent ingestion of carbon-14 or any other radioisotope by personnel "breaking into" portions of the ML-1 coolant system.

In case of a defective fuel element, it is probable that more fission products would be dispersed in an air coolant system than in a reference gas coolant system. The reason for this is that in an air system more oxidant is available to oxidize the UO_2 pellets, causing swelling of the cladding and propagation of the original defect. This phenomenon may be counter-balanced; initially the oxidized material formed in the defect may seal the element and prevent further in-flow of oxygen. Tests are planned to investigate the self-healing effect.

C. HAZARDS CAUSED BY HYDROCARBON LEAKAGE INTO REACTOR COOLANT

1. Hydrocarbon Content of Coolant During Normal Operation

Normally, the t-c set bearing lubrication oil is prevented from entering the main gas loop. This is accomplished by the means of the oil seals and a buffer layer of seal gas - maintained at a pressure higher than that of the oil and continuously circulated past the seals. The buffer gas passes through the oil separation system before returning to the main gas loop.

During normal operations, the adsorption filter in the gas cleanup system will maintain hydrocarbon content of the gas loop at a level of less than 1 ppm (10^{-4}% by volume). A detector based on infrared absorption in the volatilized hydrocarbons is operating at all times, analyzing a loop gas sample. A visible and audible alarm will notify the reactor operator whenever the hydrocarbon concentration in the loop gas rises above a predetermined level between 0 and 30 ppm. Whenever the alarm is annunciated, the operator will shut down the system. Inasmuch as the minimum explosion limit of any flammable liquid or gas in air is approximately 1% by volume, and the maximum concentration of oil in the loop is well below this limit, no explosion could occur during normal plant operation with air as the coolant.

2. Gross Hydrocarbon Leakage Into Air Coolant

If an oil seal should deteriorate during operation, it is possible that lubricating oil will be released into the main loop in sufficient quantity to form an oil-air mixture within the explosive or flammable limits (the mixture may also contain lighter hydrocarbon fractions and hydrogen resulting from cracking of the oil in the main loop). Such a condition will normally be alarmed to permit the operator to take corrective action. However, if a flammable or explosive mixture did occur as a result of multiple equipment malfunctions, the mixture could be ignited as a result of auto-ignition at hot spots in the reactor core or as a result of spark formation due to the rubbing of rotating machinery parts.

If an explosion or fire occurred, sufficient heat of combustion is added to the gas to increase the pressure in the closed loop by a factor of 2.8. The potential energy release due to oxygen in the loop (in excess of the explosion limiting concentration of 12%) combining with hydrocarbons is approximately 2.65×10^4 Btu or 26.5 megajoules.

The result may be a high-pressure failure of portions of the coolant loop accompanied by the hazards of a coolant loss accident. Thus, the possibility of a leak and subsequent detonation of lubricating oil is a credible but highly improbable cause of a coolant loss accident.

D. EFFECT OF AIR COOLANT ON MAXIMUM CREDIBLE ACCIDENT

The presence of the greatly increased amount of oxygen in the reactor does not significantly affect the total energy release of the maximum credible accident - 125 megajoules. This accident assumes that the piping system is ruptured and that the gas pressure within the reactor is instantaneously reduced to atmospheric pressure. Reaction of the molten cladding with air results in an energy release of only 0.2 megajoule. This is not an appreciable amount in comparison to the 125-megajoule release of the maximum credible accident. Therefore, is is concluded that operation of the ML-1 with air as the coolant does not alter the phenomena or the results of the maximum credible accident as it was originally described in Report No. IDO-28560.

IV. ML-1 PHASE II TEST PROGRAM

The test program for the ML-1 nuclear power plant has been divided into three phases:

Phase I: Initiated when the reactor skid and control cab arrived at the NRTS, this phase of the program is currently in progress. The test consists of low-power runs ($\leq$ 30 kw) directed toward calibration and checkout of the reactor skid.

Phase II: At the time the power-conversion skid arrives at the NRTS, this phase will be initiated to demonstrate performance characteristics of the integrated power plant. The program commences with skid coupling and uncoupling tests and terminates with limited endurance tests.

Phase III: This phase will consist of loading, unloading, setting up, transporting, and environmental testing of the power plant and auxiliaries following demonstration of the power plant performance characteristics. During this phase field operation will be simulated to the greatest degree possible.

Outlined in this section of the report are: the ML-1 Phase II Test Program and descriptions of test operations in the sequence in which they will be performed. Also included are descriptions of the ML-1 test facility, the ML-1 plant, and the ML-1 instrumentation system.

The Phase II Program provides the initial opportunity for experimental operation of the ML-1 as an integrated nuclear power plant. The planning assumed that performance characteristics of the power-conversion equipment would be known insofar as possible from the Azusa tests, and that deficiencies in the p-c skid that might cause unsatisfactory performance during the Phase II tests would be corrected at Azusa. In addition, it was assumed that the Phase I tests had demonstrated safe operation of the reactor skid in the ML-1 power plant.

Except as necessary for adequate descriptions of the Test Program, detailed information about equipment such as the reactor is not included. A bibliography of appropriate documents, Paragraph IV.D below, is referenced throughout the text.

Sample detailed procedures, to be processed according to established practices, for execution of the test plan are presented in Section V of this Supplement. Inasmuch as some experiments depend upon data from preceding tests, procedures for later tests in the series will not be completed until the test program is underway.

A. PROGRAM SUMMARY

1. Objectives

The Phase II Program is designed to determine the performance characteristics of the ML-1 power plant and to uncover any latent deficiencies that may exist in design, fabrication, and/or assembly. In addition, the program is intended to generate operating and maintenance experience with the plant. Specific objectives are:

1 Determine maximum gross and net electrical load capability of the ML-1 plant.

2 Generate performance data to permit evaluation of the ML-1 plant and components in comparison with specifications and performance predictions.

3 Determine response characteristics of the control systems.

4 Determine response characteristics of the gas cycle and heat exchanger.

5 Demonstrate the capability of the lubricating oil system to adequately control the lubricating oil.

6 Optimize startup, operation, and shutdown procedures.

7 Determine the effectiveness of the nuclear radiation shield system during and after full-power operation.

8 Determine the effects of scramming the reactor from power.

9 Provide endurance testing of the ML-1 plant.

2. Major Areas of Effort

Although the program is concerned primarily with describing the operating plan for test operations, a significant fraction of program effort is devoted to the preparation of tests, the development of approved test procedures, and the analysis and reporting of test data. Thus, the Phase II Program consists of three major aspects:

1 Preparation of test procedures

2 Test operations

3 Interpretation and reporting of test results

Procedures for executing the experiments of this test plan are to be generated and approved in accordance with the ANSOP covering such activities, as illustrated in Figure 7.

Test operations are comprised of five separate test series:

1 Pre-operational tests

2 Initial power tests

3 Steady-state performance tests

4 Transient tests

5 Endurance tests

Presented in Paragraph IV.C, below, are discussions of each test series and of the individual tests to be carried out. Table 6 on the following page lists the experiments covered by the test plan, with the corresponding ANSOP numbers.

Test program data are to be processed as shown in Figure 8.

B. ML-1 TEST FACILITY[1]

The ML-1 test facility consists of two major areas: 1) the test site, and 2) the control site. Each site is surrounded by a perimeter security fence. The control site is located approximately 500 ft from the test site. A 12-ft-high earth berm located between the two sites serves as the operating radiation shield for the control building.

Facilities at the test site include a metal-curtained, steel-framed building designed to provide weather protection, thus facilitating power plant operation and maintenance. The building is equipped on each end with large sliding doors (open for most of the power plant tests) with a concrete outdoor test pad (essentially an extension of the test building floor) on the east end of the building, and with a personnel change area. Utilities at the test site include: the building heating and ventilating system; a 6000-gal tank for fuel oil storage; an indoor, 15,000-gal tank for fresh water storage; an underground 10,000-gal waste storage tank; and 480-volt, 3-phase power (from the NRTS 13,800-volt supply).

---

[1]Numbers in superscripts refer to items in Bibliography, Paragraph IV.D.

TABLE 6

ML-1 PHASE II TEST PROGRAM EXPERIMENTS

ANSOP	Experiment Title
16290	Package Coupling
16291	Package Uncoupling
16405	Precooler Checkout
16406	Moderator/Lubricating Oil Cooler Checkout
16407	Moderator/Alternator Water Cooling System Checkout
16430	Reactor Temperature Control System
16425	Speed Control System Checkout
16423	Electrical System Checkout
16435	Load Bank Checkout
16500	Instrumentation Checkout
16475	Gas Analysis Equipment Checkout
16450	Gas Storage Skid Checkout
16605	Charging/Leak Testing the Loop with Nitrogen
16415	Lubricating System Checkout
16520	Instrumentation Compatibility Test
16607	Cold Rotation
16615	Initial Self-Sustained Operation
16625	Full Power Test
16635	Limited Endurance Test
16650	Thermodynamic Performance Evaluation
16642	Shield Performance Test
16646	Auxiliary Power Requirement Test
16640	Manual Control Test
16660	Startup and Shutdown Optimization
16641	Automatic Control Systems Response
16655	Systems Response
16657	Scram Test
16800	Variable Load Endurance Test
16810	Rated Load Endurance Test

OPERATING PROCEDURE
(ANSOP)
PROCESSING

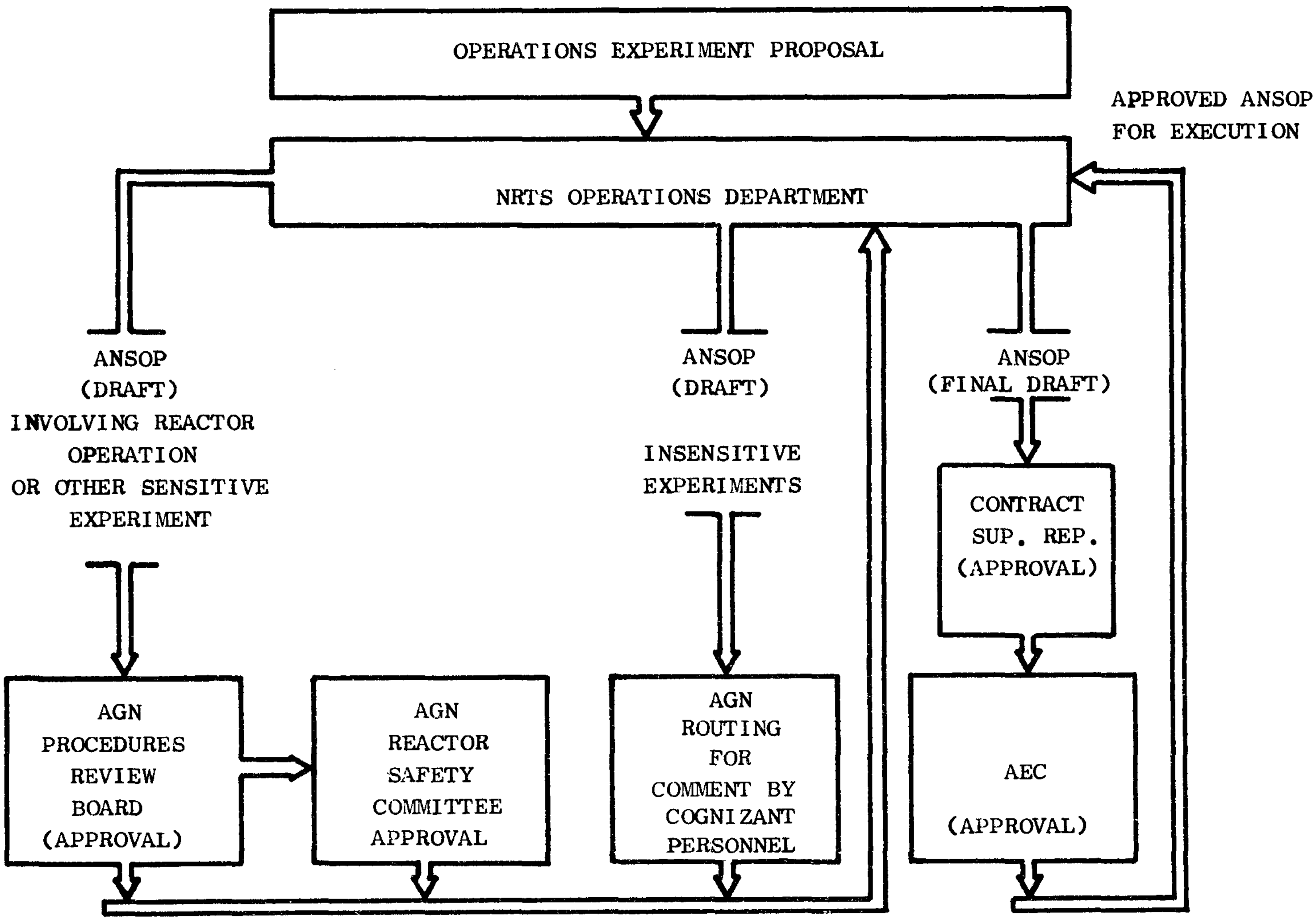


FIGURE 7

ML-1 TEST DATA PROCESSING
NRTS OPERATIONS DEPARTMENT

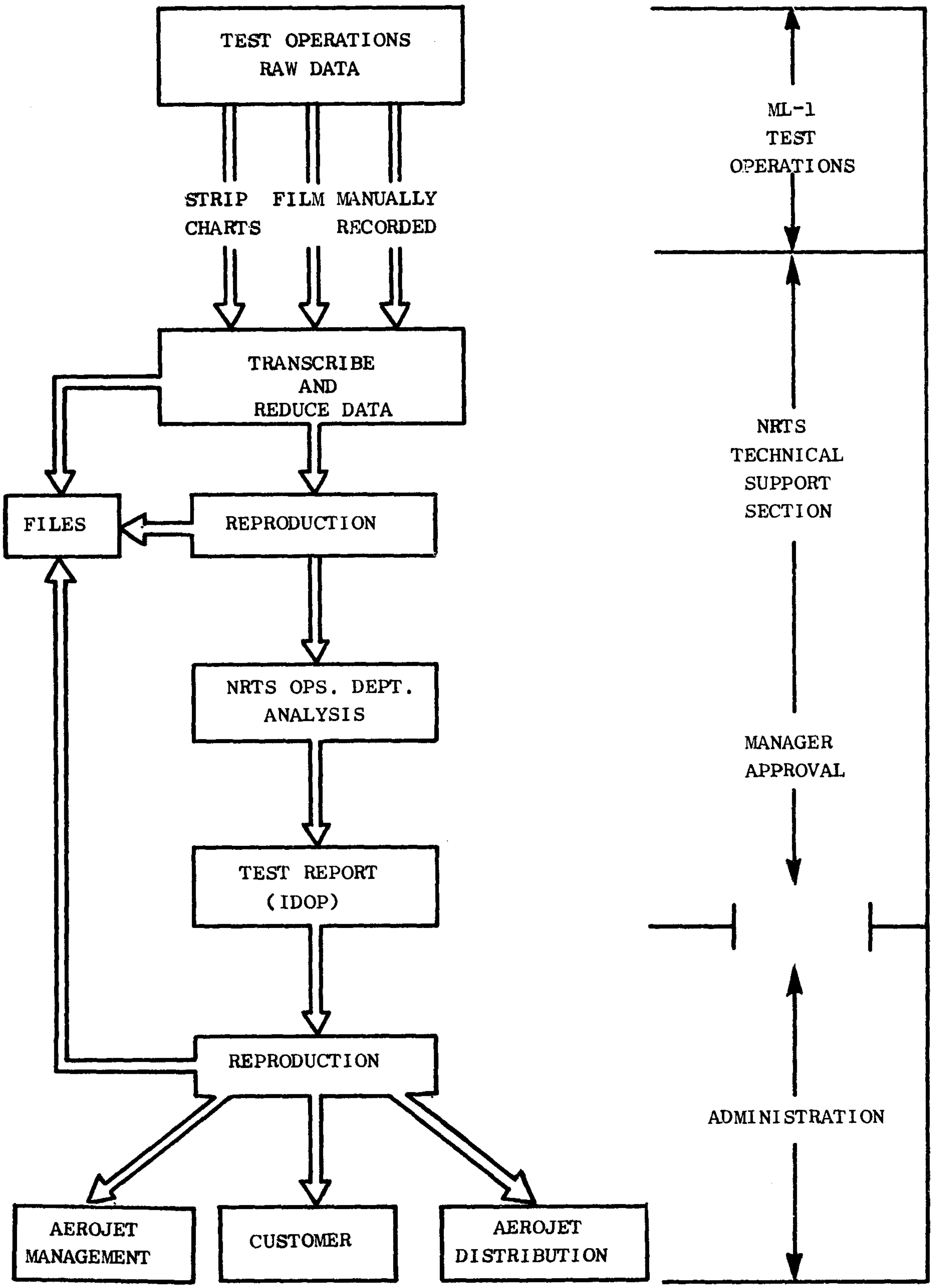


FIGURE 8

The ML-1 power plant is to be located in the test building for Phase II testing. The power plant will be operated from a prototype control cab located for convenience adjacent to the auxiliary control building. The control cab is connected to the reactor and p-c skids by portable cables routed above ground.

The auxiliary control building contains office space and analysis instrumentation. Utilities at the building include: the air conditioning system; fresh water system, including a 5000-gal tank; sanitary facilities; an outdoor, 500-gal tank for fuel oil; and emergency power (a 10-kw, 460-volt alternator inside and a 60-kw alternator outside).

C. TESTS

The tests described on succeeding pages are divided into five categories, corresponding to the following paragraph numbers:

1 Pre-operational

2 Initial power

3 Steady-state

4 Transient

5 Endurance

The pre-operational tests provide for checking out the power plant, the controls, and the instrumentation to establish the basis for initial self-sustained operation. During this test series, procedures and equipment will be tested for: coupling and uncoupling the power plant package, functionally checking components and systems prior to power plant operation, and charging the loop with nitrogen. The machinery set will be rotated with the starting motor to check integrity; instrumentation will be tested; and input torque requirements will be recorded for future reference.

During the initial power test series, self-sustained operation will be attained. The reactor will be brought to an intermediate power level. The machinery set will be rotated at rated speeds with turbine inlet temperatures up to 1200°F. Alternator load will be increased in increments until the design capacity of the power plant is reached or until design conditions are attained - 1200°F inlet temperature, 120 psia compressor suction pressure, 315 psia compressor discharge pressure, and 130.6°F compressor inlet temperature.[2] A limited endurance run will be performed in the interest of accumulating operating experience and demonstrating a measure of component reliability before subjecting the power plant to more severe transients and thermal cycles than those produced by scrams.

The steady-state performance test series is concerned with power plant operations under normal conditions. Performance data will be generated at many steady-state points and compared with predicted and specified performance. Although manual control capability will be evaluated during this period, intentional transient conditions will be avoided.

Experiments comprising the transient test series are designed to intentionally induce transients by making step changes in various systems and components. The tests are necessary to evaluate system response characteristics and to study the ability of components to withstand sudden load and power level variations. Experiments aimed at optimizing startup and shutdown procedures will also be conducted.

Finally, the endurance test series provides for extended operation of the plant under various loads up to the maximum allowable conditions established by previous testing. Operation of the power plant during this period is expected to closely simulate field operation.

Locations of equipment described in the test plans or otherwise referenced on the following pages are shown in the Piping and Instrumentation Diagram included as part of Appendix 2 to the Test Program.

1. Pre-Operational Tests

a. Package Coupling[8] (ANSOP 16290)

Objective

The object of this test is to check the fit-up and connection of the reactor skid with the power-conversion (p-c) skid, including all mechanical and electrical fittings. In addition, this test will permit the establishment of the final coupling procedure.

Description

The p-c skid will be unloaded from the transport vehicle and placed on greased 2 x 12-in. planks. The mating flanges and connections will be prepared for joining by removing protective covers, inspecting lines and flanges, and installing gaskets.

The skid will then be winched and/or pushed to within about 5 in. of the mating location. At this point, a final check will be made to assure that all obstructions are clear for final fit-up.

The p-c skid will then be moved to the reactor skid until the tapered pins of the p-c skid enter the sockets in the base of the reactor package. Both of the upper coupling links will be attached. The spring-loaded retainer pin will be pulled and the tension bar adjusted so that it is free-riding. The packages will slowly be winched together; during this time observations will be made to determine any interference to coupling links or mating shim pins.

The skids will be winched to a position in which the mating flanges and connections can be properly connected together.

The flanges will be connected and a check made to insure that the packages are in the correct mating position. The bellows and precooler tiedowns will then be removed. The precooler spring support and t-c set/recuperator/alternator tiedown bolts will be adjusted.

Shims will be added or removed as required to firmly adjust the tension bar of the coupling link to its coupled position. The alignment operation may also require adjustment shimming of the bottom coupling pins.

Handling Equipment and Special Tool Requirements

Mobile crane (15-ton capacity, minimum)

Spreader bar (T-710258)

Wooden planking, 100 lineal feet, 2 x 12-in. (with grease)

Hydraulic jacks (2, each 10-ton capacity)

Winch, 10,000-lb capacity

ML-1 Parts Requirements

Coupling link assembly (1-423688)	
Studs - reactor outlet flange, 3/4-10 UNC x 5 (19-9DL)	20 ea.
Nuts, 3/4-10 UNC (19-9DL)	20 ea.
Bolts - reactor inlet flange, 5/8-11 UNC x 3-3/4	24 ea.
Nuts, 5/8-11 UNC	24 ea.
Flange clamp - moderator cooling outlet line, 5-in. Grayloc	1 ea.
Bolts - moderator cooling inlet line	4 ea.
Gaskets - 10-in. Flexitallic #8-1160-2-PAJ	2 ea.
Gaskets, Grayloc	2 ea.
Bolts, coupling 1-1/4 in. x 8 UNC	2 ea.
Washers - 3/4 in. bolt (3/4 x 0.109)	40 ea.
Washers - 5/8 in. bolt (5/8 x .078)	48 ea.

Connections

1 Tapered Plugs: The two tapered plug connections at the base of the skid serve to bring the two packages into final alignment. The plug nuts serve to hold the two packages in intimate aligned contact.

2 Coupling Links: The two coupling links are used to assist in bringing the two packages into final alignment and form the upper package structural connection points.

3 Reactor Outlet (101-10-A1): This joint is a bolted flange using 3/4-in. studs and nuts of special high-temperature steel (19-9DL) for fasteners. A Flexitallic gasket is used.

4 Reactor Inlet (105-10-A1): The reactor inlet line connection is a bolted flange that uses a 10-in. Flexitallic gasket and 24 5/8-in. B-5 bolts.

5 Moderator Cooler Inlet (202-4-B1): This line connection uses a 5-in. bolted flange, a gasket, and four bolts.

6 Moderator Cooler Outlet (203-4-B1): A Grayloc clamp and gasket are required for this joint.

7 Alternator Cooling Supply (291-1-B1): This connection is a 1-in. AN fitting.

8 Electrical Cables: Structural cable requirements are listed in Table 7 on the following page.

b. Package Uncoupling (ANSOP 16291)

Objective

The objective of this test is to check out the procedure and equipment for uncoupling the p-c skid from the reactor skid.

Description(8)

The necessary equipment and tools will be assembled and the procedure for uncoupling the package reviewed. The precooler supports will be shimmed, the bellows and shipping tie-rods installed, and the machinery set tiedown bolts secured; then the ducting and electrical connections will be broken, tapered plugs freed, and coupling links extended. The packages will be separated, using hydraulic jacks to permit installation of the flange and fitting protective covers.

Handling Equipment Requirements

Hydraulic jacks (2, each 10-ton capacity) Winches or mobile crane

Parts Requirements

1 Blank Fittings for:

Alternator cooling supply line (291-1-B1)AN
Moderator cooler outlet line (203-4-B1)
Moderator cooler inlet line (202-4-B1)
Reactor inlet line (101-10-A1)
Reactor outlet line (101-10-A1)

2 Precooler shims

3 Bellows tiedown rods

TABLE 7

SKID ELECTRICAL CONNECTIONS

Control Cab	Cable				P-C Skid
J1315	P1315	POWER W1304		P1222	J1222
J1316	P1316			P1223	J1223
J1317	P1317			P1227	J1227
J1318	P1318			P1228	J1228
J1338	P1338	PROCESS W1305		P1239	J1239
J1319	P1319			P1221	J1221
J1320	P1320	NUCLEAR & W1306 PROCESS		P1220	J1220
J1321	P1321			P1225	J1225
J1322	P1322			P1226	J1226
J1336	P1336	NUCLEAR W1303 COAX		P1219	J1219
J1337	P1337			P1224	J1224
J1355	P1355	Temp.	Dry Skid	P1232	J1232
J1339	P1339	Wind	Gas Supply	P1234	J1234
J1313	P1313	Analysis	Gas Supply	P1236	J1236
J1314	P1314	Analysis	Cable Reel	P1235	J1235
			Misc.	P1233	J1233
			60 kw power	P1230	J1230
Reactor Skid					
J1118	P1118	COAX		P1214	J1214
J1119	P1119			P1218	J1218
J1111	P1111	ROD DRIVE #1		P1231	J1231
J1103	P1103				
J1110	P1110				
J1102	P1102	ROD DRIVE #2		P1229	J1229
J1101	P1101				
J1104	P1104				
		POWER		P1217	J1217
		PROCESS		P1213	J1213

c. Precooler Checkout (ANSOP 16405)

Objective

The objective of this test is to check out the operational integrity of the precooler, the precooler cooling fans, and the associated control circuitry. During p-c skid tests at Azusa, the precooler air flow distribution was checked. Therefore, it is not planned to duplicate the flow distribution test during this test program.

Description

Each of the precooler fan motor circuits will be checked for continuity and for acceptable insulation resistance prior to energizing the precooler fan circuits. Motor and circuit insulation resistances will be appropriately recorded to serve as the initial entry in the insulation resistance history of the component involved.

With the precooler covers removed, the unit will be visually inspected and the precooler fans rotated by hand to check for free rotation. Fans will be energized in groups of three and checked for operation on "slow" and "fast" speed. Evidence that each fan rotates in the proper direction on both "slow" and "fast" speeds will be obtained. The fans will be checked for smoothness of operation.

After at least 30 min operation, the fan motors will be de-energized from "fast" speed; and the deceleration time of each fan will be recorded, along with the inlet air temperature. These data will serve as bases for future deceleration checks.

Data Required

1 Insulation resistance for each fan motor

2 Deceleration time for each fan motor from "fast" speed

d. Moderator/Lubricating Oil Cooler Checkout(ANSOP 16406)

Objective

The objective of this test is to functionally check out the operation of the moderator and lubricating oil coolers.

Description

Each of the two moderator/lubricating oil cooler fan motor circuits will be checked for continuity and insulation resistance prior to energizing the fan motor circuits. In addition, the louver actuator circuits will be checked. Motor and circuit insulation resistance will be appropriately recorded.

The moderator and lubricating oil cooler louvers will be driven through the full range of travel. Visual inspection, as well as observation of the indicating lights, will be used to check actuation of the louvers. As a single 115/24-volt transformer supplies both sets of louver actuators, the lubricating oil louvers and moderator louvers will not be operated simultaneously.

With cooler louvers in the full-open position, the two fans will be functionally checked as described above (ANSOP 16405). The two-speed check will not apply to one of the moderator cooler fans, as it is driven by a single-speed motor.

With the fans running, the louvers will be actuated through the full range of travel, and the vibration level in the louvers will be checked.

Data Required

1 Insulation resistance for each fan motor

2 Deceleration time for each fan

e. Moderator/Alternator Cooling System (ANSOP 16407)

Objective

The objective of this test is to perform a functional check of the moderator/alternator water cooling system after the p-c skid is connected to the reactor skid but prior to initial power plant operation.

Description

With the moderator system filled to proper level, the moderator system will be operated with the 300-gpm pump (P-201) and with the standby 15-gpm pump (P-208). Rotational direction of each pump will be determined to be in the proper direction. A reactor scram will be simulated to check the operation of the pump transfer and interlock circuits. Water flow through the demineralizer and the water conductivity instrumentation will be checked.

Marmon clamp joints in line (293-1½-A7) will be disconnected to facilitate checking the alternator cooling water flow rate. After this test, lines will be connected and the system operated to check for leaks. Specific functions and items of equipment to be checked are:

1 Orifice bypass solenoid valves (V216)

2 Moderator water pump (P201)

3 Standby moderator pump (P208)

4 Temperature sensing circuit (TX-215)

5 Temperature indicating and alarm circuits (TI-201, TAH-201, TAL-201)

6 Low-flow scram circuit and sensor (FYL-201)

7 Flow to demineralizer circuit (FI-205)

8 Water conductivity instrumentation (CI-201, CAH-201a, CAL-2016)

9 Alternator cooling water valve (V291)

10 Alternator cooling water flow rate

The moderator cooler checkout is covered by ANSOP 16406, described above.

Data Required

1 Calibration curves for temperature sensors

2 Calibration curves for readout equipment.

3 Moderator water pressure or flow rate to actuate "low flow scram"

4 Cooling water flow rate through alternator with moderator pump in operation

f. Reactor Temperature Control System (ANSOP 16430)

Objective

The object of this test is to functionally check the operation of the reactor temperature control system and to calibrate the reactor outlet (turbine inlet) temperature indication, alarm, scram, recording, and control circuits.

Description

Two separate resistance-type temperature detectors are used to sense turbine inlet (reactor outlet) temperature (T-7). One resistance bulb is used exclusively to provide for reactor scram (TYH-103) when a pre-selected gas temperature is reached. The other resistance bulb provides a temperature signal for regulating rod control (TIC-101), high temperature alarm (TAH-101), temperature error indication (T_eI-101), high temperature error alarm (T_eAH-101), temperature error record (T_eR-101B), temperature patch panel indication (T_x-101a).

To functionally check the temperature control system, the reactor outlet temperature probe will be disconnected from the control system and a precision wire-wound decade box provided to simulate probe output.

The following temperature and resistance values are typical of those to be used for simulating the reactor outlet temperature:

Decade Box Resistance, Ohms	Simulated Reactor Outlet Temperature, ^{o}F
77	502
600	961
1050	1320
1500	1647
1580	1697

The reactor outlet temperature, error indicating, recording and alarm system will be checked and adjusted, as necessary, for correct response to actuating signals at temperatures through the startup and operating ranges. Voltage signals from magnetic amplifiers (output from temperature transducer) will be fed into the control rod actuating circuitry to simulate reactor outlet (turbine inlet) temperature changes. The shim and safety rods will be fully inserted in the reactor core and disabled during the regulating drive mechanism check. Previous tests have demonstrated that the reactor cannot be made to go critical with the shim and safety rods fully inserted.

g. Speed Control System Checkout (ANSOP 16425)

Objective

This test is designed to functionally check the operation of the turbine-compressor speed control and overspeed trip systems. As a matter of convenience, checkout and adjustment of the auxiliary lubricating oil pump and the startup compressor control circuitry as associated with the speed control system will also be accomplished during this test.

Description

Speed sensing in the TCS 670 is effected by two electromagnetic pickup heads located in close proximity to a gear containing eleven square teeth. The gear, shaft-mounted between the compressor and reduction gear, rotates at compressor shaft speed. Eleven impulses per revolution from each speed pickup are thus available to use as signals to indicate speed and as input signals to control systems. One pickup feeds signals to the turbine speed control system and speed error indicators and recorder. The other pickup is used with the overspeed valve (SAV-101), auxiliary lubricating oil pump control (P640), and the startup compressor control (C628).

This test will be initiated by checking for continuity and grounds in the electromagnetic pickups. Next, the speed control valve will be checked for satisfactory operation with the speed controller set at "manual". The valve position indicator and recorder will be checked and calibrated during this test phase. When the speed control valve (SCV 102) and manual control circuits perform satisfactorily, the automatic speed control system will be checked.

By using input signals to simulate the speed pickup output, the set-point controller will be checked and calibrated against input signals of known frequency. At this time the speed and speed error indicating and recording circuits and readout devices will be checked and calibrated. Input signals from a pulse generator will be applied at the t-c set speed pickup connections on the p-c skid. The speed set-point in the control cab will be adjusted to indicate a "zero" error on the speed error indicator. The speed set-point value should match the rpm value corresponding to the frequency of the input signal. If it does not, the speed set-point controller will be adjusted until it does. This procedure will be repeated for selected "speeds" throughout the operating range. With the newly calibrated set-point control, the speed control valve will be checked for proper response to known error signals.

The turbine high-speed trip circuits, controls and valve will be checked and calibrated for proper performance. The overspeed trip point will be adjusted to open the overspeed bypass valve at 110% of rated speed.

The auxiliary lubricating oil pump control will be checked, and adjusted as necessary, to see that the drive motor is energized at 55% of rated turbine speed and de-energized at 65% of rated turbine speed.

In addition, the startup compressor control will be checked and adjusted, as necessary, so that the motor is energized at 90% of rated speed and de-energized at 100% of rated speed. Speed signals for controlling these motors emanate from the overspeed trip speed pickup. The motor will not actually be rotated during this test, but the contactors will be made to open and close.

Specific functions and equipment to be checked during this test include:

1	Speed control valve	(SCV-102)
2	Overspeed trip valve	(SAV-101)
3	Speed control valve position	(VP_hI-102)
4	Speed control valve position record	(VP_hR-102)
5	Speed control valve position indication	(VP_hX-102)
6	Speed control and indicating signal	(SIC-102)
7	Speed error indication	(S_eI-102)
8	Speed error record	(S_eR-102)
9	Speed error record	(SX-102)
10	Speed signal to overspeed trip control	(SC-101)

11 Overspeed alarm (SAH-101a)

12 Auxiliary lubricating oil pump control (SC-101b)

13 Startup compressor control (SC-101c)

14 Speed set-point controller

15 Speed control valve controller and drive loop

16 Speed control valve feedback loop

Data Required

1 Speed set-point calibration curve (set point vs rpm)

2 Speed readout calibration curve or table (actual vs indicated speed)

3 Speed error calibration curve

4 Speed control bypass valve position vs turbine speed error

h. Electrical System Checkout (ANSOP 16423)

Objective

This test is scheduled to provide a functional checkout of the power plant electrical systems.

This test will yield up-to-date insulation resistance data on all power plant motors and the alternator.

Description

With Circuit Breaker "K" (CD 1202) open 120-volt, single-phase power will be applied to the 120-volt control circuits. This will permit actuation of 480-volt line contactors without power being applied to the 480-volt auxiliary bus.

Motor line circuits will be checked individually by using normal control circuits to close line starter contactors. Cab indicating lights will be checked, and each set of line contactors will be visually or otherwise inspected for proper operation. Insulation resistance readings will be recorded for each motor, or group of motors in the case of precooler fans. The insulation resistance checks may be made at the terminal blocks behind junction board.

Operation of transfer contactors and interlocks will be checked. Insulation resistance on all 4160-volt circuitry will be checked and recorded along with that of the alternator. All electric circuitry and cables will be left in condition for power plant operation following this checkout.

Data Required

1 Insulation resistance readings

2 Item checkout check-off list

i. Load Bank Checkout (ANSOP 16435)

Objective

The objective of this test is to check out, connect and adjust the load bank system for initial power plant test operation.

Description

The load bank consists of a trailer-mounted assembly of components and a control console to provide 625-kva (500 kw), 4160/2400-volt, 3-phase 80% power factor load at 50 or 60 cycles. The assembly includes a 15-hp, 484-volt, 3-phase motor-driven fan to provide forced air ventilation for the resistor bank. The console is portable and caster mounted. During storage and transport the console is stored in the trailer walkway.

The trailer will be towed to a pre-selected location at the ML-1 control site. The console will be removed from the trailer and installed in the desired location inside the Auxiliary Control Building. Cable connections will be made in accordance with ANSOP 16435.

The unit will then be checked out by testing circuit breakers, switches, indicating lights and the ventilation fan. Insulation resistance of all circuits will be measured and recorded. Operators will run through a simulated loading and unloading sequence using as guides the manufacturer's reference manuals and the load bank ANSOP[6].

j. Non-Nuclear Instrumentation Checkout (ANSOP 16500)

Objective

The purpose of this test is to systematically check the power plant instrumentation for correct installation, provide up-to-date calibration records and functionally check, where practical, each instrumentation circuit or system of circuits.

Description

It will first be determined that power plant instrumentation is installed in accordance with the current ML-1 instrumentation plan. Pressure transducers, thermocouples, and other sensors will be calibrated. Each instrument circuit, including the readout device, will be checked as a complete system.

Control sensors such as turbine inlet temperature (TIC-101) will be checked under special experiments. A review of calibration records will be made in the course of this procedure and a check made to determine that a copy of the current calibration data for each sensor is in the instrumentation files.

In isolated cases where calibration data are available from Azusa tests and where it is impractical to repeat the calibration for sensors installed in the p-c skid, Azusa calibration data may be used.

Data Required

1 Calibration data for each sensor installed in the power plant

2 Calibration data for each instrument circuit, including the readout device, as a separate system

k. Gas Analysis Equipment Checkout (ANSOP 16475)

Objective

The objective of this test is to install and check out the gas analysis equipment.

Description

This equipment consists of an infrared analyzer (for hydrocarbons), electrolytic hygrometer (for moisture), and an oxygen analyzer. A 6-point recorder is used as a readout device, and the unit is equipped with an alarm system. Two control cables connect the gas analysis equipment cart (housing the gas analyzing and sensing equipment) to the control relay rack.

Before checking out this equipment, it should be energized for a 24-hour warmup period. A circulating air supply (17 psig) will be required during this warmup period.

For regulator adjustment and checkout, a regulated supply of nitrogen will be required (100 - 120 psia at 200 cc/min).

The moisture monitor will be put into operation and the system and readout channel (point 6 on recorder) will be checked out in accordance with the manufacturer's service manual.

The oxygen analyzer will be checked out, calibrated, and put into operation. Oxygen content is read out on point 4 on the recorder.

The infrared analyzer (IR unit) will be checked after purging the unit for at least 3 min. The hydrocarbon readout devices, recorder points 1, 2, 3, and 5, will be calibrated for zero and upscale calibration in accordance with the manufacturer's service manual.

Data Required

1 Hygrometer calibration data

2 Oxygen analyzer calibration data

3 Gain control setting for IR unit: zero and up-scale calibration (A change of the zero control setting with time indicates inadequately filtered gas - decreasing setting - or deterioration of a unit component - increasing setting.)

1. Gas Storage Skid Checkout (ANSOP 16450)

Objective

The objectives of this test are to install and check out the operation of the gas storage skid.

Description

The unit will be visually inspected for integrity of fittings and equipment, and any deficiencies will be corrected. The compressor and vacuum pump will be lubricated. Oil and gas filters will be inspected for cleanliness. The electrical circuits will be checked for continuity and insulation resistance.

The 1/2-in. nitrogen source inlet will be connected to a nitrogen source (N_2 bottles). The proper manual charging valves will be opened for charging the system. The power cable will be connected to the unit receptacle and to the 440-volt, 3-phase, 60-cycle source provided on the p-c skid. The pressure regulator on the 1/2-in. nitrogen source inlet and on the transfer compressor inlet will be adjusted to discharge the gas at 150 psig and 2 psig, respectively. The transfer compressor will be used to charge the two storage spheres to 3000 psig. The nitrogen source bottles will be disconnected from the 1/2-in. nitrogen source inlet and dumped to atmospheric pressure. These bottles, now at atmospheric pressure, provide a convenient volume to simulate the ML-1 gas loop for checkout of the gas storage skid charging and evacuating systems. The bottles will then be connected to the 1-1/2-in. makeup and exhaust line to simulate the ML-1 system. The source bottles will be charged from the gas storage skid to 95 psia. During the charging process, the oxygen supply system will be used in its normal mode of operation.

Next, the evacuation of the power plant loop (N_2 bottles) to the gas storage spheres will be simulated. This will be performed using the vacuum pump and transfer compressor. When the source bottles are evacuated, they will be disconnected from the skid. The skid will then be blown down through the 1-1/2-in. line that would normally connect to the waste gas discharge line.

Functional operation and calibration of all instrumentation associated with this skid will be checked during this test. Following checkout of this skid, the storage spheres will be isolated, the filters checked, and the makeup and exhaust line (109-$1\frac{1}{2}$-A4) connected to the p-c skid in preparation for the initial charging of the main loop with nitrogen. The facility low-pressure storage tank will be connected to the system.

m. Charging and Leak-Testing with Nitrogen (ANSOP 16605)

Objective

The objective of this test is to charge and exhaust the loop, using the gas storage skid. This experiment will provide an opportunity to optimize the procedure for charging the loop with nitrogen (ANSOP 16605). In addition, the loop will be leak-checked during this experiment.

Description

Before pressurizing the loop, all pressure transducers will be protected either by disconnecting and isolating from the loop or by opening sensing line valves on both sides of the transducers to equalize pressure.

With the metering valve adjusted to meter gas at a slow rate and other gas storage skid valves set properly, the loop will be pressurized slowly through the motorized admission/exhaust valve (V109).

Admission will be interrupted at intervals to check for gross leaks and to inspect bellows. The loop will be pressurized to 130 psia and the main loop isolated from the gas supply skid. The loop will be thoroughly inspected for leaks. Leak-rate data will be recorded, and pressure indicating instruments will be checked.

If no significant leaks are discovered, the loop pressure leak-rate will be timed for approximately 8 hr. If the leak rate is no greater than 0.02 psi/psi-hour, the loop will be considered satisfactorily tight for Phase II testing (approximately 32 scf makeup/hr, corresponding to a 2.4-psi leak per hour at 130 psia). The loop will then be exhausted to the emergency dump tank.

If significant leaks develop, repairs may be required; then it will be necessary to repeat the pressurizing procedure.

After the loop is established to be satisfactorily tight it will be pumped down - with the vacuum pump discharging to atmosphere - to 5 mm Hg (absolute)or to the lowest pressure attainable.

The loop will then be refilled with nitrogen to a pressure slightly above atmospheric.

Data Required

1 Leak rate data

2 Exhaust rate data

n. Lubricating System Checkout (ANSOP 16405)

Objective

The objectives of this test are to operate and check out the lubricating oil system prior to rotating the turbomachinery, and to compare operating characteristics with Azusa data.

Description

The previous experiment, Charging and Leak Testing the Loop with Nitrogen (ANSOP 16605), left the loop filled with nitrogen at slightly above atmospheric pressure. All gas and oil filters will be inspected to insure that they are clean and that new filter elements are installed. The auxiliary oil pump, sump equalizing compressor, and startup compressor motors will be checked to insure proper direction of rotation. The lubricating oil sump will be filled to the desired level through line 601-2-A7. During the filling operation, the sump level indicators will be calibrated and checked with Azusa data.

The loop will be pressurized to approximately 30 psia, and the sump equalizing compressor will be started. When it has been determined that the sump equalizing compressor is operating (by observing sump pressure, PI-601), the startup compressor will be started on "slow" speed. With these two units in operation, a check will be made; and all lubricating oil system pressures, including bearing seal cavity pressures, will be recorded. The startup compressor will also be operated on "fast" speed as necessary to obtain proper differentials and to obtain a compressor check. This test will check for proper seal differentials before circulating the lubricating oil.

When the seal startup gas system is functioning properly, the lubricating oil heater in the lubricating oil sump will be energized to check out the heater and control. The solenoid-operated dump valve in line 641-1½-A7 will be opened to permit recirculation of oil through the sump. With the use of the auxiliary lubricating oil pump, oil will be circulated through the "dump" system (641-1½-A7), and the oil will be heated to approximately 80°F in order to check out the sump heater, the auxiliary lubricating oil pump, and the solenoid dump valve.

With the sump heater shut down, the solenoid dump valve will be closed; and the lubricating oil system will be put into operation. Gas will be bled from the oil cooler through V 600-3. The filter isolation valve, V 603, should be open. Flow and pressure instrumentation will be carefully monitored, and the lubricating oil flow rate through each bearing and through other measurable flow paths will be determined.

The heater in the lubricating oil separator will be energized as required to maintain the oil at a temperature of at least 80°F.

The entire lubricating oil system and associated instrumentation will be operated for several hours and checked for correct functional operation. Data will be recorded. The lubricating oil will be heated with the sump and separator heaters and cooled with the cooler to maintain an oil temperature of approximately 100°F. The gas will be sampled and monitored for oil particles. The temperature control (TC-603, TCV-642) will be checked out. Oil cooler louvers and fans will be re-checked.

Data Required

1 Seal gas flows

2 Oil flows

3 System pressures

4 System temperatures

5 Hydrocarbon content of process gas

6 Amounts of certain metallic elements in oil before and after test

o. Instrumentation Compatibility Test (ANSOP 16520)

Objective

This test will determine if power plant electrical and electrical control apparatus interferes with reliable operation of the ML-1 reactor instrumentation, particularly in the case of the nuclear instrumentation. This test will also serve as a final functional operational check of the power plant auxiliary systems prior to initial rotation of the t-c set.

Description

Reliable,uninterrupted startup and operation of the reactor depend, to a great extent, upon low-level control signals emanating from neutron detectors (2 proportional counters for startup, 2 compensated ion chambers, and 3 uncompensated ion chambers) located in wells in the reactor shield tank. The low-level instrument channels are susceptible to interference and spurious signals caused by noise-producing electrical power circuitry and equipment such as that installed on the p-c skid. Therefore, it is considered necessary to determine whether or not power plant electrical apparatus interferes with the reliable operation of the nuclear instrumentation by operating, where practical, all electrical systems associated with the power plant during a nuclear instrumentation checkout.

By using the built-in nuclear instrumentation test provisions, all nuclear instrumentation channels will be checked out; and count rates with known input will be recorded. Power plant electrical systems will be put into operation one at a time. After the 60-cycle system is operating, each nuclear instrumentation channel output will be checked for 60-cycle perturbation with a sonic analyzer or other suitable test equipment.

The loop will be pressurized to at least 30 psia before the lubricating oil system is put into operation.

Data Required

1 Indicated count rates

2 60-cycle harmonic component level in nuclear channel output signal

3 Lubricating oil system data

4 Evidence of "noise" from switching transients

p. Cold Rotation (ANSOP 16607)

Objective

The primary objective of this test is to check the mechanical integrity of the machinery set (t-c set, reduction gear, alternator, and starting motor) before attempting to start the power plant.

The test will also provide an opportunity to operate all power plant systems except the alternator control center and the reactor. All process instrumentation will be checked, including the speed control system. This test will be essentially a "dry run" for the initial power plant startup.

Description

The reactor will remain shut down throughout the test.

The loop will be pressurized to 30 psia. The moderator cooling system, precooler, alternator cooling system, lubricating oil system, and all process and control instrumentation will be put into operation. It will be determined that all auxiliary systems are performing satisfactorily and that the lubricating oil temperature to the bearings is between 90° and 110°F.

With the starting motor in 4-pole mode, the unit will be "bumped" to approximately 1000 rpm (turbine speed) and allowed to decelerate. This will provide an opportunity to note unusual rotational noises, check the operation of the speed indicating systems, and detect signs of internal mechanical interference by monitoring deceleration time. Special attention will be paid to the axial movement of the rotor by observing the rotor position indicator.

If the unit rotates freely and smoothly during the 1000-rpm "bump", the unit will be accelerated to a speed corresponding to 4-pole starting motor speed. The machinery set will be allowed to rotate for approximately 15 min. During this period, at least one set of data will be recorded. Bearing and oil temperatures, oil and seal gas flows, speed, and vibration will be monitored continuously and, as necessary, appropriate action will be taken.

After the unit has stabilized and a complete set of data has been taken, the starting motor will be secured. The unit will be allowed to decelerate to a stop, and the deceleration time will be recorded. As the deceleration rate is an important indication of the condition of the rotating machinery, care will be taken to duplicate, where practicial, the same conditions when deceleration data are being taken. The oil temperature and the system loop pressure (compressor inlet pressure) will be held constant during data recording.

If performance of the unit and instrumentation appears satisfactory, the unit will again be rotated at 4-pole speed for up to an hour, but not to exceed the starting motor limitations. On shutdown, the deceleration rate will be recorded and compared with the previous run.

During this operation, system pressure may be varied, but caution must be exercised to see that the starting motor limitations are not exceeded. Starting motor power will increase approximately in proportion to compressor inlet pressure under these conditions. All intrumentation and readout equipment will be thoroughly checked during this operation.

Data Required

1 Machinery set deceleration rate data

2 Process gas data

3 Starting motor power vs speed

4 Starting motor power vs system pressure

5 Oil and seal gas system data

6 Vibration data

2. Initial Power Tests

a. Initial Self-Sustained Operation (ANSOP 16615)

Objective

The test objective is to obtain initial experimental data with the ML-1 power plant main process loop operating as a self-sustained system with the reactor as a heat source.

Description

To some degree it is expected that optimized startup techniques will be developed at Azusa. These techniques will be evaluated to establish compatibility with desirable reactor power ascension procedures. On the basis of this study, a safe realistic power plant startup procedure will be evolved. A detailed description of the test sequence is not practical without knowledge of the performance characteristics of the power-conversion machinery. However, it is possible to present a general test plan, based on predicted performance data for ML-1 equipment and on the experience gained at the Gas Turbine Test Facility.

Because of starting motor limitations it is anticipated that, during startup, the power plant will be pressurized to some low system pressure level (compressor inlet less than 45 psia) until the turbine inlet temperature reaches several hundred degrees, Fahrenheit.

The loop will be pressurized to the desirable pressure and checked for leaks. All main loop temperature and pressure readouts will be checked. Auxiliary systems will be put into operation and checked in accordance with procedures and check lists derived from previous tests. The machinery set will be rotated with the starting motor (4-pole mode); the instrumentation will be checked; and the deceleration rate will be recorded.

With the starting motor shut down but in a standby condition, the reactor will be checked out, brought to critical condition, and stabilized at some low power level (approximately 1 kw). Reactor startup will be accomplished under manual control and in accordance with established procedures.

The starting motor will be energized, and the turbine-compressor unit will be stabilized at "warmup" speed (less than 50% rated speed). All instrumentation readouts will be checked at this point, along with the speed control system. The speed control system will be placed on "automatic", with the speed control set-point at approximately 1000 rpm above the stabilized "warmup" speed.

Turbine inlet temperature will slowly be increased by raising the reactor power on manual control. Reactor power level will be stabilized at intervals during power ascension in order to monitor and record steady-state data. Compressor inlet pressure will be held essentially constant at a low pressure (less than 45 psia).

A running plot of starting motor power (kw) versus turbine inlet temperature (^{o}F) will be maintained in order to predict the self-run point at the "warmup" system pressure level. If starting motor power is not at or near zero by the time the turbine inlet (reactor outlet) temperature has reached 1000^{o}F, it will be determined whether or not the unit is developing net work, by slowly increasing the compressor inlet pressure by 5 psi. A decrease in starting motor power with an increase in system pressure (T_7 = 1000^{o}F) indicates that net work is available from the turbine. If the 5-psi increase in system pressure significantly reduces starting motor power, self-sustained operation can very likely be obtained by simply further increasing system pressure, if a compressor surge condition does not develop. Self-sustained operation also can likely be achieved by holding the system pressure constant and continuing to increase turbine inlet temperature. Caution should be exercised to not exceed the 500^{o}F limitation on precooler inlet temperature if the turbine inlet temperature is raised to much over 1050^{o}F at this slow turbine speed.

Based on all factors involved, it appears more desirable to continue to raise the turbine inlet temperature until rated value (1200^{o}F), precooler inlet limit of 500^{o}F, or self-sustained condition is reached while still at low system pressure. A reactor scram during startup at low system pressure will not seriously affect the rest of the power plant, because the starting motor can maintain rotation of the unit at low pressure without overload. A scram at high system pressure may mean that the loop pressure must be decreased as turbine inlet temperature decreases in order to prevent overloading the starting motor. In summary, the turbine inlet temperature will be increased until one of the following occurs:

1 Turbine inlet temperature reaches 1200^{o}F

2 Reactor power reaches 3.3 Mw(t)

3 Precooler inlet temperature reaches 500^{o}F

4 Acceleration of the unit to starting motor synchronous speed with starting motor power equal to zero occurs

5 First indication of compressor surge occurs

When self-sustained conditions are reached, the starting motor will be shut down, and the unit will be allowed to accelerate slowly to rated speed by advancing the set point on the speed control in 1000-rpm increments to rated speed. Speed will be allowed to stabilize at each 1000-rpm level provided such stablization does not occur in a region of vibration resonance as determined either by Azusa experience or by vibration readings. Complete state-point data will be recorded at each even 1000-rpm setting and at rated speed.

If at any time during the startup period the speed control bypass valve is more than 60% open in order to hold speed, turbine inlet temperature or system pressure will be reduced until the bypass valve is less than 20% open.

Should self-run not be obtainable within the limits established, or due to compressor surge problems at 4-pole starting motor speed, self-run will be attempted using the starting motor in 2-pole mode to help accelerate the unit.

At rated speed, with the control bypass valve open between 20% and 60%, the power plant will be operated for at least two hours at stabilized temperature and pressure with the reactor on manual control. A complete set of data will be recorded at intervals of at least every 30 minutes. At the end of each 2-hr period either the system pressure level or the turbine inlet temperature will be changed to a new level, and a new set of data will be recorded.

After the first 2 hr operation the reactor may be transferred to automatic temperature control. Temperature changes will then be effected by changing the temperature control demand (set point).

After approximately 8 hr reliable no-load operation is demonstrated, the alternator, the control center and the load bank will be functionally checked by exciting the alternator and applying a small load (approximately 10 kw). Performance of the power plant under light load will be monitored for approximately 2 hr with complete data being recorded every 30 min.

After a total of 10 to 12 hr operation the plant will be shut down. The alternator load will be eliminated and the turbine inlet temperature slowly reduced. On each shutdown the self-sustaining point will be defined for the plant at 4-pole starting motor speed at a different system pressure (in the interest of generating self-run data). The starting motor will be energized when the unit reaches 4-pole speed (assuming self-run is obtainable at 4-pole speed). The reactor may then be secured with after-cooling provided by the t-c set rotating on the starting motor. Caution must be exercised to see that the starting motor is not overloaded. System pressure will be reduced as required to decrease starting motor load.

Data Required

1 Complete set of power plant data recorded at least every 30 minutes

2 Deceleration rate from 4-pole starting motor speed at given conditions

3 Amounts of certain metallic elements present in oil before and after operation

4 Neutron and gamma-ray dose rates versus reactor power level at given distances

b. Full-Power Test (ANSOP 16625)

Objective

The primary objective of this experiment is to determine the maximum load that can be applied to the alternator without exceeding any of the following power plant operating limits:

Reactor power	3.3 Mw (t)
Turbine inlet temperature(2)	1200°F
Compressor inlet pressure(2)	120 psia
Compressor discharge pressure	345 psia
Precooler inlet temperature	500°F
Bearing temperatures	190°F
Compressor inlet temperature(2)	131°F
Vibration	1.5 g
Reactor inlet pressure	315 psia
Alternator stator winding temperature	275°F
Starting motor stator winding temperature	400°F
Starting motor current per phase	53 amps

Description

Based on the preceding test, Initial Self-Sustained Operation (ANSOP 16615) and on other established procedures, the power plant will be brought to 60-cycle speed (18,338 rpm for TCS-670 22,000 rpm for CSN-1). With the power plant stabilized at full mass conditions,balanced electrical load will be applied to the alternator until the control bypass valve is essentially closed ($\sim$1% open) and the turbine inlet temperature is 1200°F. The power plant will then be at essentially the full power attainable at conditions within the design operating envelope.

As it is anticipated that startup will have to be accomplished at reduced system mass, acceleration to rated speed will be effected by slowly increasing the turbine inlet temperature. With startup system pressure, turbine inlet temperature will be increased only as required to reach rated speed, with the speed control valve essentially closed. Once stabilized conditions have been achieved at rated speed with reduced mass and turbine inlet temperature, the system pressure will be increased to the rated mass flow rate. Actually, the compressor mass flow rate should be somewhat greater than rated 25.5 lb/sec because of the effect of the control bypass valve opening as system pressure is increased.

It is expected that a compressor inlet pressure of about 115 psia will correspond to the correct mass flow rate at zero load, with a compressor inlet temperature of 90°F and turbine inlet of about 1100°F. Should compressor inlet temperature be 132°F, then 123 psi at the compressor inlet would correspond to "full" system mass. (Note that 123 psi exceeds design rated pressure of 120 psia.) Should the control bypass valve stabilize at greater than 80% open while the system pressure is being increased, the turbine inlet (reactor outlet) temperature will be reduced as necessary to obtain the desired loop (compressor inlet) pressure, without the speed control valve being more than 80% open in order to hold rated speed. Once the desired system pressure is reached, the turbine inlet temperature will be increased until the speed control valve (SCV-102) is 80% open or until a temperature of 1200°F is reached, whichever occurs first. The power plant will be operated for one hour at this no-load condition - maintaining constant compressor inlet pressure, turbine inlet temperature, and speed. At least three sets of data will be recorded at this no-load condition.

After the alternator output voltage is adjusted to the correct value, load will be applied in increments. The power plant will be allowed to stabilize after each application of load. Initially, after load is applied, the turbine inlet temperature will be raised to maintain the speed control valve at 80% open until a turbine inlet temperature of 1200°F is reached. A complete set of data will be recorded after each 30- to 50-kw increment of load has been applied. Load will be added until the bypass valve is essentially closed; and the power plant will be operated for at least one hour, provided that no temperature, vibration, or pressure limit established for this test is exceeded. At least three sets of steady-state data will be recorded while at full power.

Alternator load will be reduced in small increments until a no-load condition is reached, and a "normal" power plant shutdown is executed.

Data Required

1 Complete set of power plant data recorded at least once every 30 minutes

2 Three sets of data at full power

3 Deceleration rate from 4-pole stating motor speed at controlled condition

4 Amounts of certain metallic elements present in oil after separation

5 Data to define self-run point on startup and shutdown

6 Neutron and gamma-ray dose rates versus reactor power at given distances

7 Post-shutdown activation counts from selected power plant components

8 Makeup gas required versus time

9 Health physics instrumentation data

c. Limited Endurance Test (ANSOP 16635)

Objective

The object of this test run is to provide limited endurance evaluation of the power plant early in the test program. Extensive steady-state data at several power levels will be generated. Additional operating experience will be gained before intentionally imposing severe transients on the power plant.

Shutdown shield evaluation data will be taken during and following reactor shutdown.

Description

The power plant will be operated at reated speed continuously for a period up to 100 hr. Although the plant may be operated at several power levels, normally a period of several hours will elapse between load changes. A complete set of power plant data will be recorded at least once each hour. Both reactor outlet temperature and turbine speed will be controlled automatically after the conditions of ANSOP 16635 (transfer from manual to automatic control) have been met.

The plant will be started in accordance with procedures developed to this point. By using the load bank, load will be added until the turbine inlet temperature is 1200^{o}F and the speed control bypass valve is no more than 80% open. System pressure will correspond to rated mass flow rate. The plant will be operated for several hours at this power level. Care will be taken to see that no established operating limit is exceeded.

The load will be added in small increments. For the final 4 hr of the run the plant will be operated at full power as established in the previous test.

After it has been determined that the limited endurance run has served its purpose, a normal shutdown will be executed. Post-shutdown gamma and neutron intensity and spectrum measurements will be taken to provide shutdown shield evaluation data.

Data Required

1 Complete set of power plant data for each hour of operation

2 Machinery set deceleration rate from 4-pole starting motor speed

3 Amounts of certain metallic elements present in oil after operation

4 Makeup gas rate versus operating time at various system power levels

5 Post-shutdown activation counts from selected power plant components

6 Operational and shutdown neutron and gamma-ray dose rates versus reactor power at given distances from reactor

7 Health physics instrumentation data

8 Post-shutdown gamma-ray and neutron radiation levels as a function of distance and direction from the core center line

3. Steady-State Performance Tests

a. Thermodynamic Performance Evaluation (ANSOP 16650)

Objective

The objective of this experiment is to generate steady-state performance data at specific operating conditions for comparison with specified and predicted performance information. Although a considerable volume of steady-state performance data will be obtained in the course of endurance tests and other operations, there is no assurance that these data will be at or near the desired state point conditions. Therefore, this experiment is designed to provide system conditions, where possible, that match the state points used to specify and predict power plant performance.

Description

The power plant will be started up and stabilized at rated speed. Slow transitions will be made to obtain desired pressure and temperature conditions. Both the reactor outlet temperature and the turbine speed will be controlled automatically.

The ambient temperature will be controlled, within limits, by using the test building hanger doors as dampers to control circulation of the precooler cooling air. The building ventilating system will also be used to help control ambient air temperature. Advantage will be taken of cold winter days to obtain data at low ambient air conditions. The precooler fans will be used to help regulate compressor inlet temperature. Fans and louvers will be used to control the temperature of the lubricating oil and moderator water.

The power plant will be operated at several different mass flow rates to determine heat exchange effectiveness. Turbine efficiencies will be determined, as instrumentation capabilities permit, as functions of velocity ratio and of corrected speed at a given expansion ratio. Data will be obtained to show the effects of system pressure on compressor performance. Reactor fuel element temperatures as functions of mass flow and gas temperature will also be obtained.

Data Required

1. Complete system data at each data point
2. Fuel element temperatures versus system mass flow, thermal power level, and gas temperature
3. Health physics instrumentation data
4. Machinery set deceleration rate from 4-pole starting motor speed at a given system pressure level and turbine inlet temperature
5. Amounts of specific metallic elements present in oil following operation
6. Activation count rates
7. Neutron and gamma-ray dose rates versus reactor power at specific locations

(1) Gross Electrical Power and Heat Exchanger Effectiveness

The maximum available gross electrical power and the heat exchanger effectiveness (within specified limits) at selected ambient temperatures will be determined. The desired ambient temperatures for data points are: $0^{o}F$, $60^{o}F$, $100^{o}F$, and $125^{o}F$ (although this last temperature exceeds rated conditions).

Because of limited control over ambient conditions it may be necessary to specify less desirable data points than those listed above. Ambient temperature will be controlled to a limited degree by use of test building doors and the building ventilating system. The power plant will be operated in a manner which avoids severe transients and in accordance with standard procedures.

(2) Gross Electrical Power at Specific Conditions

The maximum gross electrical power produced at four specified system conditions will be determined. These conditions are as follows:

	Compressor Inlet		Turbine Inlet
	Pressure psia	Temperature °F	Temperature °F
1	93	24*	990
2	106	88	1112
3	117	132	1200
4	121	156	1200

* If attainable

(3) State-Point Data at Specific Conditions

State-point data will be obtained, where practical, at 0%, 25%, 50%, 75%, and 100% of the maximum available gross electrical power at the following system conditions:

	Compressor Inlet		Turbine Inlet
	Pressure psia	Temperature °F	Temperature °F
1	106	88	1112
2	117	132	1200
3	121	156**	1200

** Exceeds rated conditions

b. Shield Performance Test (ANSOP 16642)

Objective

The object of this test is to generate specific shield performance data that are not available from other tests, but are considered necessary to adequately evaluate the performance of the ML-1 nuclear Radiation Shield System, both at power and after shutdown.

Description

With the reactor at power - above 1 Mw(t) - neutron and gamma dose measurements will be made at intervals along the circumference of a 25-ft-radius circle (or other radius) measured from the reactor vertical center line. The measurements will be made as a function of power at a given distance. If conditions and instrumentation permit, the measurements will be taken or repeated at three elevations: at ground level, above the reactor, and at an intermediate elevation. Where peaks in radiation levels are detected, detailed surveys will be made in an attempt to pinpoint the source.

Detectors should include columnated as well as uncolumnated instruments in order to help separate scattered and direct beam components.

Data Required

1 Complete set of power plant data for each hour of plant operation

2 Fast neutron, thermal neutron, and gamma radiation levels at specified locations around the power plant

3 Gamma spectra at selected locations

4 Health physics instrumentation data

5 Deceleration rate from 4-pole starting motor speed

c. Auxiliary Power Requirement Test (ANSOP 16646)

Objective

The objective of this test is to transfer the 480-volt, 3-phase bus load to the ML-1 alternator in parallel with the load bank. The auxiliary power requirement will be determined by noting the increase in alternator load.

Description

The power plant will be stabilized and moderately loaded with the load bank (less than 50% of maximum allowable load). With circuit breaker "B" (CB-1208) closed, the external 480-volt source will be synchronized with the ML-1 alternator, and the auxiliary bus transfer contactors will be actuated to transfer the auxiliary bus load to the ML-1 alternator. After at least two hours of operation, the auxiliary bus load will be transferred to an external source, and a normal power plant shutdown will be effected.

Data Required

1 Complete set of power plant data at least every hour

2 Changes in alternator load when auxiliary bus is transferred

3 Other data required for the Limited Endurance Test

d. Manual Control Test (ANSOP 16640)

Objective

The object of this test is to start, operate, and secure the power plant on manual control.

Description

The power plant will be started on manual control in accordance with approved procedures. Load will be applied up to 50% of rated load, and the plant will be operated for at least two hours. During this period, the mode of operation will be transferred from manual to automatic and back to manual control. The plant will be shut down on manual control.

Data requirements are the same as those for the Auxiliary Power Requirements Test (ANSOP 16646), paragraph c, above.

4. Transient Tests

a. Startup and Shutdown Optimization (ANSOP 16660)

Objective

The object of this experiment is to further optimize startup and shutdown techniques in the interest of decreasing the time required for plant startup and shutdown.

Description

Several power ascensions and shutdowns will be executed. Variations in startup techniques will explore the manner and timing of pressurizing the loop. By the time the detailed procedure (ANSOP 16660) for the experiment is written, it will have been determined whether or not it is necessary for the starting motor to operate at "fast" speed (2 pole) to obtain a start. At the present time it is anticipated that a satisfactory start can be obtained below half speed, provided that turbine performance meets expectations and that no compressor surge problem is encountered above 45% rated speed. Ideally the plant should be started at full system mass. However, starting motor limitations probably will prevent this. The proposed experiment assumes that satisfactory starts can be obtained with the starting motor in 4-pole mode; and three trial starts will then be made, as follows:

(1) Constant Mass Warmup - Acceleration by Increasing Temperatures

The plant will be warmed up at the highest system mass compatible with starting motor limitations and will be accelerated to the rated speed by increasing the turbine inlet temperature to the rated maximum limit (1200°F) while at the same time not exceeding the 500°F precooler limit. Fuel element temperatures, will be closely monitored to determine the rate of increase in the turbine inlet (reactor outlet) temperature. Instruments will be carefully monitored for indications of compressor surge. The same startup technique will also be evaluated with the starting motor in 2-pole mode to help the acceleration to rated speed.

(2) Constant Mass Warmup - Acceleration by Increasing System Pressure

The plant will be warmed up as described above. When the starting motor power is below 5 kw, the unit will be accelerated by adding system pressure - attempting to maintain constant reactor outlet temperature. Fuel element temperatures will be carefully checked to determine the rate of gas admission. This startup method will also be attempted with both 4-pole and 2-pole starting motor operation.

(3) Variable Mass Warmup - Acceleration by Increasing Temperature and Pressure

Rotation will be started at highest system pressure compatible with starting motor limitations. During the warmup period, nitrogen will be added to hold the starting motor power constant until the system is at full mass. The temperature will be increased to design point. It is expected that this method will result in the fastest startup. The reactor can be brought up to power more rapidly (probably with lower peak fuel temperatures) because of better heat transfer characteristics as pressure increases.

(4) Shutdown

Shutdown procedures will be evaluated by shutting down at full mass until the starting motor power limit is reached and by bleeding off the system pressure to a selected low value and then decreasing turbine inlet temperature.

Data Required

1 Power plant data at intervals during startup and shutdown

2 At least one set of power plant data at rated speed on each run

3 Fuel element temperatures versus time and turbine inlet temperature during startup

4 Startup and shutdown time requirements

b. Automatic Control Systems Response (ANSOP 16641)

Objective

The objective of this experiment is to determine the response characteristics of the automatic control systems for: 1) reactor outlet (turbine inlet) gas temperature and, 2) turbine speed.

(1) Reactor Outlet (Turbine Inlet) Temperature Control

The reactor power level is maintained (in automatic control) by a servo-loop that controls reactor outlet temperature by automatically positioning the regulating blades. The regulating blades are controlled by an error signal representing the difference between the measured reactor outlet gas temperature and the set-point at the reactor outlet.

Manual positioning of the shim blades insures that the regulating blades have an adequate control range (-0.15 to + 0.35% $\Delta k/k$). It is predicted that this servo-loop is capable of controlling 1200^{o}F at the reactor outlet within $\pm$ 35^{o} for a 15% step change in mass flow rate. Temperature recovery is expected in about 40 sec.

(2) Turbine Speed Control

Design specifications stipulate a constant load speed regulation of $\pm$ 1/3% and less than a 3% speed deviation following a 50% load change. Recovery is to be within 4 sec.

Turbine speed is sensed and compared with a desired value (demand) set on the controller. The error, together with valve position feedback, drives and stabilizes the speed control bypass valve (SCV 102) at a new position. Approximately 20% bypass is equivalent to full electrical load.

Description

The power plant will be stabilized at no-load condition. The auxiliary bus will be energized from an external source. Load will be applied in steps of approximately 10% until full load (as determined in Full Power Test, ANSOP 16625) is applied. Data will be recorded before, during, and after application of load. The load will be removed in the same manner as it was applied.

Next, load will be applied and removed in steps of 25% and 50%. Finally, with the power plant stabilized at no-load condition, full load will be applied in a single step. After operation at full load for at least 30 min, all load will be removed in one step.

Speed error or actual speed versus time at various loads, and reactor outlet (turbine inlet) temperature error or temperature versus time at various loads will be recorded. Speed error and temperature error or actual speed and temperature (T_7) will be recorded with the oscillograph before, during, and after (until recovery) a step load change is made.

Data Required

1 Complete power plant data at all stabilized points

2 Speed and turbine inlet (reactor outlet) temperature as a function of time before, during, and after a step load change

3 Steady-state speed error, temperature error, temperature, and speed data versus time at various loads

4 Health physics instrumentation data

5 Neutron and gamma measurements at specific points during operation

6 Gamma measurements after shutdown at specific locations

7 Deceleration rate from 4-pole starting motor speed at a given set of conditions

8 Gas analysis data

9 Oil analysis data following run

c. Systems Response (ANSOP 16655)

Objective

The object of this experiment is to obtain systems response data for the recuperator, precooler, and circulating coolant system.

Description

Obtaining systems response data involves stabilizing the power plant and then inducing a step change and observing selected parameters in the system being studied. Much of this information may be obtained from the previous test (ANSOP 16641). However, instrumentation limitations may make it necessary to conduct this separate experiment.

Recuperator transfer function data will be obtained by making step or rapid changes in turbine flow rate and measuring the heat exchanger inlet and outlet temperatures as a function of time before, during, and after the transit. The maximum allowable rate change in the turbine inlet temperature will be made; and heat exchanger inlet and outlet temperatures will be recorded on the oscillograph before, during, and after (until stabilization occurs) a step change.

Coolant system flow response data will be obtained as a function of step load changes. Turbine flow rate, compressor flow rate, turbine inlet pressure, compressor inlet pressure, and selected temperatures will be recorded during transient conditions.

Data Required

1 Turbine flow, compressor flow, turbine inlet, and compressor inlet pressure response as a function of step load change

2 Heat exchanger temperature "in-and-out" response as a function of step change in turbine flow rate (load change)

3 Complete power plant data at all stabilized points

4 Health physics instrumentation data

5 Neutron and gamma measurements at specific points during operation

6 Gamma measurements after shutdown at specific location

7 Deceleration rate from 4-pole starting motor speed at given conditions

8 Gas analysis data

9 Oil analysis data following run

d. Scram Test (ANSOP 16657)

Objective

The object of this experiment is to study the transients and other effects on the power plant following a reactor scram from power.

Description

It is quite possible that a scram transient will have already occurred on any one of previous power tests. However, unless adequate data were obtained as a result of such a scram, this experiment will be executed.

With the power plant stabilized at power (75%), a reactor scram will be initiated. This scram will not simulate a power failure. The axuiliary bus will be energized from an external source throughout this test. When the turbine decelerates to 50% speed, the starting motor will be energized in 4-pole mode to maintain rotation and reactor coolant flow. System pressure will be reduced as necessary to prevent overloading the starting motor.

Selected transient data, such as speed, turbine inlet temperature, compressor inlet temperature and flow rates, will be recorded by the oscillograph and photo panel.

Data Required

1 Selected parameter measurements versus time after scram

2 Steady-state data before scram

3 Complete power plant data at all stabilized points

4 Health physics instrumentation data

5 Neutron and gamma measurements at specific points during operation

6 Gamma measurements after shutdown at specific location

7 Deceleration rate from 4-pole starting motor speed at given conditions

8 Gas analysis data

9 Oil analysis data following run

5. Endurance Tests

a. Variable Load Endurance Test (ANSOP 16800)

Objective

The object of this test is to provide for extended power plant operation at electrical loads up to 75% of maximum allowable load (as established by previous tests).

Description

The plant will be stabilized with approximately 50% of maximum allowable load applied. The plant will be operated up to 1000 hr with load being varied between 25% and 75%.

Data Required

1 Complete set of power plant data for each hour of operation

2 Health physics instrumentation data

3 Neutron and gamma-ray data at given distance from the reactor during operation

4 Shutdown gamma measurements, including spectra data

5 Deceleration rate from 4-pole starting motor speed

6 Oil analysis following run

b. Rated Load Endurance Test (ANSOP 16810)

Objective

The objective of this test is to operate the power plant at rated load (maximum load obtainable at rated conditions) for an extended period in order to learn more about the reliability and endurance capabilities of the power plant.

Description

The power plant will be stabilized with rated load applied. Operation will continue for up to 500 hr.

Data Required

1 Complete set of power plant data for each hour of operation

2 Health physics instrumentation data

3 Neutron and gamma-ray data at given distance from the reactor during operation

4 Shutdown gamma measurements, including spectra data

5 Deceleration rate from 4-pole starting motor speed

6 Oil analysis following run

D. BIBLIOGRAPHY

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(2) Turbine-Compressor Set Specifications for ML-1, AGC 60015, MLS-55, April 1960

(3) ML-1 Design Report, IDO-28550, May 1960

(4) ML-1 Performance Data, AGN SK-200-60-181, May 1960

(5) Maintenance Package for Gas Supply Unit, Report AN-ENGR-8, 1961

(6) Portable Load Bank, Westinghouse I.B. No. 15000C397, 1961

(7) PGCR Preliminary Design Report, AGN TM-341, January 1959

(8) ML-1 Transport Manual, AGN TM-389, February 1961

(9) Review of Start and Scram Transients with the Stratos TCS-670, AN-182, April 1960

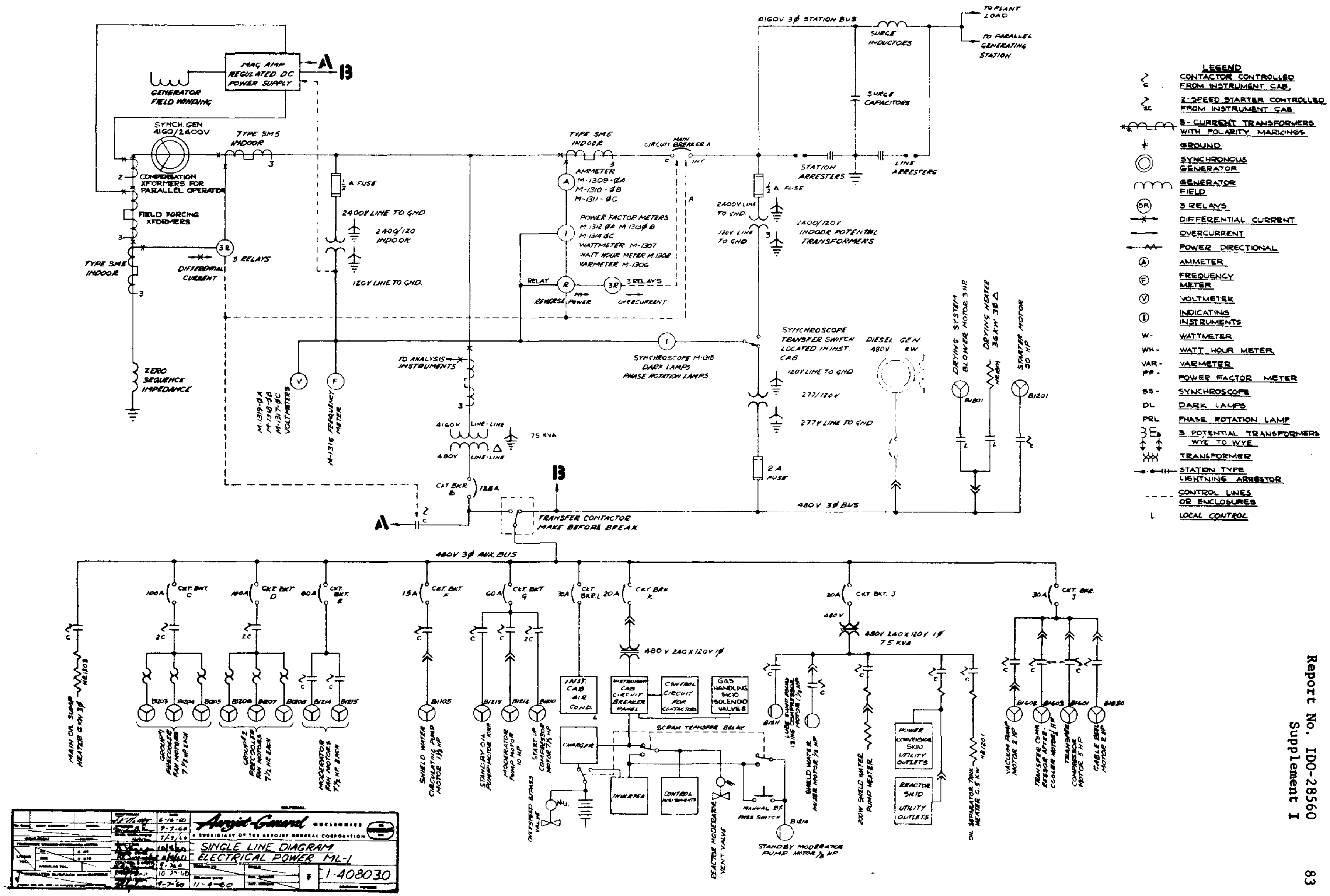
(10) ML-1 Components Design Report, AGN TM-378, July 1960

IV. ML-1 PHASE II TEST PROGRAM

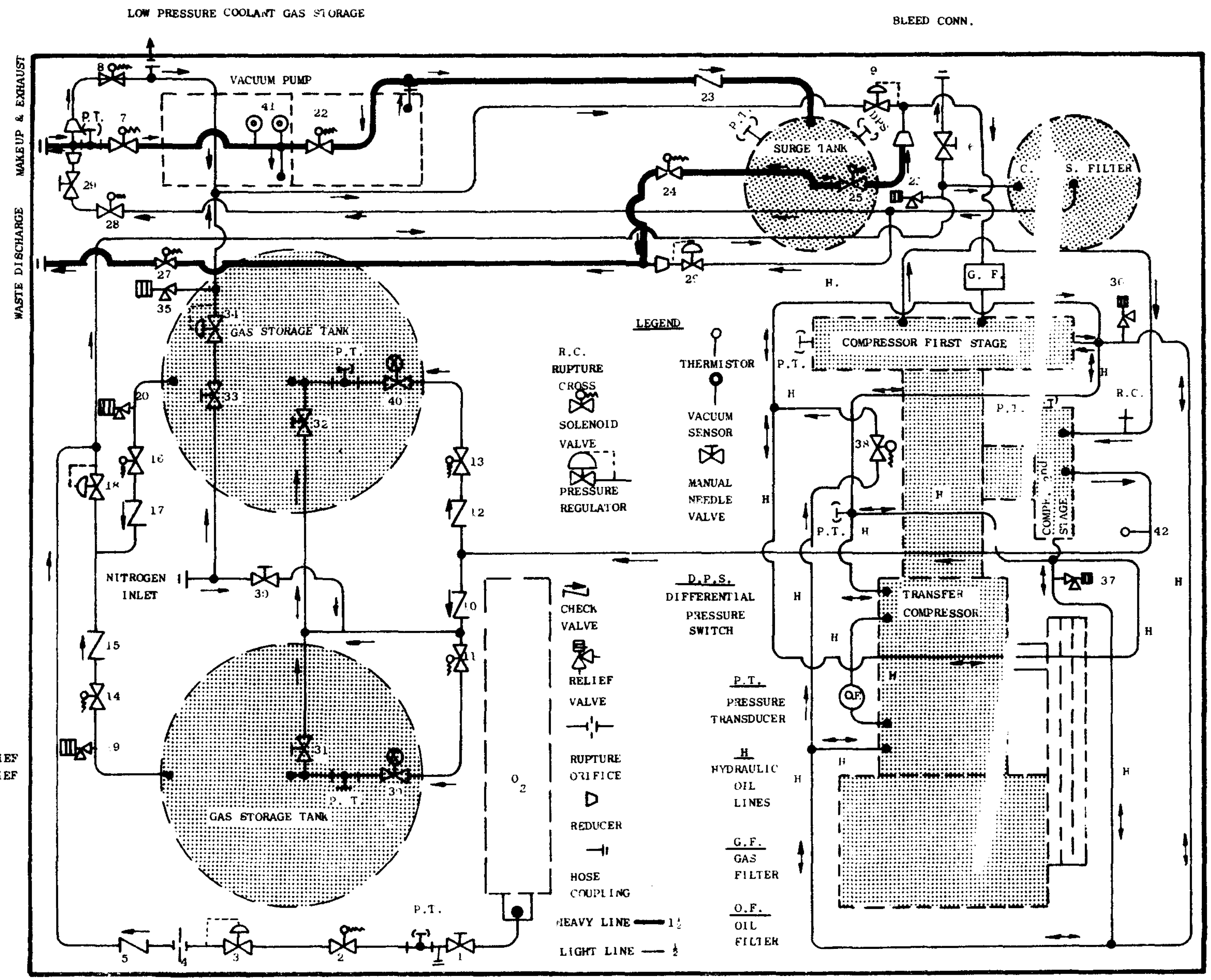
E. SUPPLEMENTAL INFORMATION

1. ML-1 Power Plant Systems Diagrams:

Electrical System, Single-Line Diagram
Gas Storage Skid, Schematic Diagram
Speed Control System, Schematic Diagram
Reactor Outlet Temperature Control System,
  Schematic Diagram (2 pages)


LEGEND
CONTACTOR CONTROLLED FROM INSTRUMENT CAB.
2-SPEED STARTER CONTROLLED FROM INSTRUMENT CAB.
3-CURRENT TRANSFORMERS WITH POLARITY MARKINGS
GROUND
SYNCHRONOUS GENERATOR
GENERATOR FIELD
3 RELAYS
DIFFERENTIAL CURRENT
OVERCURRENT
POWER DIRECTIONAL
AMMETER
FREQUENCY METER
VOLTMETER
INDICATING INSTRUMENTS
W - WATTMETER
WH - WATT HOUR METER
VAR - VARMETER
PF - POWER FACTOR METER
SS - SYNCHROSCOPE
DL DARK LAMPS
PRL PHASE ROTATION LAMP
3 POTENTIAL TRANSFORMERS WYE TO WYE
TRANSFORMER
STATION TYPE LIGHTNING ARRESTOR
CONTROL LINES OR ENCLOSURES
L LOCAL CONTROL
MAG AMP REGULATED DC POWER SUPPLY
GENERATOR FIELD WINDING
SYNCH GEN 4160/2400V
COMPENSATION XFORMERS FOR PARALLEL OPERATION
FIELD FORCING XFORMERS
TYPE SM5 INDOOR
3 RELAYS
DIFFERENTIAL CURRENT
ZERO SEQUENCE IMPEDANCE
1/2 A FUSE
2400V LINE TO GND
2400/120 INDOOR
120V LINE TO GND.
AMMETER M-1309-ØA M-1310-ØB M-1311-ØC
POWER FACTOR METERS M-1312 ØA M-1313 ØB M-1314 ØC
WATTMETER M-1307
WATT HOUR METER M-1308
VARMETER M-1306
RELAY
REVERSE POWER
OVERCURRENT
CIRCUIT MAIN BREAKER A
4160V 3Ø STATION BUS
SURGE INDUCTORS
SURGE CAPACITORS
TO PLANT LOAD
TO PARALLEL GENERATING STATION
STATION ARRESTERS
LINE ARRESTERS
2400/120V INDOOR POTENTIAL TRANSFORMERS
SYNCHROSCOPE TRANSFER SWITCH LOCATED IN INST. CAB
SYNCHROSCOPE M-1315
DARK LAMPS
PHASE ROTATION LAMPS
M-1319-ØA M-1318-ØB M-1317-ØC VOLTMETERS
M-1316 FREQUENCY METER
TO ANALYSIS INSTRUMENTS
4160V LINE-LINE
480V LINE-LINE
75 KVA
120V LINE TO GND
277/120V
277V LINE TO GND
2 A FUSE
DIESEL GEN 480V KW
DRYING SYSTEM BLOWER MOTOR 3 HP
DRYING HEATER 36 KW 3Ø
STARTER MOTOR 30 HP
480V 3Ø BUS
CKT BKR B 125A
TRANSFER CONTACTOR MAKE BEFORE BREAK
480V 3Ø AUX. BUS
MAIN OIL SUMP HEATER 6 KW 3Ø
GROUP 1 PRECOOLER FAN MOTORS 7 1/2 HP EACH
GROUP 2 PRECOOLER FAN MOTORS 7 1/2 HP EACH
MODERATOR FAN MOTORS 7 1/2 HP EACH
SHIELD WATER CIRCULATING PUMP MOTOR 1 1/2 HP
STANDBY OIL PUMP-MOTOR 10 HP
MODERATOR PUMP MOTOR 10 HP
START-UP COMPRESSOR MOTOR 7 1/2 HP
INST. CAB AIR COND.
INSTRUMENT CAB CIRCUIT BREAKER PANEL
CONTROL CIRCUIT FOR CONTACTORS
GAS HANDLING SKID SOLENOID VALVES
480V 240 X 120V 1Ø
480V 240 X 120V 1Ø 7.5 KVA
CHARGER
INVERTER
CONTROL INSTRUMENTS
SCRAM TRANSFER RELAY
OVERSPEED BYPASS VALVE
REACTOR MODERATOR VENT VALVE
MANUAL BY PASS SWITCH
STANDBY MODERATOR PUMP MOTOR 1/2 HP
SHIELD WATER MIXER MOTOR 1/2 HP
200W SHIELD WATER PUMP HEATER
POWER CONVERSION SKID UTILITY OUTLETS
REACTOR SKID UTILITY OUTLETS
OIL SEPARATOR TANK HEATER 0.5 KW
VACUUM PUMP MOTOR 2 HP
TRANSFER CMP. RESERVOIR AFTER COOLER MOTOR 1 HP
TRANSFER COMPRESSOR MOTOR 5 HP
CABLE REEL MOTOR 2 HP
Aerojet-General NUCLEONICS
A SUBSIDIARY OF THE AEROJET-GENERAL CORPORATION
SINGLE LINE DIAGRAM ELECTRICAL POWER ML-1
F 1-408030

PRACTICAL PIPING DIAGRAM-GAS STORAGE SKID



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2	V302-2
3	PCV301-3
4	RO301-4
5	V301-5
6	V302-1
7	V304-1
8	V305-1
9	PCV305-2
10	V306-1
11	V306-2
12	V306-3
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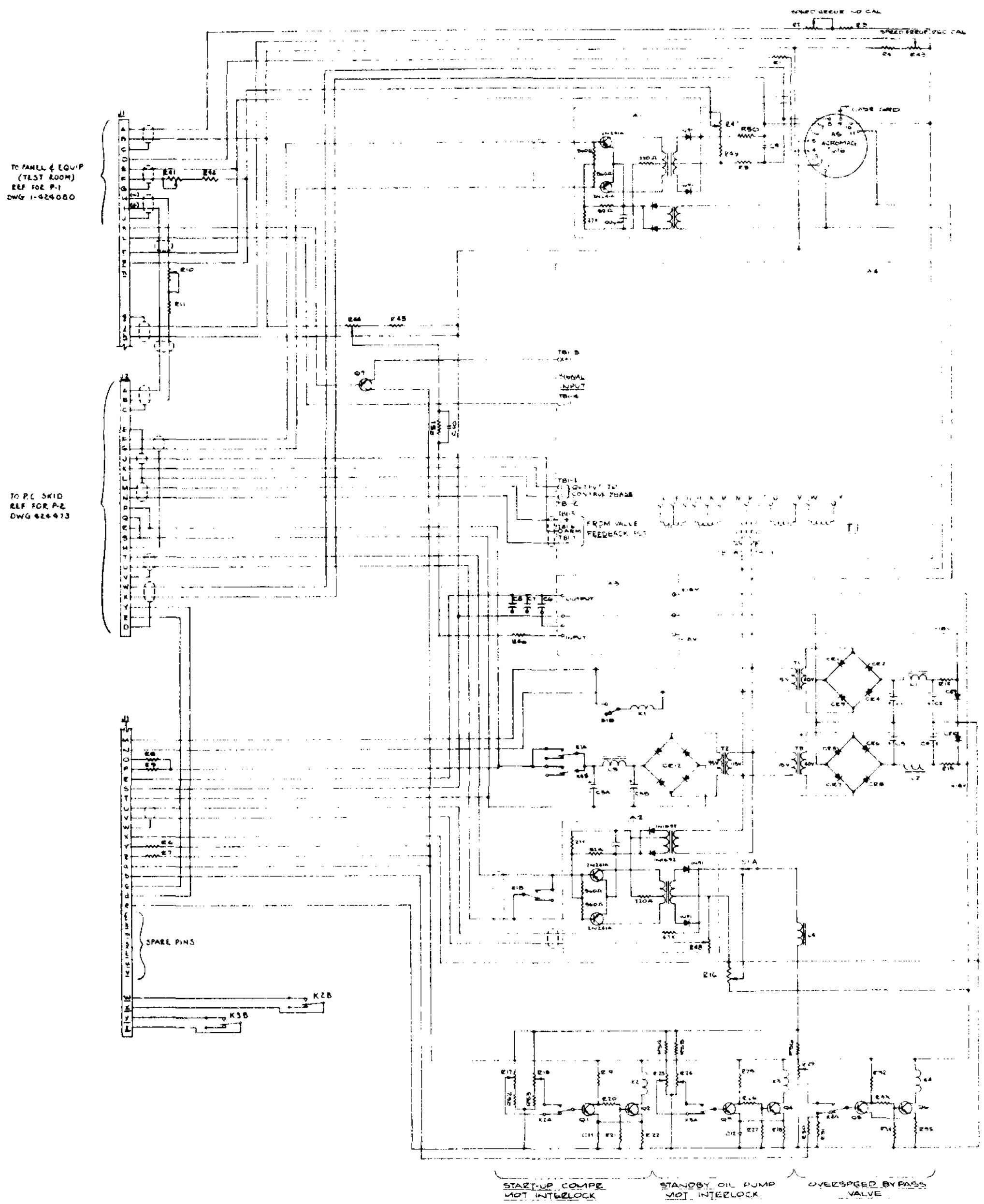
17	V307-4
18	PCV307-5
19	RV307-6
20	RV307-7
21	RV308-1
22	V309-1
23	V310-1
24	V311-1
25	V312-1
26	POV313-1
27	V314-1
28	V315-1
29	V315-2
30	V319-1
31	V319-2
32	V319-3
33	V320-1
34	PCV-320-2
35	RV320-3
36	COMP. 1ST STAGE RELIEF
37	COMP. 2ND STAGE RELIEF
38	SOLENOID UNLOADER
39	PI309
40	PI310
41	PI302
42	TI301



EQUIP. - REF ONLY

ITEM No	DESCRIPTION	MFR OR TYPE	PART No
A1, A2	TACH PAK	AIRPAX INC, CAMBRIDGE, MD	F5450B
A3	INT AMPL	AGN	424040-1
A4	VALVE MAG AMPL	CCC	
A5	MAG AMPL	AIRPAX INC	M5268
C1, C2, C3, C4	CAP ELECT	SPRAGUE	TE1307
C5	↓	↓	PE 2428
CR, CR2, CR3, CR4, CR5, CR6, CR7, CR8	DIODE	G E CO SYRACUSE, N Y	1N91
CR9, CR10, CR11	ZENER DIODE	HOFFMAN CORP, EL MONTE CALIF	1N1777
CR12	SE BRDG RECT	↓	1985AX1
J1	CABLE RECP	BENDIX CORP, SIDNEY, N.Y	MS3102A36-16P
J2	↓		MS3102A28-28S
K1	RELAY	↓	MR-14A
K2, K3, K4	↓	SIGMA, INC S. BRAINTREE, MASS	22RJCC-5000G-SIL
L1	FILTER CHOKE	TRIAD CORP VENICE, CALIF	C 3X
L2			C 3X
L3			C 40X
L4	↓	↓	C 2X
Q1, Q2, Q3, Q4, Q5, Q6, Q7	TSTR	TEXAS CORP, DALLAS, TEXAS	2N364
R1	RESISTOR	OHMITE MFG CO SKOKIE, ILL	2.7K ±5% ½W
R2, R10	POT	BOURNS INC, RIVERSIDE, CALIF	120-1-E1000 1K
R3	RESISTOR	OHMITE MFG CO	36K ±5% ½W
R4			56K ±5% ½W
R5			100K ±5% ½W
R6			22K
R7			2.2K
R8, R9			15K ±10% 5W WW
R11, R12			47K ±5% ½W
R13			68Ω ±5% 2W
R22			220Ω
R14			100Ω ±5% ½W
R15	↓	↓	680Ω ±5% ½W
R16	10 TURN POT	HELIPOT DIV, FULLERTON, CALIF	5K MODEL A
R17, R18, R23, R24, R29	POT (TRIMPOT)	BOURNS, INC	1K 10 TURN
R19, R25, R32	RESISTOR	OHMITE MFG CO	47K ±5% ½W
R20, R26, R33			12K ±5% ½W
R2, R27, R34			620Ω ±5% ½W
R28, R36			390Ω ±5% ½W
R30			16K ±5% ½W
R31	↓		1K ±5% ½W
R42	RESISTOR	↓	50Ω ±5% ½W
R43	POT	BOURNS, INC	200L-1-500 100Ω
S1	TGL SW	H H SMITH BROOKLN, N Y	512
T1	XFMR	TRIAD CORP	F 90X
T2			N 34X
T3	↓	↓	F 91X
R44	POT	BOURNS INC	120-15-00000 100K
R45	RESISTOR	OHMITE MFG CO	27K ±5% ½W
R46	↓	↓	15K ±5% ½W
C6	CAP	AEROVOX CORP NEW BEDFORD, MASS	CR70V506AM 2 MFD 150V
C7			CR90V106AM
C8	↓	↓	CR90V206AM
R41	POT	BOURNS, INC.	120-1-E100 100Ω
R47	POT	BOURNS, INC	120-1-E1000 1K
R48	↓	↓	↓
R49	RESISTOR	OHMITE, INC.	5.8K ±5% ½W
R51			150Ω
R50, R52, R53			470Ω
R54, R55, R56	↓	↓	470Ω
C9	CAP	AEROVOX CORP NEW BEDFORD MASS	10 MFD 150V
C10			8 MFD 50V
C11, C12	↓		10 MFD 25V

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AEROJET	GOVERNMENT
APPLICABLE SPECIFICATIONS	

LIST OF MATERIALS

SCHEMATIC DIAGRAM, SPEED FUNCTION CONTROL-ML-1 TEST

Aerojet-General NUCLEONICS SAN RAMON, CALIFORNIA

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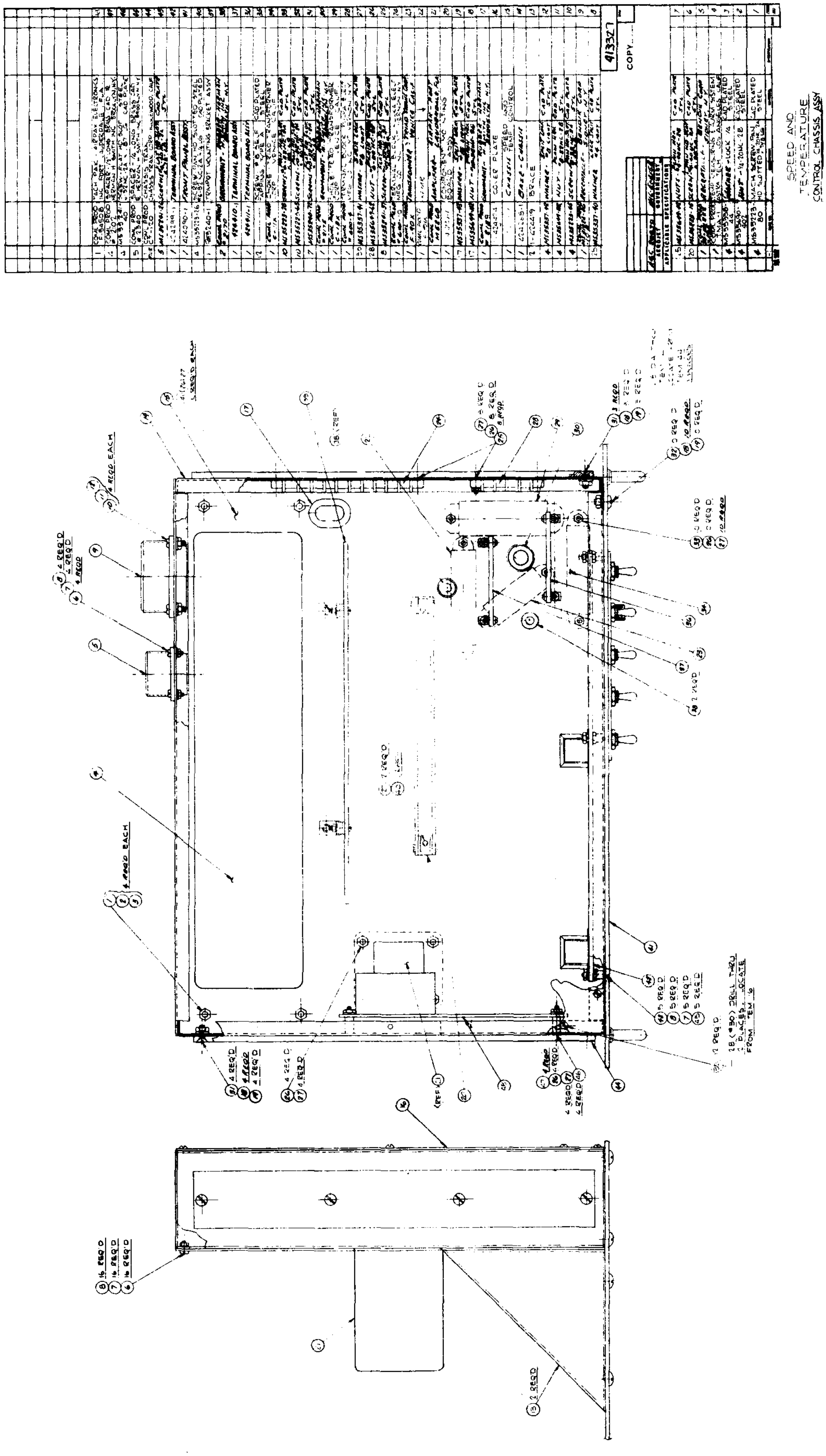
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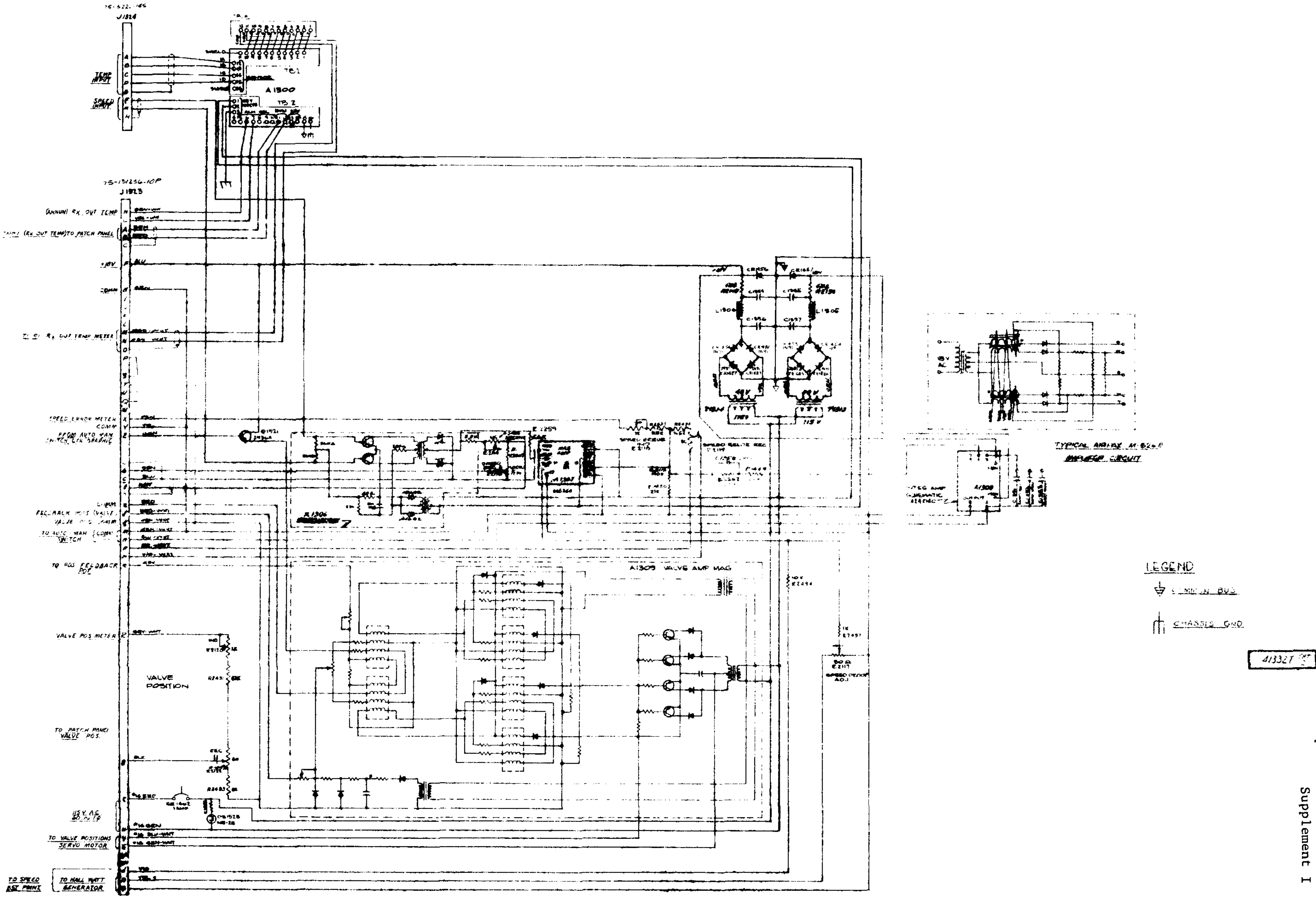

J1824
J1823
A1500
VALVE POSITION
A1309 VALVE AMP MAG
VALVE POS METER
SPEED ERROR METER
FEEDBACK POS (VALVE)
TO VALVE POSITIONS SERVO MOTOR
TO SPEED SET POINT
TO HALL WATT GENERATOR
115 V AC
TYPICAL AIRPAX M-624-B AMPLIFIER CIRCUIT
LEGEND
CHASSIS GND
41332T

IV. ML-1 PHASE II TEST PROGRAM

E. SUPPLEMENTAL INFORMATION

2. ML-1 Operational Instrumentation

Process Instrumentation
Electrical Power Instrumentation
Nuclear Instrumentation
Annunciator System
Control Blade Operation
Control Blade Position - Indicating Instrumentation
Piping and Instrumentation Diagram, Primary Systems

PROCESS INSTRUMENTATION

1. TIC-101 Reactor outlet temperature indicator, controller and alarm

The reactor outlet temperature is controlled to a pre-set but manually adjustable value by controlling the reactivity by insertion or withdrawal of the regulating rod. The insert or withdraw signal to the regulating rod emanates from a temperature sensor in the gas stream. Thus, any rise or fall in reactor outlet gas temperature will cause the regulating rod to either insert or withdraw, thereby controlling the temperature.

The physical location of gas temperature sensor will be in the main reactor discharge duct on the power conversion skid to avoid the necessity for additional connectors.

The temperature sensing element is one leg of a bridge circuit, the remainder of which is located in the control cab. The signal will be displayed on a temperature indicator mounted on a graphic panel which schematically portrays the entire gas loop. The meter with a temperature setpoint potentiometer and an error switch is mounted next to its respective monitoring point on the graphic panel. The error between the setpoint and actual temperature will be displayed on a secondary scale of the outlet temperature indicator when the error switch is depressed. The error switch is used to reduce the error between the temperature and actual temperature to a minimum when switching the control system from manual to automatic control.

A trip circuit in the bridge circuit will actuate an annunciator when the reactor temperature error deviates beyond an allowable deadband. The deviation beyond the deadband is annunciated as temperature error high. The operator will then determine whether the actual temperature is high or low and take necessary corrective action.

2. TYH-103 Reactor outlet temperature scram control

A trip circuit, whose signal originates from a separate sensor located adjacent to the above described sensor for the indicator, will scram the reactor if the outlet temperature is high and continues to rise after the operator has attempted corrective action. The annunciator will be actuated when the reactor is scrammed by the reactor outlet temperature being high.

The point at which the trip circuits actuate will be adjustable over the entire instrument range. A screwdriver type trip adjustment will be located on the top of the bridge chassis to avoid accidental misadjustment.

3. TI-102 Compressor inlet temperature indicator and alarm

The gas entering the precooler is a mixture of the gas flowing through the system and the gas that is being bypassed around the compressor. A temperature indication of the gas entering the compressor is used to determine whether additional fans are needed and the effectiveness of the precooler. The temperature will be indicated on a meter on the graphic panel.

A trip circuit will supply contacts for a high temperature alarm. The point at which the trip circuit actuates will be adjustable over the entire range of the instrument. The actual adjustment will be mounted on the top of the bridge circuit chassis to prevent accidental misadjustment. The temperature trip setting will be set just below the maximum allowable inlet temperature into the compressor.

4. PI-101a Compressor outlet pressure indicator and alarm

The pressure sensor, of the unbonded strain gage type, will receive its excitation voltage from a bridge unit mounted in the control cab. An annunciator will warn the operator when the outlet pressure reaches the maximum pressure allowable to the reactor. An adjustable low pressure alarm will be used to warn of compressor malfunction. The adjustment control will be located on the front panel of the bridge unit.

The compressor outlet pressure indicator will be shared with the compressor inlet pressure. The pressure to be indicated will be at the discretion of the operator by the use of a selector switch mounted below the indicator on the graphic panel.

5. PI-101b Compressor inlet pressure indicator

The inlet pressure sensor will receive its excitation voltage from a bridge unit located in the control cab.

6. QAH-101 Compressor vibration alarm

The Clark turbine-compressor set will operate at 18,000 rpm and the Stratos turbine-compressor set at 22,000 rpm. The speed indicator controller will maintain and indicate the speed. The bearings of turbine compressor sets will be monitored for overheating. With the speed of the turbine and the temperature of the bearings being monitored, the next most indicative point of fault location will be vibration. An indicator is supplied, with a selector switch, with which the operator can determine the direction of the excessive vibration.

An alarm will sound when the vibration level of the turbine compressor set becomes excessive.

The operator will then monitor other measured values and take corrective action.

7. VP_n-I-102 Valve position indicator

The position of the valve is an indication of the bypass flow rate and control range capability. A signal will emanate from the valve that is proportional to the valve opening and will be indicated on the graphic panel.

During normal operation, the valve position is an important parameter to be monitored, giving an indication of the bypass flow in the system.

The position indicator will also serve as an indication of the speed control range left under the power output and other conditions of operation.

8. SAH-101 Turbine high speed alarm

The turbine speed indicator controller (SIC-102) will regulate turbine-compressor speed. The controller will maintain turbine speed constant under normal conditions. A turbine high speed trip circuit has been incorporated using a separate speed sensor. The high speed trip circuit can operate independently of the turbine and speed controller. The trip circuit acts as a backup for the controller and prevents possible runaway conditions.

9. SIC-102 Turbine speed indicator and controller

The speed of the turbine-compressor set is measured by a tachometer. The signal of the tachometer is fed to the controller which positions the bypass valve, and thus regulates the alternator shaft speed and controls the frequency of the electrical power output of the plant. Lead networks and frequency corrective circuits are built into the controller to maintain stability.

An indication of turbine speed is displayed on a meter on the graphic panel. A speed control potentiometer, for manual control of speed, an auto-manual switch and a speed error switch are also located on the graphic panel. The speed error switch functions in the same manner as the temperature error switch. The speed set potentiometer, for automatic speed set, is located with the above.

Both the speed error and the temperature error will be set to their minimum value before transfer to automatic control.

10. P_uI-101 Precooler louver position indicator & controller

The mass flow of air through the precooler heat exchanger is varied by (1) the number of fans operating, (2) the speed of the fan motors, and (3) the position of the louvers over the fans or by any combination thereof. Since the louver position is important for temperature control, indication of their position is necessary. Remote manual control of the louver positioning motors and a position indicator are mounted on the graphic panel adjacent to the precooler symbol.

11. O_2I-101 Loop Oxygen Indicator

The quantity of oxygen in the main loop must be maintained between 0.5 $\pm$ 0.1% for optimum fuel element operation (HFED Note 117, Ref. ML-1 Cooling Specifications). Since the oxygen in the loop is gradually being depleted, it is necessary to add fresh oxygen to the system.

An oxygen indicator will be supplied that can be used by the operator to determine when more oxygen need be added to the system. An alarm will sound when the oxygen content drops below the allowable percentage or rises above the allowable percentage.

12. $\frac{dp}{dt}$ YH-101b Fast pressure loss scram

The compressor outlet pressure will fluctuate as the load demand on the generator fluctuates. The increases and decreases will normally stay within a small range.

The fast pressure loss scram circuit will be included in the compressor outlet pressure instrument that will detect any large quantity of pressure loss over a short period. This fast pressure loss would primarily be caused by a large system leak, thus the necessity of the scramming action.

The actuation of the fast pressure loss scram circuit will be annunciated.

13. TI-201 Moderator water temperature indicator

The moderator water temperature will be controlled by varying the number of fans blowing air through the moderator heat exchanger and controlling the position of the louvers on the heat exchanger. Fan motor control will be by manual pushbutton start-stop switches and the louver position will be controlled by a manual louver positioning switch.

An indication of the temperature outlet water being discharged from the heat exchanger is needed for determining what exchanger control is necessary.

14. TI-202 Moderator water temperature, reactor outlet

For proper operation, an indication of this temperature is needed to maintain the water temperature below boiling.

The sensing element will be mounted in the heat exchanger inlet pipe. The indicator will be mounted on the graphic panel.

15. TI-203 Shield water temperature indicator and alarm

Boric acid added to the shield water will go into solution when the water temperature is above 120°F. An indication of shield water temperature is needed to determine the range of readings to be expected from the conductivity instrumentation.

The temperature sensing element will be located in the shield tank, forming a leg of the bridge circuit. A trip circuit is included that will annunciate when the temperature drops below 120^{o}F.

The indicator will be mounted on the cab process panel and will be shared with two other sensors.

16. LI-201b Moderator surge tank liquid level indicator

The water in the moderator loop circulates through the reactor, through the moderator heat exchanger and then into the surge tank and back to the pump.

The surge tank is used for storage of moderator water and its level is a direct indication of the amount of moderator water available.

Water level indication in the surge tank determines the time to add water to the system. A level alarm will sound when the water level is below the minimum safe level.

17. LI-201a Shield water liquid level indicator and alarm

To effectively shield the reactor, the level of the water in the shield tank must be maintained. An indication of the water level will determine the necessity of adding more water. An annunciator will warn when the water level drops below a preset minimum. The indicator will be shared with the moderator water and sump oil levels.

18. CI-201a & b Shield or moderator water conductivity

Shield water conductivity is a function of the amount of boric acid dissolved in the water which is an indication of effectiveness of the shield water.

The shield water conductivity will have a low level alarm that will warn of low boric acid content.

An indication of high conductivity of the moderator water may be due to the water becoming contaminated with sludge or corrosive elements.

A high conductivity indication will be a warning that the demineralizer must be changed.

19. FYL-201 Moderator water low flow alarm (scram)

The flow of moderator water through the reactor must be maintained if the reactor is to operate at high power levels. Stagnant water in the reactor will boil.

A flow indication is not deemed a necessity since the temperature of the moderator water is indicated. The operator does not need the actual flow rates as long as it is above a preset minimum for sufficient cooling. Consequently, a simple flow switch is utilized. At a preset minimum flow, a scram action will occur and be annunciated.

20. P_nC-201 Moderator louver limit control

One control of the moderator water temperature is the control of the heat exchange louver position.

A center neutral switch is employed that will control the power to the louver positioning motor. By manipulation of this switch the operator can control the position of the louvers.

Monitor lights are provided that actuate when either louver limit is reached (i.e., full open, full closed).

21. PI-301 a & b Nitrogen and oxygen makeup pressure indicator and alarm

The nitrogen makeup supply will be located on the nitrogen fill and makeup skid. An indication of the pressure in the manifold will inform the operator of the amount of gas available. A low pressure alarm will sound when the pressure in the manifold drops below a preset value. Low pressure annunciation will occur when the volume in the tanks is insufficient to refill the system.

One standard 200 cubic foot bottle of oxygen is connected in parallel with the nitrogen bottles.

A low pressure alarm will sound when the pressure in the oxygen bottle drops below a preset value.

Both bridge circuits and their necessary power supplies for pressure measurement will be mounted on a single chassis and the indication of the pressure will be displayed on a single indicator in the cab. A selector switch will be used for selection of pressure to be monitored.

22. PI-302 Gas evacuation system vacuum indicator

When the main loop is pumped down to atmospheric by the transfer compressor, the vacuum pump will be used in series with the transfer compressor.

An indication of the loop pressure or vacuum will inform the operator when to shut off the vacuum pump and admit clean gas or air.

The vacuum pump will not be allowed to start pumping from the system until the loop pressure is down to 1 atmosphere. The interlock will be accomplished by using a locally mounted pressure switch ahead of the solenoid valve (V-304-1) that opens the line from the system to the vacuum pump. The pressure switch will actuate at 1 psig and close the circuit for the solenoid valve.

The vacuum indicator and a small light that indicates when the pressure switch has actuated, will be mounted on the gas handling graphic panel.

23. PI-303 a & b Storage sphere pressure indicator

When pump-down of the system is required, the transfer compressor will pump the gas into one of two storage tanks. The choice of tank to be used is at the discretion of the operator and is accomplished by actuating the correct solenoid valve.

A pressure sensor is mounted in the inlet line to each of the storage tanks.

The amount of gas in either of the tanks must be considered before evacuation of the system.

An indicator, shared with PI-301 a & b, can be used to determine the pressure in either sphere.

A high pressure alarm will sound when the pressure in either sphere exceeds its maximum allowable pressure.

24. PML-304 Pressure switch for recirculation valve

When pump-down of the system is required, the transfer compressor will pump the system down to atmospheric pressure. At atmospheric pressure, the vacuum pump will be activated and will operate in series with the transfer compressor.

The output of the vacuum pump is 32 scfm while the allowable intake at the transfer compressor is only 2 scfm. The vacuum pump outlet will have to be shunted into a surge tank (T-303) to hold some of the gas.

The pressure in the surge tank (T-303) must not exceed the allowable back pressure of the vacuum pump. To prevent the buildup of excessive pressure, a pressure sensitive switch will be mounted on the surge tank. The switch will actuate, upon closure, a solenoid valve in a bypass line around the vacuum pump. The solenoid valve will allow the excess gas in the surge tank to be recirculated around the vacuum pump until the transfer compressor can pump the gas below the pressure allowed by the pressure switch.

25. PML-305 Vacuum system admission valve

The vacuum pump will not be allowed to start pumping from the system until the loop pressure is down to 1 psig. This will be accomplished by using a local mounted pressure switch in advance of the solenoid valve (V 304-1) that opens the line from the system to the vacuum pump.

A monitor light that indicates when the loop system is at 1 psig will be mounted near the vacuum pump start switch.

26. TI-301 Transfer compressor gas discharge temperature

A knowledge of the gas temperature as it is discharged from the transfer compressor will aid the operator in determining the true quantity of gas in the storage spheres and as a monitor of the performance of the inter-cooler and after-cooler blower.

27. PI-306 Transfer compressor oil pressure indicator

The transfer compressor uses oil as the working medium which actuates the diaphragm. An oil pressure indicator will serve a two-fold purpose: 1) as an indication of the oil pressure to the diaphragms, 2) as an indication that the quantity of oil in the system is sufficient for proper operation.

28. PAH-307 a & b Pressure switches on transfer compressor diaphragms

These pressure switches will monitor the inner diaphragm cavity pressure. The pressure in the cavity is normally static. Upon rupture of a diaphragm, the pressure in the cavity will increase.

A knowledge of a diaphragm rupture when it happens will allow the operator to shut the system down and thereby possibly avoid permanent damage or gross oil contamination of the gas storage system.

29. PML-308 Surge tank cutoff for transfer compressor

Since the surge tank has a small volume, the transfer compressor will evacuate the gas in the tank faster than the vacuum pump can supply the gas. Under these circumstances the transfer compressor would soon be pumping against a vacuum or near vacuum. This is an undesirable situation.

A pressure switch mounted onto the surge tank will interrupt the power to the transfer compressor motor when the pressure drops to 0 psig. A monitor light will indicate when this situation exists.

30. PI-601 Sump-gas pressure indicator and alarm

The pressure of the gas in the main lube oil sump is reference pressure for the lube system. An indication of the pressure will tell the operator of the expected performance of the lube system.

An alarm will sound when the pressure exceeds a preset value.

31. PML-602 Seal compressor cutoff

For initial startup of the lube system, the seal compressor will have to be started first to increase the pressure in the gas seals. The compressor pressure to the seal will drop to zero when the main compressor reaches sufficient speed to supply seal pressure. A pressure switch is connected in the main compressor outlet piping that will actuate when the pressure increases to a value sufficient to maintain the seals. Actuation of the pressure switch cuts off the seal compressor power. An indicator light will be on while the seal compressor is operating. Upon actuation of the pressure switch which deactivated the seal compressor, the indicator light will go out.

32. PAL-603 Auxiliary oil pump actuation

A pressure switch will be installed at the outlet of the gear driven lube oil pump, which will actuate upon reduction of pressure below a preset value. The actuation of the pressure switch will start the auxiliary oil pump. An annunciator will warn the operator when this condition exists.

33. PdAH-605 Oil filter differential pressure high

A differential pressure switch will be installed in parallel with the main lube oil filter. The filter will be changed at periodic intervals but the switch will warn the operator of filter clog in between periods.

34. LI-601 Sump oil level indicator and alarm

The bulk of the lube oil in the lube system is stored in the main sump.

An indication of the oil level in the sump will be an indication of sufficient oil for sustained operation. The indicator is charged with the water level systems.

An annunciator will warn the operator when the level of the oil in the sump drops below a preset level.

35. TI-601 Oil cooler outlet temperature indicator

The oil cooler outlet temperature must be maintained within the temperature limits allowable to the bearings.

An indication of the temperature at the cooler outlet will inform the operator that readjustment of the louver position is necessary or when bypass of the heat exchanger is needed. The indicator is shared with shield water and transfer compressor gas temperatures.

36. TI-602 a, b, c, d & etc. Bearing temperature indicator and alarm

Two thermocouples will sense each bearing temperature. These thermocouples will operate in parallel so that failure of any one will not cause loss of bearing temperature indication. The thermocouples will be routed through a reference junction back to the cab.

At the cab, the signals will be routed through an "or" circuit. The circuit will, upon a high temperature signal, actuate a single annunciator. Any one of the thermocouples can, upon a high temperature signal, actuate this one annunciator.

To determine which thermocouple has caused the annunciation, the operation must scan the entire system. Scanning is accomplished by switching the signal from each bearing position.

37. P_nC-601 Lube oil louver position control

The control of the louvers above the lube oil heat exchanger will be controlled manually, in the same manner as the moderator louvers.

Monitor lights will tell the operator when the limits of travel have been reached.

ELECTRICAL POWER INSTRUMENTATION

Electrical instrumentation is provided to monitor the plant output and to provide switching for the load shifts of the generator system. Each of the three phases of generated power has a voltage and current measuring system for balancing phase loads. The meters for monitoring the system are as follows:

1. Synchroscope (1)

A synchroscope is provided to insure that the phase, rotation speed and voltage of the ML-1 alternator matches that of a distribution network to which the plant is connected.

2. Frequency meter (1)

One frequency meter is provided to insure that the frequency of the system will work in synchronism with other supplies.

3. Voltmeters (3)

The voltmeters are used to read the output voltages of the synchronous generator. These units read the voltages of the 3-phase , line-to-neutral voltage.

4. Ammeters (3)

The ammeters are provided to read the current of each phase of the 3-phase system. Three meters are required for ML-1 application to determine any instantaneous variation of load due to unbalanced conditions.

5. Polyphase wattmeter (1)

This meter is used to determine the total power output of the synchronous generator. In addition, the power reading obtained is used in computing the average power factor for the system.

6. Polyphase varmeter (1)

This varmeter is used to determine the reactive power output of the synchronous generator. This indication is used together with the readings obtained from the wattmeter to compute the average power factor of the plant.

7. Single-phase (two quadrant) power factor meters (3)

These meters measure the power factor of each phase. Each phase is monitored as the polyphase power factor meter will read correctly only under balanced conditions which is not necessarily the operating condition of this system.

8. Watthour meter (1)

This meter records the total output of the system.

9. High-power disconnects

This equipment is provided to protect the alternator from sudden load short-circuits.

NUCLEAR INSTRUMENTATION

The neutron flux measuring instruments provide the most rapid and sensitive indication of reactor power and are therefore key operational aids. As no one measurement channel can monitor the eight-decade span from source level to full power, three ranges of nuclear instrumentation are provided. Additional safety and reliability are gained by installing more than one channel of instrumentation in each of the three ranges. The ranges overlap to insure a continuous indication of reactor power.

The ML-1 nuclear instrumentation is being fabricated to AGN specifications by the Stromberg-Carlson division of the General Dynamics Corporation. The equipment is completely transistorized to insure highest reliability, smallest size, lowest weight and maximum resistance to the vibration and shock experienced during transport of the plant.

Nuclear instrumentation components are located on the reactor skid, the power conversion skid and in the control cab. Coaxial cables interconnect the components.

Seven detectors comprising two B^{10}-coated proportional counters for the source range, two gamma-compensated ionization chambers for the intermediate range and three uncompensated ionization chambers for the power range are located in moisture-proof wells in the reactor shield water tank.

The pulse signals from the source range detectors, which are proportional in rate to the neutron flux for values below 1.7×10^4 nv, are amplified at the P-C skid to insure accurate readings at the control cab. The amplified signal pulses can therefore be counted while lower level noise signals picked up in the long cables are eliminated by a pulse height discriminator. The preamplifiers are located on the power-conversion skid to minimize the radiation exposure, to provide ready access and because all cable connections are centered on the skid to facilitate plant setup. Twenty coaxial conductors (including six spares) are used to connect all of the detectors and preamplifiers with the computer-amplifier equipment in the control cab. The coaxial conductors will be cabled with a steel leader cable for strength and sheathed with an "Arctic" Neoprene jacket.

The computer-amplifier equipment will occupy 42 inches of standard 19-inch electronic rack space in the control cab. Readout of the seven channels is provided by 4 console-mounted meters with selector switches being provided so that the different detectors may be cross-checked. Two additional meters are used to monitor the detector polarizing-potentials and to monitor the currents to the clutch rod solenoids. The solenoids are powered by silicon-rectifiers located in a nuclear instrument chassis. All of the nuclear meters are Westinghouse Series K240, shock resistant, taut-band suspension type.

Test provisions are built into the equipment to check the source range channels at four different counting rates, the intermediate range channels at four different neutron flux levels, and the three power range channels at the zero and 100% power calibrations. Three period signal calibration signals are also provided.

A "source count" interlock circuit is incorporated in channel No. 1 of the two source range channels. This interlock can be set from 2 to 100 cps and will prevent energization of the control rod clutches (and thereby rod withdrawal) unless the measured count rate is greater than the interlock set point value.

Period scram signals are derived from the 2 source range channels and from the 2 intermediate range channels. The set points can be adjusted over a wide range. To prevent inadvertent misadjustment these and other set point adjustments must be made by partially withdrawing the chassis from the racks.

Scram signals also originate from the three power range channels. A switch permits selection of two-out-of-three channel coincidence or one-out-of-three. This arrangement permits in-operation checking or replacement of a channel.

All nuclear scrams will be identified as to channel of origin and nature by simultaneous signals to the annunciator system. Manual reset is required before a re-start can be made.

The source range proportional counters are protected against premature burnout by a circuit in one of the intermediate range channels which removes the high voltage to the two detectors when the reactor power is in the intermediate or power range. The source range signal is automatically restored when the power is decreased below the protection set point. The period scram signals from the source range channels are also automatically disabled when these channels are bypassed. Pilot lights on the operating console indicate whether the source range channels are in use or bypassed.

ANNUNCIATOR SYSTEM

The fault monitoring annunciator system is being fabricated to AGN specifications by Radar Relay Inc. This fifty-channel system will produce an audible signal upon the detection of an abnormal plant condition; the operator will then be able to take corrective action to restore normal operation. This system is especially important in the ML-1 because recording instruments, which would provide a "trend" indication, are not used because of space considerations. The specification calls for the use of solid-state diodes and transistors as switching elements to insure highest reliability and maximum resistance to the shock and vibration experienced during transport of the plant.

The operating sequence is as follows: When a field "trouble" contact is closed, an audible alarm is produced in the control cab;and a small, suitably inscribed back-lighted nameplate on the control console begins to flash and indicates to the operator the specific component or system where there is incipient trouble. When the operator presses the acknowledging reset button, the audible alarm is silenced and the visual presentation changes to steady illumination of the nameplate. When the trouble is cleared, the field contact will open and the nameplate lamp is de-energized.

CONTROL BLADE OPERATION

The reactor is controlled by the electro-mechanical positioning of two "safety", three "shim" and one "regulating" control rods. The shim rods provide coarse power control and flux distribution balance; the regulating rod provides fine power control. All rods are inserted to effect shutdown.

The position of these rods in the reactor, and thereby their effectiveness in controlling the neutron generation, is manually controlled during startup and shutdown of the reactor and may be controlled automatically during power range operation of the reactor at the discretion of the operator. The rods are inserted or withdrawn by the energization of electric clutches and drive motors.

The plant control philosophy is one that emphasizes manual control. No provision is made for automatic startup and the maximum amount of manual operating flexibility is maintained by using as few interlocks as consistent with the usual reactor safeguards. This minimization of automatic controls will provide the greatest amount of sustained trouble-free operation and also minimizes the weight and volume of control equipment.

The operator carries out the desired rod control function by the manipulation of console-mounted switches. Special decked pushbuttons and rotary-type control switches are used for manual control to minimize the number of electro-mechanical relays required. The Manual-Automatic switch is a two position rotary switch manufactured by the JANCO Corp., which remains in the position to which it is actuated. The Rod Selector is a bank of six special Mossman Corp. pushbutton switches which are mechanically interlocked so that only one may be actuated at a time. The buttons are mechanically maintained in position after being depressed. The Rod Movement switch is a special switch manufactured by Electro-Switch Corp. which has a neutral center and is spring loaded to return to the center neutral from the right "insert" position and the left "withdraw" position. The handle must also be pulled out against a spring before being rotated to the "withdraw" position.

To insure safe manipulation of these reactor controls, certain "interlock" functions are designed into the rod control system by relay contact circuitry to: 1) prevent improper sequential operation of the rods; 2) to insure that the safety rods are in their position of maximum potential effectiveness before movement of the other rods is permitted; and 3) to prevent withdrawal of any rods until the plant is ready for startup. If some process variables reach unsafe limits, automatic shutdown is provided for by the rapid insertion of the rods.

The control rods are positioned by 150 ounce-inch torque Superior Electric "Slo-Syn" motors. The motors operate through a 60 pound-inch torque Warner Co. solenoid-held clutch. A spring mechanism is provided to drive the rods to the fully inserted position upon release of the electric clutches. (Loss of power thereby causes rod insertion.) When the clutch is engaged the rods may be positioned in either direction by energization of the proper field of the reversible drive motors.

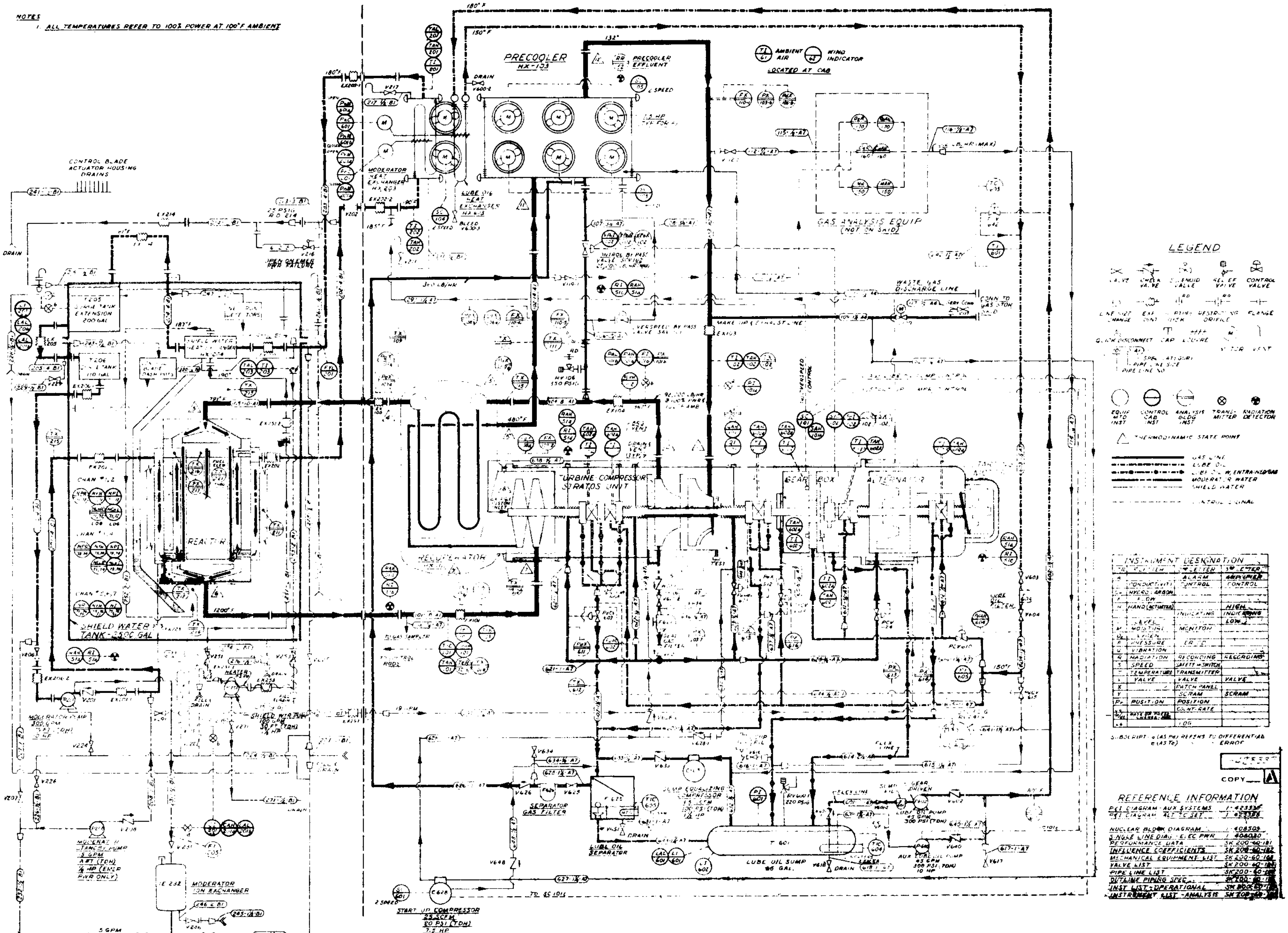
Limit switches are incorporated on all drives to stop the motors when the rods are full in or out. The switches also provide a means of energizing console-mounted indicating lamps (through relays) to provide travel limit indication. Two switches short of the full travel points will be provided on shim #3 and the regulating rod to annunciate the need for manual shim rod repositioning.

CONTROL BLADE POSITION-INDICATING INSTRUMENTATION

The continuous indication of the position of three shim and one power-regulating control rods must be provided to the plant operator to expedite startup of the reactor and to give an indication of the reactivity control available in the regulating rod. A signal proportional to regulating rod position is also needed for the automatic control loop. The two safety rods are either positioned "full in" or "full out" and their position is indicated by pilot lamps from signals derived from position sensing switches on these rod drives.

The Bush Company "Metrisite" is used as the angular position-to-electrical signal transducer. This contactless, induction-type device produces a linear output signal over $\pm 40^{\circ}$. The signal level is 0 to 2 milliamperes into an approximately 12,000-ohm load.

The connecting cable consists of twisted, shielded, stranded #18 AWG conductors. The resistance and reactance of this line at 50/60 cps is negligible when compared to the load. Therefore, parameter changes in the cables will have no effect on the performance of the system. The position indicating meters mounted on the operating console are Westinghouse K-24 series qualified to the Navy HI shock requirements of MIL-S-901.



REACTOR SKID

POWER CONVERSION SKID

P & I DIAGRAM, PRIMARY SYSTEMS

IV. ML-1 PHASE II TEST PROGRAM

E. SUPPLEMENTAL INFORMATION

3. ML-1 Predicted Performance Data

Performance Data Sheets
Influence Coefficients
Starting Operation Diagram

ML-1 PERFORMANCE DATA

The following assumptions were used for the basic design condition:

1.	Ambient air temperature	100°F
2.	Reactor outlet temperature	1200°F
3.	Reactor inlet pressure (maximum)	315 psia
4.	Control bypass flow rate	1%
5.	Internal leakage flow rates	1% (Clark t-c set) 2% (Stratos t-c set)
6.	Auxiliary power requirements	70 kw

The above data were used to determine a system mass and net power output. The resulting mass and net power were held constant for all ambient conditions below 100°F. The turbine inlet temperature was decreased in such a manner that the net plant output for the fixed mass remained constant until 0°F ambient temperature was reached. Below 0°F, both the turbine inlet temperature and the compressor inlet temperature were held constant. A constant compressor inlet temperature is maintained by adjusting the precooler fan speed. At the 125°F ambient condition, the mass and turbine inlet temperature were held constant and the net power was allowed to decrease. The system pressure level was selected such that with 0% bypass flow (i.e., with the bypass valve fully closed) the reactor inlet pressure is 315 psia for the 100°F ambient condition.

The following "judgement factors" have been applied to the calculations from which the enclosed data was derived:

The turbine isentropic efficiencies for the Clark turbine were reduced 2%. The Clark turbine performance map indicated a maximum efficiency of approximately 88%, a value which was not considered realistic.

The Stratos compressor seal leakage was assumed to be 2% of the compressor flow. This leakage, which represents approximately a-40 kw loss at the basic design condition, is based on a study of the Stratos t-c set made by an AGN consultant. The seal leakage for the Clark compressor was assumed to be 1% of the compressor flow, representing a 20-kw loss.

The temperature of the air entering the precooler was assumed to be 3^{o}F higher than the ambient air. This correction is based on calculations made to determine the effect of heat losses from the power conversion equipment to the air entering the precooler.

The turbine inlet temperature was assumed to be 6.5^{o}F lower than the reactor outlet temperature. This correction is based on calculations made to determine the heat losses from the reactor outlet pipe.

ML-1 PERFORMANCE DATA

125 °F AMBIENT TEMP

CLARK T-C SET

SK 200-60-328

REV
DATE 10-3-60

SHEET 1 OF 5

STATE POINTS		NET POWER 0% °F	0% PSIA	25% °F	25% PSIA	50% °F	50% PSIA	75% °F	75% PSIA	100% °F	100% PSIA	ΔP EQUIP.	ΔP PIPING	STATE PTS
MASS 51.9 LB														
COMPRESSOR	IN 1	159.2	125.7	159.0	124.3	158.9	123.1	158.7	121.8	158.4	120.6			1
	OUT 2	368.3	300.0	374.9	305.6	380.9	310.5	387.1	315.5	393.6	320.7		0.3	2
RECUPERATOR (HP)	IN 3	368.3	299.7	374.9	305.3	380.9	310.2	387.1	315.3	393.6	320.4	6.7		3
	OUT 4	822.3	293.6	815.8	299.0	810.2	303.8	804.7	308.1	799.3	313.7		0.7	4
REACTOR	IN 5	822.3	293.0	815.8	298.4	810.2	303.2	804.7	308.1	799.3	313.0	22.3		5
	OUT 6	1200	272.6	1200	277.5	1200	281.8	1200	286.2	1200.0	290.7		0.7	6
TURBINE	IN 7	1193.5	272.0	1193.5	276.9	1193.5	281.2	1193.5	285.6	1193.5	290.0			7
	OUT 8	943.3	129.2	934.1	127.9	926.1	126.7	918.2	125.5	910.3	124.3		0.1	8
RECUPERATOR (LP)	IN 9	943.3	129.2	934.1	127.8	926.1	126.6	918.2	125.4	910.3	124.2	1.4		9
	OUT 10	494.1	128.1	498.4	126.6	501.8	125.4	505.3	124.1	509.1	122.8		0.1	10
PRECOOLER	IN 11	475.7	128.0	483.9	126.6	491.3	125.3	498.9	124.0	506.8	122.7	2.7		11
	OUT 12	159.2	125.9	159.0	124.5	158.9	123.2	158.7	122.0	158.4	120.7		0.1	12
												33.1	2.0	

	0%	25%	50%	75%	100%
NET POWER KW	0	67.4	134.8	202.2	269.6
REACTOR POWER KW	2453	2556	2648	2740	2836
COMPRESSOR FLOW LB/HR	97110	95746	94475	93125	91699
TURBINE FLOW LB/HR	82325	84373	86162	87980	89863
CONTROL BYPASS LB/HR	12845	9461	6422	3279	917
COMPR EFF (ISEN)	0.83	0.835	0.838	0.840	0.841
RECUP EFFECTIVENESS	0.79	0.788	0.787	0.786	0.785
TURBINE EFF (ISEN)	0.855	0.857	0.858	0.859	0.86
PRECOOLER EFFECTIVENESS	0.91	0.913	0.915	0.917	0.92

ML-1 PERFORMANCE DATA

100 °F AMBIENT TEMP

SK 200-60-328	
REV DATE 10-3-60	SHEET 2 OF 5

CLARK T-C SET

MASS 51.9 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	133.8	122.5	133.7	120.7	133.5	119.2	133.2	117.7	132.9	116.2			1
	OUT 2	339.0	295.7	347.2	302.8	354.3	308.8	361.8	315.0	369.7	321.3		0.3	2
RECUPERATOR (HP)	IN 3	339.0	295.4	347.2	302.4	354.3	308.5	361.8	314.7	369.7	321.0	6.7		3
	OUT 4	813.5	289.4	805.1	296.3	798.1	302.2	791.3	308.2	784.9	314.3		0.7	4
REACTOR	IN 5	813.5	288.8	805.1	295.7	798.1	301.5	791.3	307.6	784.9	313.6	22.5		5
	OUT 6	1200.0	268.7	1200.0	274.8	1200.0	280.1	1200.0	285.6	1200.0	291.1		0.7	6
TURBINE	IN 7	1193.5	268.1	1193.5	274.2	1193.5	279.5	1193.5	284.9	1193.5	290.4			7
	OUT 8	939.9	126.0	928.1	124.3	918.4	122.9	908.7	121.4	899.2	120.0		0.1	8
RECUPERATOR (LP)	IN 9	939.9	126.0	928.1	124.2	918.4	122.8	908.7	121.4	899.2	119.9	1.4		9
	OUT 10	471.1	124.9	475.7	123.1	479.7	121.6	484.0	120.0	488.6	118.5		0.1	10
PRECOOLER	IN 11	447.6	124.8	458.0	123.0	467.0	121.5	476.4	119.9	486.3	118.4	2.0		11
	OUT 12	133.8	122.6	133.7	120.9	133.5	119.4	133.2	117.9	132.9	116.4		0.2	12
												32.6	2.1	
NET POWER	KW	0		84.5		169.1		253.6		338.1				
REACTOR POWER	KW	2478		2611		2727		2844		2962				
COMPRESSOR FLOW	LB/HR	99230		97570		95918		94280		92524				
TURBINE FLOW	LB/HR	81338		83920		86098		88373		90673				
CONTROL BYPASS	LB/HR	15907		11699		7902		4025		925				
COMPR EFF (ISEN)		0.825		0.831		0.835		0.838		0.839				
RECUP EFFECTIVENESS		0.79		0.788		0.787		0.786		0.784				
TURBINE EFF (ISEN)		0.856		0.858		0.859		0.86		0.86				
PRECOOLER EFFECTIVENESS		0.911		0.914		0.916		0.919		0.922				

ML-1 PERFORMANCE DATA

60 °F AMBIENT TEMP

CLARK T-C SET

SK 200-60-328	
REV ___ DATE 10-360	SHEET 3 OF 5

MASS 51.9 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	90.3	112.8	90.1	111.1	90.0	109.5	89.7	108.0	89.5	106.4			1
	OUT 2	292.7	284.4	300.9	291.4	308.3	297.6	316.3	304.0	324.9	310.7		0.3	2
RECUPERATOR (HP)	IN 3	292.7	284.0	300.9	291.1	308.3	297.3	316.3	303.7	324.9	310.4	7.1		3
	OUT 4	734.4	278.3	726.0	285.2	719.0	291.2	712.3	297.4	705.7	304.0		0.7	4
REACTOR	IN 5	734.4	277.7	726.0	284.6	719.0	290.6	712.3	296.8	705.7	303.3	22.0		5
	OUT 6	1114.0	258.2	1114.0	264.4	1114.0	269.8	1114.0	275.4	1114.0	281.3		0.7	6
TURBINE	IN 7	1107.5	257.6	1107.5	263.7	1107.5	269.1	1107.5	274.7	1107.5	280.6			7
	OUT 8	853.4	116.4	841.7	114.7	831.7	113.3	821.9	111.8	811.9	110.2		0	8
RECUPERATOR (LP)	IN 9	853.4	116.4	841.7	114.7	831.7	113.2	821.9	111.7	811.9	110.2	1.5		9
	OUT 10	416.3	115.3	420.9	113.5	425.1	111.9	429.8	110.4	434.9	108.7		0.1	10
PRECOOLER	IN 11	393.8	115.2	403.9	113.4	413.1	111.8	422.7	110.2	432.7	108.6	2.1		11
	OUT 12	90.3	113.0	90.1	111.2	90.0	109.7	89.7	108.2	89.5	106.5		0.1	12
												32.7	1.9	

		0%	25%	50%	75%	100%
NET POWER	KW	0	84.5	169.1	253.6	338.1
REACTOR POWER	KW	2394	2530	2645	2763	2886
COMPRESSOR FLOW	LB/HR	99353	97618	95994	94320	92639
TURBINE FLOW	LB/HR	80982	83599	85903	88308	90785
CONTROL BYPASS	LB/HR	16382	12066	8172	4124	926
COMPR EFF (ISEN)		0.819	0.825	0.829	0.831	0.832
RECUP EFFECTIVENESS		0.788	0.786	0.785	0.783	0.782
TURBINE EFF (ISEN)		0.856	0.858	0.859	0.86	0.86
PRECOOLER EFFECTIVENESS		0.917	0.92	0.923	0.926	0.928

ML-1 PERFORMANCE DATA

0 °F AMBIENT TEMP

CLARK T-C SET

SK 200-60-328	
REV	SHEET
DATE 10-3-60	4 OF 5

MASS 51.9 LB			NET POWER										
STATE POINTS			0%		25%		50%		75%		100%				STATE PTS
			°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN	1	25.7	98.9	25.4	97.1	25.4	95.5	25.2	93.9	24.5	92.5			1
	OUT	2	223.1	267.2	231.1	274.2	239.7	281.0	248.8	287.9	255.0	293.3		0.3	2
RECUPERATOR (HP)	IN	3	223.1	266.9	231.1	273.9	239.7	280.7	248.8	287.6	255.0	293.0	6.0		3
	OUT	4	621.2	261.6	613.1	268.4	605.8	275.0	598.9	281.7	593.4	287.0		0.6	4
REACTOR	IN	5	621.2	261.0	613.1	267.8	605.8	274.4	598.9	281.1	593.4	286.4	21.0		5
	OUT	6	991.2	242.4	991.2	248.5	991.2	254.5	991.2	260.7	991.2	265.4		0.7	6
TURBINE	IN	7	984.7	241.8	984.7	248.0	984.7	253.9	984.7	260.0	984.7	264.7			7
	OUT	8	730.1	102.5	718.6	100.8	707.9	99.3	697.4	97.7	689.3	96.4		0.1	8
RECUPERATOR (LP)	IN	9	730.1	102.5	718.6	100.8	707.9	99.2	697.4	97.6	689.3	96.3	1.4		9
	OUT	10	335.4	101.3	339.9	99.6	344.9	97.9	350.1	96.3	353.5	94.9		0.1	10
PRECOOLER	IN	11	313.7	101.2	323.6	99.5	333.4	97.8	343.5	96.2	351.5	94.8	2.1		11
	OUT	12	25.7	99.1	25.4	97.3	25.4	95.7	25.2	94.0	24.5	92.7		0.2	12
													30.5	2.0	

		0%	25%	50%	75%	100%
NET POWER	KW	0	84.5	169.1	253.6	338.1
REACTOR POWER	KW	2285	2411	2533	2657	2693
COMPRESSOR FLOW	LB/HR	99576	97668	96062	94324	92056
TURBINE FLOW	LB/HR	80226	82951	85543	88128	90212
CONTROL BYPASS	LB/HR	17358	12763	8600	4309	921
COMPR EFF (ISEN)		0.807	0.813	0.816	0.817	0.819
RECUP EFFECTIVENESS		0.785	0.784	0.782	0.78	0.779
TURBINE EFF (ISEN)		0.857	0.858	0.859	0.859	0.859
PRECOOLER EFFECTIVENESS		0.927	0.930	0.932	0.935	0.938

ML-1 PERFORMANCE DATA

- 65 °F AMBIENT TEMP

CLARK T-C SET

SK 200-60-328
REV
DATE 10-3-60
SHEET 5 OF 5

MASS 51.9 LB

STATE POINTS			NET POWER 0% °F	0% PSIA	25% °F	25% PSIA	50% °F	50% PSIA	75% °F	75% PSIA	100% °F	100% PSIA	ΔP EQUIP.	ΔP PIPING	STATE PTS
COMPRESSOR	IN	1	25.7	98.9	25.4	97.1	25.4	95.5	25.2	93.9	24.5	92.5			1
	OUT	2	223.1	267.2	231.1	274.2	239.7	281.0	248.8	287.9	255.0	293.3		0.3	2
RECUPERATOR (HP)	IN	3	223.1	266.9	231.1	273.9	239.7	280.7	248.8	287.6	255.0	293.0	6.0		3
	OUT	4	621.2	261.6	613.1	268.4	605.8	275.0	598.9	281.7	593.4	287.0		0.6	4
REACTOR	IN	5	621.2	261.0	613.1	267.8	605.8	274.4	598.9	281.1	593.4	286.4	21.0		5
	OUT	6	991.2	242.4	991.2	248.5	991.2	254.5	991.2	260.7	991.2	265.4		0.7	6
TURBINE	IN	7	984.7	241.8	984.7	248.0	984.7	253.9	984.7	260.0	984.7	264.7			7
	OUT	8	730.1	102.5	718.6	100.8	707.9	99.3	697.4	97.7	689.3	96.4		0.1	8
RECUPERATOR (LP)	IN	9	730.1	102.5	718.6	100.8	707.9	99.2	697.4	97.6	689.3	96.3	1.4		9
	OUT	10	335.4	101.3	339.9	99.6	344.9	97.9	350.1	96.3	353.5	94.9		0.1	10
PRECOOLER	IN	11	313.7	101.2	323.6	99.5	333.4	97.8	343.5	96.2	351.5	94.8	2.1		11
	OUT	12	25.7	99.1	25.4	97.3	25.4	95.7	25.2	94.0	24.5	92.7		0.2	12
													30.5	2.0	

	0%	25%	50%	75%	100%
NET POWER KW	0	84.5	169.1	253.6	338.1
REACTOR POWER KW	2285	2411	2533	2657	2693
COMPRESSOR FLOW LB/HR	99576	97668	96062	94324	92056
TURBINE FLOW LB/HR	80226	82951	85543	88128	90212
CONTROL BYPASS LB/HR	17358	12763	8600	4309	921
COMPR EFF (ISEN)	0.807	0.813	0.816	0.817	0.819
RECUP EFFECTIVENESS	0.785	0.784	0.782	0.78	0.779
TURBINE EFF (ISEN)	0.857	0.858	0.859	0.859	0.859
PRECOOLER EFFECTIVENESS	0.767	0.773	0.779	0.785	0.791

ML-I PERFORMANCE DATA

125 °F AMBIENT TEMP

STRATOS T-C SET (# 670)

SK 200-60-329	
REV DATE 10-3-60	SHEET 1 OF 5

MASS 51.4 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	160.1	122.6	159.2	122.4	158.4	122.2	157.3	122.1	155.6	121.9			1
	OUT 2	391.5	317.3	391.4	318.5	391.2	319.4	390.3	320.1	388.4	320.0		0.3	2
RECUPERATOR (HP)	IN 3	391.5	317.0	391.4	318.2	391.2	319.2	390.3	319.9	388.4	319.7	6.1		3
	OUT 4	808.2	311.3	806.9	312.3	805.7	313.2	804.6	313.8	803.9	313.6		0.6	4
REACTOR	IN 5	808.2	310.7	806.9	311.7	805.7	312.6	804.6	313.2	803.9	313.0	20.1		5
	OUT 6	1200.0	292.0	1200.2	292.5	1200.0	292.9	1200.0	293.2	1200.0	292.9		0.6	6
TURBINE	IN 7	1193.5	291.4	1193.5	291.9	1193.5	292.3	1193.5	292.6	1193.5	292.3			7
	OUT 8	919.1	126.2	917.9	126.0	916.9	125.7	916.1	125.5	915.7	125.3		0.1	8
RECUPERATOR (LP)	IN 9	919.1	126.2	917.9	125.9	916.9	125.7	916.1	125.5	915.7	125.2	1.2		9
	OUT 10	507.0	125.0	507.0	124.7	507.0	124.5	506.4	124.3	504.9	124.0		0.1	10
PRECOOLER	IN 11	489.6	124.9	492.9	124.6	496.4	124.4	499.0	124.2	501.5	123.9	1.8		11
	OUT 12	160.1	122.8	159.2	122.6	158.4	122.4	157.3	122.2	155.6	122.1		0.2	12
												29.2	1.9	
NET POWER	KW	0		53.4		108.8		163.2		217.5				
REACTOR POWER	KW	2526		2576		2616		2650		2659				
COMPRESSOR FLOW	LB/HR	96520		94781		93074		90922		87869				
TURBINE FLOW	LB/HR	81785		83091		84179		85010		85230				
CONTROL BYPASS	LB/HR	12803		9795		7035		4092		879				
COMPR EFF (ISEN)		0.83		0.832		0.833		0.834		0.833				
RECUP EFFECTIVENESS		0.79		0.789		0.789		0.788		0.788				
TURBINE EFF (ISEN)		0.843		0.843		0.843		0.843		0.844				
PRECOOLER EFFECTIVENESS		0.911		0.914		0.917		0.921		0.926				

ML-I PERFORMANCE DATA

100 °F AMBIENT TEMP

STRATOS T-C SET (# 670)

SK 200-60-329
REV
DATE 10-3-60
SHEET 2 OF 5

MASS 51.4 LB			NET POWER												
STATE POINTS			0%		25%		50%		75%		100%				STATE PTS
			°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN	1	137.4	119.5	136.8	119.1	135.9	118.7	134.9	118.4	133.7	118.2			1
	OUT	2	368.4	316.0	368.9	317.9	368.9	319.6	368.7	321.1	368.4	322.8		0.3	2
RECUPERATOR (HP)	IN	3	368.4	315.6	368.9	317.6	368.9	319.3	368.7	320.8	368.4	322.5	6.7		3
	OUT	4	799.3	309.6	797.1	311.4	795.1	312.9	793.2	314.2	791.3	315.8		0.7	4
REACTOR	IN	5	799.3	309.0	797.1	310.8	795.1	312.3	793.2	313.6	791.3	315.1	22.6		5
	OUT	6	1200.0	288.9	1200.0	289.9	1200.0	290.7	1200.0	291.5	1200.0	292.5		0.7	6
TURBINE	IN	7	1193.5	288.3	1193.5	289.3	1193.5	290.1	1193.5	290.8	1193.5	291.8			7
	OUT	8	915.2	123.4	913.1	123.0	911.3	122.6	909.5	122.6	907.8	122.0		0.1	8
RECUPERATOR (LP)	IN	9	915.2	123.3	913.1	122.9	911.3	122.6	909.5	122.2	907.8	121.9	1.4		9
	OUT	10	489.2	122.1	489.8	121.7	489.9	121.2	489.8	120.8	489.6	120.5		0.1	10
PRECOOLER	IN	11	468.9	122.0	473.5	121.6	477.5	135.9	481.6	120.7	486.0	120.4	2.0		11
	OUT	12	137.4	119.7	136.8	119.3	121.1	118.9	134.9	118.6	133.7	118.4		0.2	12
													32.7	2.0	

		0%	25%	50%	75%	100%
NET POWER	KW	0	71.1	142.2	213.3	284.4
REACTOR POWER	KW	2666	2745	2808	2873	2928
COMPRESSOR FLOW	LB/HR	101808	100249	98352	96250	93924
TURBINE FLOW	LB/HR	85010	86504	88164	89640	91033
CONTROL BYPASS	LB/HR	15271	11740	8215	4684	939
COMPR EFF (ISEN)		0.823	0.827	0.831	0.834	0.836
RECUP EFFECTIVENESS		0.788	0.787	0.786	0.785	0.784
TURBINE EFF (ISEN)		0.844	0.844	0.845	0.845	0.846
PRECOOLER EFFECTIVENESS		0.906	0.909	0.912	0.916	0.92

ML-1 PERFORMANCE DATA

60 °F AMBIENT TEMP

SK 200-60-329	
REV DATE 10-3-60	SHEET 3 OF 5

STRATOS T-C SET (# 670)

MASS 51.4 LB		NET POWER											
STATE POINTS		0%		25%		50%		75%		100%			STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	95.8	109.4	94.7	108.6	93.5	107.8	92.2	107.1	90.8	106.6			1
	OUT 2	328.0	305.3	327.7	307.4	327.8	309.6	327.6	311.5	327.1	313.4		0.3	2
RECUPERATOR (HP)	IN 3	328.0	305.0	327.7	307.1	327.8	309.3	327.6	311.2	327.1	313.1	6.5		3
	OUT 4	709.1	298.5	705.3	300.6	701.6	302.8	698.3	304.7	695.4	306.6		0.7	4
REACTOR	IN 5	709.1	297.9	705.3	300.0	701.6	302.2	698.3	304.0	695.4	305.9	22.2		5
	OUT 6	1094.9	276.2	1094.9	278.2	1094.9	280.2	1094.9	281.9	1094.9	283.7		0.7	6
TURBINE	IN 7	1088.4	275.6	1088.4	277.5	1088.4	279.5	1088.4	281.2	1088.4	283.0			7
	OUT 8	814.9	113.7	810.4	112.8	805.9	112.0	802.1	111.2	798.7	110.6		0	8
RECUPERATOR (LP)	IN 9	814.9	113.6	810.4	112.7	805.9	111.9	802.1	111.2	798.7	110.6	1.7		9
	OUT 10	437.5	112.3	436.5	111.4	435.8	110.5	434.9	109.7	434.0	109.1		0.1	10
PRECOOLER	IN 11	422.0	112.2	423.7	111.3	426.0	110.4	428.2	109.6	430.8	109.0	2.2		11
	OUT 12	95.8	109.7	94.7	108.8	93.5	108.0	92.2	107.3	90.8	106.8		0.2	12
												32.6	2.0	
NET POWER	KW	0		71.1		142.2		213.3		284.4				
REACTOR POWER	KW	2689		2737		2783		2827		2869				
COMPRESSOR FLOW	LB/HR	104638		102524		100271		97841		95162				
TURBINE FLOW	LB/HR	89550		90263		91004		91649		92304				
CONTROL BYPASS	LB/HR	12996		10210		7263		4234		952				
COMPR EFF (ISEN)		0.812		0.820		0.827		0.833		0.837				
RECUP EFFECTIVENESS		0.783		0.782		0.782		0.781		0.781				
TURBINE EFF (ISEN)		0.844		0.845		0.846		0.847		0.847				
PRECOOLER EFFECTIVENESS		0.909		0.912		0.916		0.92		0.924				

ML-1 PERFORMANCE DATA

0 °F AMBIENT TEMP

STRATOS T-C SET (# 670)

SK	200-60-329
REV DATE	10-3-60
SHEET	4 OF 5

MASS 51.4 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	31.1	93.3	30.2	92.4	29.2	91.6	28.2	90.9	27.1	90.3			1
	OUT 2	266.8	292.6	266.6	294.8	266.7	297.0	266.5	299.0	266.3	301.1		0.3	2
RECUPERATOR (HP)	IN 3	266.8	292.3	266.6	294.4	266.7	296.7	266.5	298.7	266.3	300.8	6.3		3
	OUT 4	580.5	286.1	577.0	288.3	573.6	290.5	570.6	292.4	567.7	294.5		0.6	4
REACTOR	IN 5	580.5	285.5	577.0	287.7	573.6	289.9	570.6	291.8	567.7	293.9	21.5		5
	OUT 6	956.6	267.8	956.6	266.7	956.6	268.7	956.6	270.5	956.6	272.4		0.7	6
TURBINE	IN 7	950.1	264.1	950.1	266.0	950.1	268.0	950.1	269.8	950.1	271.7			7
	OUT 8	669.5	97.7	665.3	96.9	661.2	96.0	657.5	95.2	654.1	94.6		0.1	8
RECUPERATOR (LP)	IN 9	669.5	97.7	665.3	96.8	661.2	96.0	657.5	95.2	654.1	94.5	1.6		9
	OUT 10	358.1	96.2	357.1	95.3	356.4	94.4	355.5	93.6	354.1	92.9		0.1	10
PRECOOLER	IN 11	345.4	96.1	346.7	95.2	348.4	94.3	350.1	93.5	352.1	92.8	2.3		11
	OUT 12	31.1	93.5	30.2	92.6	29.2	91.8	28.2	91.1	27.1	90.5		0.2	12
												31.7	2.0	
NET POWER	KW	0		71.1		142.2		213.3		284.4				
REACTOR POWER	KW	2614		2662		2710		2755		2802				
COMPRESSOR FLOW	LB/HR	105664		103666		101606		99432		97034				
TURBINE FLOW	LB/HR	90752		91591		92473		93283		94122				
CONTROL BYPASS	LB/HR	12797		10002		7359		4302		970				
COMPR EFF (ISEN)		0.803		0.812		0.821		0.828		0.835				
RECUP EFFECTIVENESS		0.779		0.779		0.778		0.778		0.777				
TURBINE EFF (ISEN)		0.845		0.846		0.846		0.846		0.846				
PRECOOLER EFFECTIVENESS		0.918		0.921		0.924		0.927		0.931				

ML-I PERFORMANCE DATA

- 65 °F AMBIENT TEMP

STRATOS T-C SET (# 670)

SK 200-60-329	
REV DATE 10-3-60	SHEET 5 OF 5

MASS 51.4 LB		NET POWER												
STATE POINTS		0%		25%		50%		75%		100%				STATE PTS
		°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	°F	PSIA	ΔP EQUIP.	ΔP PIPING	
COMPRESSOR	IN 1	31.1	93.3	30.2	92.4	29.2	91.6	28.2	90.9	27.1	90.3			1
	OUT 2	266.8	292.6	266.6	294.8	266.7	297.0	266.5	299.0	266.3	301.1		0.3	2
RECUPERATOR (HP)	IN 3	266.8	292.3	266.6	294.4	266.7	296.7	266.5	298.7	266.3	300.8	6.3		3
	OUT 4	580.5	286.1	577.0	288.3	573.6	290.5	570.6	282.4	567.7	294.5		0.6	4
REACTOR	IN 5	580.5	285.5	577.0	287.7	573.6	289.9	570.6	291.8	567.7	293.9	21.5		5
	OUT 6	956.6	267.8	956.6	266.7	956.6	268.7	956.6	270.5	956.6	272.4		0.7	6
TURBINE	IN 7	960.1	264.1	950.1	266.0	950.1	268.0	950.1	269.8	950.1	271.7			7
	OUT 8	669.5	97.7	665.3	96.9	661.2	96.0	657.5	95.2	654.1	94.6		0.1	8
RECUPERATOR (LP)	IN 9	669.5	97.7	665.3	96.8	661.2	96.0	657.5	95.2	654.1	94.5	1.6		9
	OUT 10	358.1	96.2	357.1	95.3	356.4	94.4	355.5	93.6	354.1	92.9		0.1	10
PRECOOLER	IN 11	345.4	96.1	346.7	95.2	348.4	94.3	350.1	93.5	352.1	92.8	2.3		11
	OUT 12	31.1	93.5	30.2	92.6	29.2	91.8	28.2	91.1	27.1	90.5		0.2	12
												31.7	2.0	

	0%	25%	50%	75%	100%
NET POWER KW	0	71.1	142.2	213.3	284.4
REACTOR POWER KW	2614	2662	2710	2755	2802
COMPRESSOR FLOW LB/HR	105664	103666	101606	99432	97034
TURBINE FLOW LB/HR	90752	91591	92473	93283	94122
CONTROL BYPASS LB/HR	12797	10002	7359	4302	970
COMPR EFF (ISEN)	0.803	0.812	0.821	0.828	0.835
RECUP EFFECTIVENESS	0.779	0.779	0.778	0.778	0.777
TURBINE EFF (ISEN)	0.845	0.846	0.846	0.846	0.846
PRECOOLER EFFECTIVENESS	0.771	0.774	0.778	0.781	0.785

TYPICAL ML-1 INFLUENCE COEFFICIENTS

SK 200 - 60 - 182	
REV ____ DATE ____	SHEET 1 OF 7

SYSTEM PARAMETERS	REFERENCE VALUES		INDEPENDENT VARIABLES											
			+10 KW AUXILIARY POWER	-100 RPM TC SPEED	-10°F TURBINE INLET TEMPERATURE	-1°F AMBIENT AIR TEMPERATURE	+1% BYPASS FLOW	-1 LB SYSTEM MASS	-1% COMPRESSOR ISENTROPIC EFFICIENCY	-1% TURBINE ISENTROPIC EFFICIENCY	-1% RECUPERATOR EFFECTIVENESS	-1.0 RECUPERATOR NTU	-1% PRECOOLER EFFECTIVENESS	-1.0 PRECOOLER NTU
System Mass	52.5	LBS.												
Bypass Flow	1	%												
Turbine Inlet Temperature	1200	°F												
Ambient Air Temperature	100	°F												
Auxiliary Power	70	KW												
	UNIT CHANGE													
System Output Power		KW	-10	-0.85	-11.8	+2.52	-17.83	-6.46	-15.2	-19.37	-0.77	-2.79	-9.35	-30.35
Reactor Power To Gas		KWT	0	-15.9	-33.9	+5.41	-31.3	-53.3	-1.74	-16.92	+37.3	+135.8	-21.37	-68.0
Compressor Flow Rate		LBS/HR	0	-341	-172	+37.2	+326.8	-1726.3	+104.5	+88.4	+57.0	+209.5	-154.8	-488.0
Turbine Flow Rate		LBS/HR	0	-337	-170	+36.8	-604.6	-1709.1	+103.5	+87.5	+56.4	+207.5	-153.3	-483.5
Compressor Pressure Ratio		N.D.	0	-0.012	-0.005	+0.0046	-0.022	+0.02	-0.0012	0	-0.0025	-0.0094	-0.0172	-0.0536
Turbine Pressure Ratio		N.D.	0	-0.0095	-0.0045	+0.0038	-0.018	+0.02	-0.0006	0	-0.0019	-0.0047	-0.0144	-0.0439
Compressor Isentropic Eff.		%	0	+0.05	0	-0.01	0	0	-1.0	0	0	0	+0.055	0
Turbine Isentropic Eff.		%	0	0	0	0	0	0	0	-1.0	0	0	0	0
Cycle Efficiency		%	-0.3	+0.05	-0.25	+0.06	-0.4	0	-0.47	-0.56	-0.19	-0.47	-0.22	-0.49
Recuperator Effectiveness		%	0	-0.025	0	0	0	0	0	0	-1.0	-3.76	0	0
Recuperator NTU		N.D.	0	-0.004	-0.0005	-0.0008	+0.007	+0.02	0	0	+0.0006	-1.0	+0.0033	+0.0098
Precooler Effectiveness		%	0	-0.05	0	+0.01	-0.1	0	-0.06	-0.06	-0.06	-0.47	-1.0	-3.42
Precooler NTU		N.D.	0	-0.0088	+0.0045	-0.0005	-0.008	+0.06	-0.0024	-0.0024	-0.0006	-0.0047	+0.0044	-1.0
Compressor Inlet Pressure		PSIA	0	+0.187	-0.298	-0.184	+0.380	-2.48	+0.195	+0.142	+0.192	+0.700	+0.700	+2.282
Compressor Inlet Temperature		°F	0	-0.326	-0.325	-1.035	-0.016	-1.22	+0.275	+0.132	+0.536	+1.952	+4.09	+13.02
Reactor Inlet Pressure		PSIA	0	-0.902	-1.418	+0.029	-1.579	-5.96	+0.384	+0.329	+0.217	+0.802	-0.140	-0.429
Reactor Inlet Temperature		°F	0	+0.714	-6.415	-0.594	+1.663	-0.28	+0.719	+2.795	-5.01	-18.23	+2.32	+7.41
Turbine Inlet Pressure		PSIA	0	-0.816	-1.307	+0.017	-1.4	-5.60	+0.361	+0.296	+0.238	+0.872	-0.093	-0.278

ML-1 INFLUENCE COEFFICIENTS

SK 200-60-182	
REV	SHEET 2 OF 7
DATE	

SYSTEM PARAMETERS	REFERENCE VALUES	
System Mass	52.45	Lbs
Bypass Flow	1	%
Turbine Inlet Temperature	1200	°F
Ambient Air Temperature	100	°F
Auxiliary Power	70	KW

INDEPENDENT VARIABLES

System Parameters	Unit Change	-0.001 Compressor Design Point Flow Function	-1000 Turbine Design Point Flow Function	+1KW Turbine-Compressor Bearing Loss at Design Speed	- 1% Reduction Gearing Efficiency	+1 KW Generator Design Point Losses	-1000 CFM Precooler Air Flow	+1000 Ft Plant Altitude (Constant 100°F Air Temp.)	-0.01 Ft² Reactor Core Free Flow Area	+100 Reactor Core Friction Area/Flow Area Ratio	-0.001 Ft Reactor Core Hydraulic Diameter	-1 Ft² Precooler Free Flow Area-Air Side	-100 Ft² Precooler Fin Area Air Side
System Output Power	KW	-4.3	+9.35	-1.0	-4.68	-1.0	-1.45	-3.32	-5.95	-4.9	-0.95	+0.79	+0.03
Reactor Power To Gas	KW	-34.2	+7.64	0	0	0	-3.18	-7.26	-4.7	-3.96	-0.87	+1.73	+0.05
Compressor Flow Rate	Lbs/Hr	-706.9	-1007.5	0	0	0	-22.3	-51.0	-91.3	-76.9	-17.1	+11.9	+0.2
Turbine Flow Rate	Lbs/Hr	-699.8	-997.4	0	0	0	-22.1	-50.5	-90.4	-76.2	-16.8	+11.8	+0.2
Compressor Pressure Ratio	N.D.	-0.026	+0.069	0	0	0	-0.0026	-0.0059	+0.010	+0.008	0	+0.0015	0
Turbine Pressure Ratio	N.D.	-0.021	+0.073	0	0	0	-0.0022	-0.0050	0	0	0	+0.001	0
Compressor Isentropic Eff.	%	0	0	0	0	0	0	0	0	0	0	0	0
Turbine Isentropic Eff.	%	0	0	0	0	0	0	0	0	0	0	0	0
Cycle Efficiency	%	0	+0.3	-0.06	-0.15	-0.06	-0.04	-0.09	-0.2	0	0	+0.05	0
Recuperator Effectiveness	%	0	0	0	0	0	0	0	0	0	0	0	0
Recuperator NTU	N.D.	+0.008	+0.011	0	0	0	+0.0004	+0.0009	+0.002	+0.002	0	0	0
Precooler Effectiveness	%	+0.1	+0.1	0	0	0	-0.14	-0.32	0	0	0	+0.05	0
Precooler NTU	N.D.	+0.017	+0.025	0	0	0	-0.0134	-0.0306	+0.002	+0.002	0	+0.025	+0.0009
Compressor Inlet Pressure	PSIA	+0.421	-1.390	0	0	0	+0.107	+0.244	-0.106	-0.086	-0.014	-0.009	-0.002
Compressor Inlet Temperature	°F	-0.658	-0.417	0	0	0	+0.611	+1.398	+0.016	+0.012	0	-0.339	-0.012
Reactor Inlet Pressure	PSIA	-1.858	+4.490	0	0	0	-0.018	-0.041	+0.937	+0.768	+0.142	+0.009	0
Reactor Inlet Temperature	°F	+1.640	-5.720	0	0	0	+0.469	+1.071	+0.250	+0.210	+0.046	-0.191	-0.006
Turbine Inlet Pressure	PSIA	-1.679	+5.314	0	0	0	-0.011	-0.025	-0.285	-0.238	-0.072	+0.006	0

ML-I INFLUENCE COEFFICIENTS

SK	200-60-182
REV DATE	SHEET 3 OF 7

SYSTEM PARAMETERS	REFERENCE VALUES	
System Mass	52.5	LBS
Bypass Flow	1	%
Turbine Inlet Temperature	1200	°F
Ambient Air Temperature	100	°F
Auxiliary Power	70	KW

SYSTEM PARAMETERS	UNIT CHANGE	INDEPENDENT VARIABLES: -100 FT^2 Precooler Total Area Air Side	-0.001 Ft Precooler Hydraulic Diameter Air Side	-0.01 Precooler Fin Constant Air Side	-0.0001 Precooler Air Side Colburn "J" Factor	-0.01 FT^2 Precooler Free Flow Area Nitrogen Side	-100 FT^2 Precooler Fin Area Nitrogen Side	-100 FT^2 Precooler Total Area Nitrogen Side	-0.001 Ft Precooler Hydraulic Dia- Nitrogen Side	-0.001 Precooler Fin Constant Nitrogen Side	+100 Precooler Nitrogen Side Friction Area/ Flow Area Ratio	-0.0001 Precooler Nitrogen Side Colburn "J" Factor
System Output Power	KW	-0.41	+0.47	+5.78	-0.87	-0.04	+0.09	-1.86	+0.65	+0.07	-0.9	-2.43
Reactor Power To Gas	KW_T	-0.92	+1.04	+12.82	-1.94	+0.25	+0.19	-4.65	+1.63	+0.15	-1.33	-5.45
Compressor Flow Rate	LBS/HR	-6.7	+7.4	+9.15	-13.8	-2.6	+1.36	-27.3	+9.13	+1.08	-17.9	-39.1
Turbine Flow Rate	LBS/HR	-6.6	+7.3	+9.05	-13.7	-2.56	+1.35	-27.0	+8.2	+1.07	-17.7	-38.7
Compressor Pressure Ratio	N.D.	-0.0009	+0.001	+0.0014	-0.0015	+0.001	0	-0.005	+0.0029	+0.0005	0	-0.0045
Turbine Pressure Ratio	N.D.	-0.0007	+0.001	+0.0014	-0.001	+0.0001	+0.0011	-0.003	+0.0014	+0.0005	0	-0.0035
Compressor Isentropic Eff.	%	0	0	0	0	0	0	0	0	0	0	0
Turbine Isentropic Eff.	%	0	0	0	0	0	0	0	0	0	0	0
Cycle Efficiency	%	0	0	0	0	0	0	0	0	0	0	-0.05
Recuperator Effectiveness	%	0	0	0	0	0	0	0	0	0	0	0
Recuperator NTU	N.D.	+0.00014	0	0	+0.0005	0	0	+0.001	0	0	0	+0.001
Precooler Effectiveness	%	+0.043	0	0	-0.1	+0.04	0	-0.3	0	0	0	-0.3
Precooler NTU	N.D.	-0.0131	+0.015	+0.0186	-0.0275	+0.0133	+0.0033	-0.080	+0.030	+0.0025	+0.025	-0.078
Compressor Inlet Pressure	PSIA	+0.031	-0.035	-0.044	+0.065	-0.044	-0.007	+0.205	-0.076	-0.006	-0.025	+0.183
Compressor Inlet Temperature	°F	+0.174	-0.199	-0.246	+0.371	-0.183	-0.037	+1.074	-0.393	-0.029	-0.010	+1.044
Reactor Inlet Pressure	PSIA	-0.006	+0.006	+0.007	-0.012	-0.013	+0.001	-0.010	+0.001	0	-0.037	-0.035
Reactor Inlet Temperature	°F	+0.100	-0.113	-0.140	+0.211	-0.047	-0.021	+0.533	-0.190	-0.016	+0.105	+0.594
Turbine Inlet Pressure	PSIA	-0.004	+0.004	+0.004	-0.008	-0.012	0	-0.001	-0.001	0	-0.033	-0.023

SK 200-60-182
REV ______ DATE ______
SHEET 4 OF 7

ML-1 INFLUENCE COEFFICIENTS

SYSTEM PARAMETERS	REFERENCE VALUES	
SYSTEM MASS	52.45	LBS.
BYPASS FLOW	1	%
TURBINE INLET TEMPERATURE	1200	°F
AMBIENT AIR TEMPERATURE	100	°F
AUXILIARY POWER	70	KW

SYSTEM PARAMETERS	UNIT CHANGE	INDEPENDENT VARIABLES: −0.1 FT² RECUPERATOR FREE FLOW AREA -LP SIDE	−100 FT² RECUPERATOR FIN AREA LP SIDE	−100 FT² RECUPERATOR TOTAL AREA LP SIDE	−0.001 FT RECUPERATOR HYDRAULIC DIAMETER LP SIDE	−0.01 RECUPERATOR FIN CONSTANT LP SIDE	+10 RECUPERATOR LP SIDE FRICTION AREA/FLOW AREA RATIO	−0.0001 RECUPERATOR LP SIDE COLBURN "J" FACTOR	−0.01 FT² RECUPERATOR FREE FLOW AREA HP SIDE	−100 FT² RECUPERATOR TOTAL AREA HP SIDE	−0.001 FT RECUPERATOR HYDRAULIC DIAMETER - HP SIDE	+100 RECUPERATOR HP SIDE FRICTION AREA/FLOW AREA RATIO	−0.0001 RECUPERATOR HP SIDE COLBURN "J" FACTOR
SYSTEM OUTPUT POWER	KW	−1.2	+0.006	−0.072	−0.081	+0.07	−0.57	−0.06	−2.0	−0.39	−0.67	−2.1	−0.77
REACTOR POWER TO GAS	KW	−5.16	−0.29	+3.51	−1.820	−3.47	−0.61	+3.0	−6.6	+32.4	−2.72	−0.95	+17.3
COMPRESSOR FLOW RATE	LB/HR	−12.9	−0.46	+5.5	−3.3	−5.43	−3.08	+4.7	−17.8	+51.2	−6.8	−8.9	+25.4
TURBINE FLOW RATE	LB/HR	−12.7	−0.45	+5.4	−3.3	−5.37	−3.05	+4.6	−17.6	+50.7	−6.7	−8.7	+25.1
COMPRESSOR PRESSURE RATIO	N.D.	+0.0005	0	−0.0003	0	0	0	−0.0005	+0.0025	−0.0033	+0.0014	+0.0033	−0.001
TURBINE PRESSURE RATIO	N.D.	−0.0015	0	−0.0003	0	0	−0.0025	−0.0005	0	−0.0017	0	0	−0.001
COMPRESSOR ISENTROPIC EFF.	%	0	0	0	0	0	0	0	0	0	0	0	0
TURBINE ISENTROPIC EFF.	%	0	0	0	0	0	0	0	0	0	0	0	0
CYCLE EFFICIENCY	%	0	0	0	0	0	0	0	0	−0.17	0	0	−0.1
RECUPERATOR EFFECTIVENESS	%	+0.1	0	−0.1	+0.05	0	0	−0.1	+0.125	−0.83	+0.07	0	−0.45
RECUPERATOR NTU	N.D.	+0.0295	+0.0024	−0.0267	+0.0135	+0.0266	0	−0.0225	+0.045	−0.242	+0.0186	0	−0.1285
PRECOOLER EFFECTIVENESS	%	0	0	0	0	0	0	0	0	0	0	0	0
PRECOOLER NTU	N.D.	0	0	−0.0003	0	0	0	−0.0005	0	−0.0017	0	0	−0.0005
COMPRESSOR INLET PRESSURE	PSIA	−0.028	−0.001	+0.016	−0.010	−0.017	−0.003	+0.016	−0.032	+0.168	−0.014	−0.003	+0.090
COMPRESSOR INLET TEMPERATURE	°F	−0.054	−0.004	+0.050	−0.025	−0.050	0	+0.043	−0.057	+0.460	−0.026	+0.023	+0.257
REACTOR INLET PRESSURE	PSIA	−0.008	−0.002	+0.021	−0.009	−0.020	+0.008	+0.018	+1.189	+0.195	−0.023	−0.025	+0.099
REACTOR INLET TEMPERATURE	°F	+0.672	+0.039	−0.439	+0.243	+0.466	+0.073	−0.402	+0.858	−4.360	+0.355	+0.095	−2.346
TURBINE INLET PRESSURE	PSIA	−0.006	−0.002	+0.023	−0.010	−0.023	+0.008	+0.020	−0.061	+0.212	−0.024	−0.025	+0.108

ML-I INFLUENCE COEFFICIENTS

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SYSTEM PARAMETERS	REFERENCE VALUES		INDEPENDENT VARIABLES											
					+ 1 PSI REACTOR ΔP	+ 1 PSI RECUPERATOR HP ΔP	+ 1 PSI RECUPERATOR LP ΔP	+ 1 PSI PRECOOLER ΔP	+ 1 PSI PIPE 2-3 ΔP	+ 1 PSI PIPE 4-5 ΔP	+ 1 PSI PIPE 6-7 ΔP	+ 1 PSI PIPE 8-9 ΔP	+ 1 PSI PIPE 10-11 ΔP	+ 1 PSI PIPE 12-1 ΔP
SYSTEM MASS	52.5	LBS												
BYPASS FLOW	1	%												
TURBINE INLET TEMPERATURE	1200	°F												
AMBIENT AIR TEMPERATURE	100	°F												
AUXILIARY POWER	70	KW												
	UNIT CHANGE													
SYSTEM OUTPUT POWER		KW			-4.86	-4.68	-14.07	-14.87	-4.55	-4.74	-4.53	-13.8	-14.4	-14.9
REACTOR POWER TO GAS		KW_T			-3.8	-2.12	-15.1	-21.8	-1.18	-3.22	-4.05	-12.4	-18.3	-24.2
COMPRESSOR FLOW RATE		LBS/HR			-73.4	-19.3	-76.2	-293.5	+13.4	-50.5	-85.6	+12.7	-182.6	-383.5
TURBINE FLOW RATE		LBS/HR			-72.5	-19.1	-75.4	-290.5	+13.3	-50.0	-84.7	+12.6	-181.0	-379.2
COMPRESSOR PRESSURE RATIO		N.D.			+0.0085	+0.0082	+0.0049	+0.0049	+0.0107	+0.0095	+0.0083	+0.0034	+0.0048	+0.0073
TURBINE PRESSURE RATIO		N.D.			0	0	-0.0147	-0.0147	0	0	0	-0.0152	-0.0144	-0.0146
COMPRESSOR ISENTROPIC EFF.		%			0	0	0	0	0	0	0	0	0	0
TURBINE ISENTROPIC EFF.		%			0	0	0	0	0	0	0	0	0	0
CYCLE EFFICIENCY		%			-0.15	-0.12	-0.25	-0.32	0	0	-0.17	-0.34	-0.24	-0.36
RECUPERATOR EFFECTIVENESS		%			0	0	0	0	0	0	0	0	0	0
RECUPERATOR NTU		N.D.			+0.001	+0.0006	+0.0025	+0.0049	0	+0.0024	+0.0017	+0.0017	+0.0024	+0.0073
PRECOOLER EFFECTIVENESS		%			0	0	0	0	0	0	0	-0.17	0	0
PRECOOLER NTU		N.D.			+0.002	+0.0006	+0.0025	+0.0081	0	+0.0024	+0.0033	0	+0.0048	+0.0110
COMPRESSOR INLET PRESSURE		PSIA			-0.087	-0.010	-0.093	-0.405	+0.036	-0.062	-0.105	-0.034	-0.245	-0.533
COMPRESSOR INLET TEMPERATURE		°F			+0.013	+0.053	+0.007	-0.147	+0.075	+0.026	0	+0.072	-0.067	-0.212
REACTOR INLET PRESSURE		PSIA			+0.770	-0.057	+0.164	-0.586	+0.057	-0.183	+0.645	+0.473	-0.204	-0.905
REACTOR INLET TEMPERATURE		°F			+0.202	+0.212	+3.258	+1.750	+0.222	+0.204	+0.184	+1.815	+1.761	+1.692
TURBINE INLET PRESSURE		PSIA			-0.230	+0.054	+0.201	-0.504	+0.054	-0.171	-0.270	+0.494	-0.147	-0.807

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ML-1 INFLUENCE COEFFICIENTS

SYSTEM PARAMETERS	REFERENCE VALUES		INDEPENDENT VARIABLES											
			+ 1 FT^3 VOLUME$_{1-2}$	+ 1 FT^3 VOLUME$_{2-3}$	+ 1 FT^3 VOLUME$_{3-4}$	+ 1 FT^3 VOLUME$_{4-5}$	+ 1 FT^3 VOLUME$_{5-6}$	+ 1 FT^3 VOLUME$_{6-7}$	+ 1 FT^3 VOLUME$_{7-8}$	+ 1 FT^3 VOLUME$_{8-9}$	+ 1 FT^3 VOLUME$_{9-10}$	+ 1 FT^3 VOLUME$_{10-11}$	+ 1 FT^3 VOLUME$_{11-12}$	+ 1 FT^3 VOLUME$_{12-1}$
System Mass	52.5	LBS.												
Bypass Flow	1	%												
Turbine Inlet Temperature	1200	°F												
Ambient Air Temperature	100	°F												
Auxiliary Power	70	KW												
	UNIT CHANGE													
System Output Power		KW	-5.14	-6.43	-5.00	-4.20	-3.493	-2.958	-2.304	-1.503	-1.714	-2.121	-2.50	-3.32
Reactor Power To Gas		KW$_T$	-42.0	-52.5	-40.6	-34.4	-28.6	-24.3	-18.9	-12.3	-13.9	-17.4	-20.2	-27.2
Compressor Flow Rate		LBS/HR	-1360	-1697.6	-1310.8	-1112.8	-926.8	-785.9	-612.2	-399.5	-449.5	-561.3	-650.6	-880.5
Turbine Flow Rate		LBS/HR	-1346	-1680.6	-1297.7	-1101.6	-917.5	-778.0	-606.1	-395.5	-445.1	-555.7	-644.1	-871.6
Compressor Pressure Ratio		N.D.	+0.005	+0.006	+0.0045	+0.004	+0.0035	+0.003	+0.002	+0.0015	+0.0016	+0.002	+0.0023	+0.003
Turbine Pressure Ratio		N.D.	+0.0035	+0.0045	+0.0035	+0.003	+0.0025	+0.002	+0.002	+0.001	+0.0012	+0.0015	+0.0017	+0.0025
Compressor Isentropic Eff.		%	0	0	0	0	0	0	0	0	0	0	0	0
Turbine Isentropic Eff.		%	0	0	0	0	0	0	0	0	0	0	0	0
Cycle Efficiency		%	+0.05	+0.05	+0.025	+0.05	+0.05	+0.05	+0.05	0	+0.01	+ 0.02	+0.02	+0.05
Recuperator Effectiveness		%	+0.05	+0.05	+0.05	+0.05	+0.05	+0.05	0	0	+0.02	+0.02	+0.03	+0.05
Recuperator NTU		N.D.	+0.0155	+0.0195	+0.0152	+0.013	+0.0105	+0.009	+0.007	+0.0045	+0.0052	+0.0065	+0.0077	+0.010
Precooler Effectiveness		%	+0.2	+0.25	+0.23	+0.15	+0.15	+0.10	+0.10	+0.05	+0.07	+0.08	+0.11	+0.15
Precooler NTU		N.D.	+0.036	+0.044	+0.0345	+0.029	+0.024	+0.0205	+0.016	+0.0105	+0.0118	+0.0145	+0.0173	+0.0225
Compressor Inlet Pressure		PSIA	-1.941	-2.421	-1.869	-1.589	-1.324	-1.123	-0.875	-0.571	-0.640	-0.801	-0.924	-1.257
Compressor Inlet Temperature		°F	-0.970	-1.212	-0.936	-0.792	-0.658	-0.558	-0.434	-0.282	-0.318	-0.398	-0.463	-0.625
Reactor Inlet Pressure		PSIA	-5.190	-5.854	-4.519	-3.838	-3.196	-2.710	-2.112	-1.378	-1.550	-1.933	-2.242	-3.036
Reactor Inlet Temperature		°F	-0.231	-0.289	-0.221	-0.189	-0.157	-0.133	-0.103	-0.067	-0.075	-0.094	-0.108	-0.149
Turbine Inlet Pressure		PSIA	-4.409	-5.503	-4.247	-3.608	-3.005	-2.548	-1.985	-1.295	-1.457	-1.820	-2.107	-2.855

ML-1 INFLUENCE COEFFICIENTS (HARDWARE DATA)

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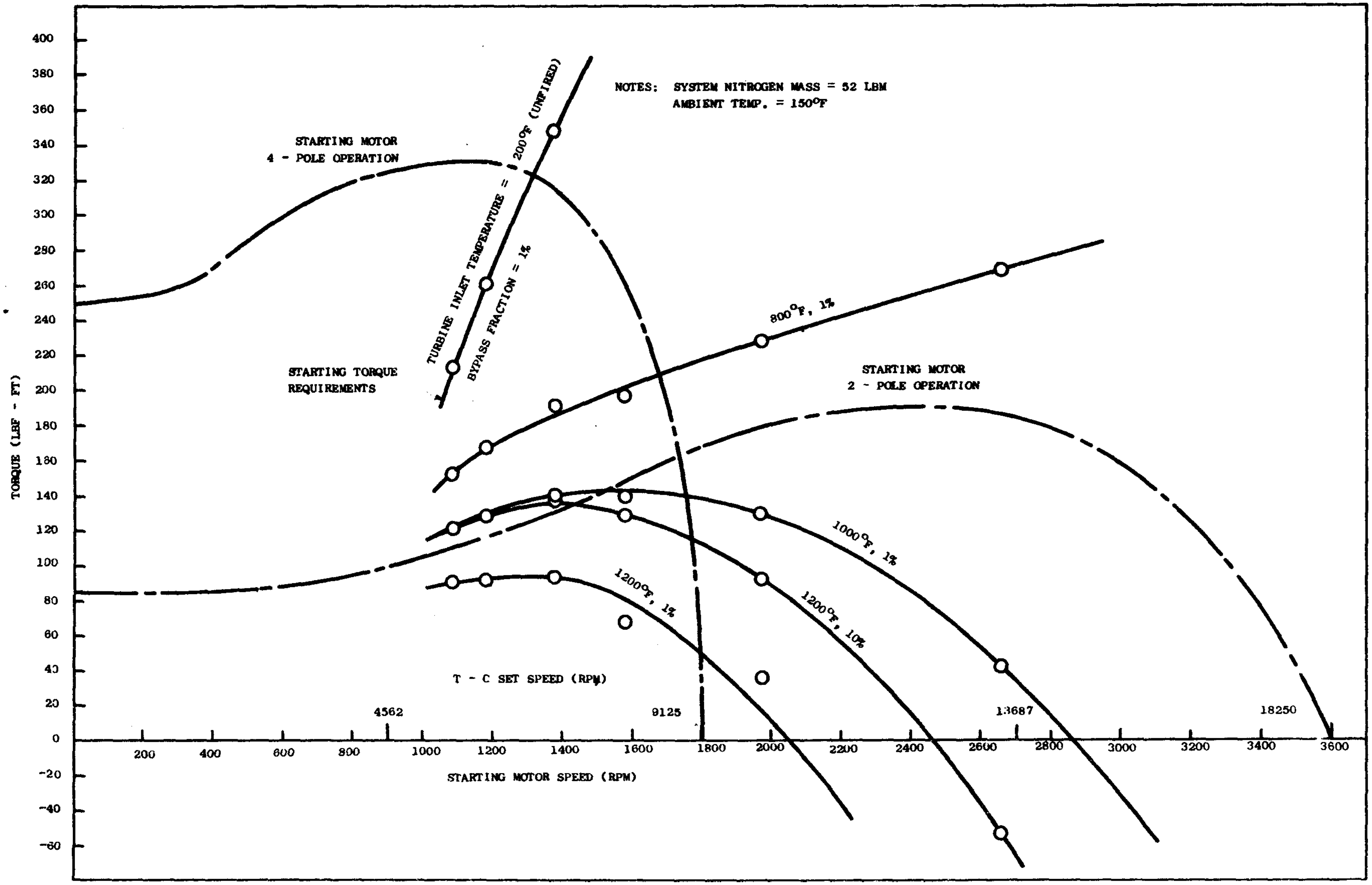
ITEM	REFERENCE VALUE
TURBINE - COMPRESSOR (AXIAL FLOW UNIT)	
UNIT SPEED	22,000 RPM
TURBINE ISEN. EFF. AT OPERATING PT.	87%
TURBINE PRESSURE RATIO AT OPERATING PT.	2.405 N.D.
TURBINE FLOW FUNCTION AT OPERATING PT. $\left(P_7/P_8 \times \frac{W_T\sqrt{T_7}}{P_7}\right)$	30505.93 $\frac{LB}{HR}\frac{\sqrt{^\circ R}}{PSIA}$
COMPRESSOR ISEN. EFF. AT OPERATING PT.	84%
COMPRESSOR PRESS. RATIO AT OPERATING PT.	2.745 N.D.
COMPRESSOR FLOW FUNCTION AT OPERATING PT. $\left(3.80167\times10^{-9}\ \frac{N \times W_C}{P_T}\right)$	0.06579 $\frac{RPM}{PSI}\ \frac{LB}{SEC}$
COMPRESSOR VOLUME	3.532 FT^3
TURBINE VOLUME	0.545 FT^3
TURBINE-COMPRESSOR MECH. LOSSES AT OPER. PT.	39 KW
REDUCTION GEARING EFF. AT OPERATING PT.	95%
GENERATOR	
GENERATOR LOSSES AT OPERATING PT.	35 KW
REACTOR	
PRESSURE DROP AT OPERATING PT.	24.0 PSI
CORE FREE FLOW AREA	0.2959 FT^2
CORE HYDRAULIC DIAMETER	0.01092 FT
CORE FRICTION AREA/FLOW AREA RATIO	1035.36 N.D.
VOLUME $(5-6)$	6.526 FT^3
RECUPERATOR	
EFFECTIVENESS AT OPERATING PT.	80%
NTU AT OPERATING PT.	4.284 N.D.
LOW PRESSURE SIDE	
PRESS. DROP AT OPERATING PT.	1.2 PSI
FREE FLOW AREA	3.00 FT^2
FIN AREA	4960 FT^2

ITEM	REFERENCE VALUE
RECUPERATOR	
LOW PRESS. SIDE (CONTINUED)	
TOTAL AREA	5950 FT^2
FIN CONSTANT	0.073 $\sqrt{\frac{HR\ ^\circ F}{BTU}}$
HYDRAULIC DIAMETER	0.0313 FT
FRICTION AREA/FLOW AREA RATIO	231.31 N.D.
COLBURN "J" FACTOR	0.005718 N.D.
VOLUME $(9-10)$	45.51 FT^3
HIGH PRESSURE SIDE	
PRESSURE DROP AT OPERATING PT.	5.8 PSI
FREE FLOW AREA	0.538 FT^2
TOTAL AREA	1200 FT^2
HYDRAULIC DIAMETER	0.02825 FT
FRICTION AREA/FLOW AREA RATIO	2780.57 N.D.
COLBURN "J" FACTOR AT OPERATING PT.	0.002264 N.D.
VOLUME $(3-4)$	13.26 FT^3
PRECOOLER	
EFFECTIVENESS AT OPERATING PT.	92%
NTU AT OPERATING PT.	4.192 N.D.
NITROGEN SIDE	
PRESS. DROP AT OPERATING PT.	1.8 PSI
FREE FLOW AREA	1.37 FT^2
FIN AREA	1770 FT^2
TOTAL AREA	2905 FT^2
FIN CONSTANT	0.0419 $\sqrt{\frac{HR\ ^\circ F}{BTU}}$
HYDRAULIC DIAMETER	0.0137 FT
FRICTION AREA/FLOW AREA RATIO	2120.44 N.D.

ITEM	REFERENCE VALUE
PRECOOLER	
NITROGEN SIDE (CONTINUED)	
COLBURN "J" FACTOR AT OPERATING PT.	0.002927 N.D.
VOLUME $(11-12)$	31.13 FT^3
AIR SIDE	
AIR FLOW RATE	68,000 CFM
FREE FLOW AREA	40.1 FT^2
FIN AREA	14580 FT^2
TOTAL AREA	15800 FT^2
FIN CONSTANT	0.1273 $\sqrt{\frac{HR\ ^\circ F}{BTU}}$
HYDRAULIC DIAMETER	0.052 FT.
COLBURN "J" FACTOR AT OPERATING PT.	0.006505 N.D.
PIPE	
VOLUMES	
PIPE $(2-3)$	1.60 FT^3
PIPE $(4-5)$	4.06 FT^3
PIPE $(6-7)$	5.68 FT^3
PIPE $(8-9)$	0
PIPE $(10-11)$	7.42 FT^3
PIPE $(12-1)$	1.35 FT^3
PRESSURE DROPS AT OPERATING PT.	
PIPE $(2-3)$	0.2 PSI
PIPE $(4-5)$	0.6 PSI
PIPE $(6-7)$	0.7 PSI
PIPE $(8-9)$	0.1 PSI
PIPE $(10-11)$	0.1 PSI
PIPE $(12-1)$	0.2 PSI

ML-1 STARTING OPERATION — STRATOS T-C SET — 50-HP, 2 - SPEED STARTING MOTOR



IV. ML-1 PHASE II TEST PROGRAM

E. SUPPLEMENTAL INFORMATION

4. ML-1 Phase I Test Plan Experimental Data

AN-IDOP-16	ML-1 Nuclear Instrumentation Test at the GCRE
AN-IDOP-20	Initial Critical Experiment for ML-1
AN-IDOP-29	Operating Core Determination for ML-1
AN-IDOP-30	Preliminary Control Rod Calibration, Shield Water and Tungsten Baffle Reactivity Worths for ML-1 (Summary)
AN-IDOP-34	Final Control Rod Calibration, Shield Water and Tungsten Baffle Reactivity Worths for ML-1 (Summary)

File: AN-IDOP-16, Page 1 of 12
7 March 1961
Standard Distribution

M E M O R A N D U M

TO: R. H. Chesworth

FROM: R. D. Peak

SUBJECT: ML-1 NUCLEAR INSTRUMENTATION TEST AT THE GCRE

SUMMARY

During the period 15 February 1961 to 1 March 1961, the nuclear instrumentation in the Control Cab for the ML-1 Power Plant was checked out and tested, using the GCRE reactor as a source of neutrons. This testing was quite successful since the test provided an almost complete nuclear instrument checkout several months before any similar tests could be performed with the ML-1 reactor. Further, the GCRE provided nearly a complete range of neutron flux levels so that the successive channel overlaps, the period scram functions and the high level scram functions could be tested and adjusted. The results of this test lend considerable confidence in the ML-1 instrumentation for the forthcoming critical and power experiments.

This memo gives the results of this instrumentation test.

GENERAL METHOD

A general outline of this test is given in "ML-1 Instrumentation Test at GCRE", OETP 623, by H. Snyder, 9 December 1960. The GCRE reactor was operated according to "ML-1 Instrumentation Test", Experiment 9623. This experiment outline required the operation of the GCRE at various power levels, from shutdown up to full power, and also on certain negative periods. There was no physical interconnection between the GCRE and the ML-1 instrumentation. The GCRE acted solely as a neutron source for the ML-1 detectors which were placed in thimbles on the north side of the GCRE core.

The detailed procedure for the test was "ML-1 Nuclear Instrument Test at GCRE", ANSOP 16001. In general, the actual neutron detectors, preamplifiers, and most of the prototype cables and connection boxes were utilized. The nuclear instruments were operated throughout their design range.

Scram actuation was simulated for the purposes of this test since the control blades were not connected to the Control Cab. The necessary startup interlocks were bypassed to obtain clutch voltage (although the current was zero) for the absent control blade mechanisms. The "Clutch Coils" switch was set to BUS V position and a scram was indicated by a zero voltage on the "Clutch Coils" meter. Each scram function also alarmed the appropriate annunciator.

A. LOG COUNT RATE CHANNELS

1. Channels 1 and 2.

Channels 1 and 2 are the startup channels and operate throughout the range of 1 to 1×10^6 cps as Log Count Rate channels. These two channels are designed to overlap the intermediate channels, Channels 3 and 4, through the range of 1×10^4 to 1×10^6 cps. The two startup channels have a scram function, short period, which is normally set at 10 sec period.

The detectors for the startup channels are made by the General Electric Co. and are proportional counters. (Catalog No. 5478906G1)

The test procedure had the following objectives:

a. To determine the optimum power supply high voltage (R16 control) for operating on the "plateau".

b. To determine the adjustment on the variable pulse amplifier gain (R13 control) to attain the two decade overlap with Channels 3 and 4.

c. To prove when the reactor is shut down that the channels count primarily neutrons and not gamma photons.

d. To prove that these channels will sense a short period and will actuate the scram system properly.

All the above objectives were attained.

Voltage vs. cps data were recorded for both channels when the GCRE reactor operated at various low power levels (0.001% to 0.1% of full power), when the detectors were wrapped with various thicknesses of cadmium foil (none up to 0.022 inch thick), and when the detectors were positioned at 41 to 45 inches away from the reactor centerline. Not all permutations of these factors were covered by the data (which have been plotted in Figures 1 and 2). For the purposes of illustrating linearity, the data has been normalized to 0.1% power; i.e., cps data taken at 0.001% power has been multiplied by a factor of 100 and then plotted. The figures show that a high voltage in the range of 740 to 820 volts would be satisfactory for either detector.

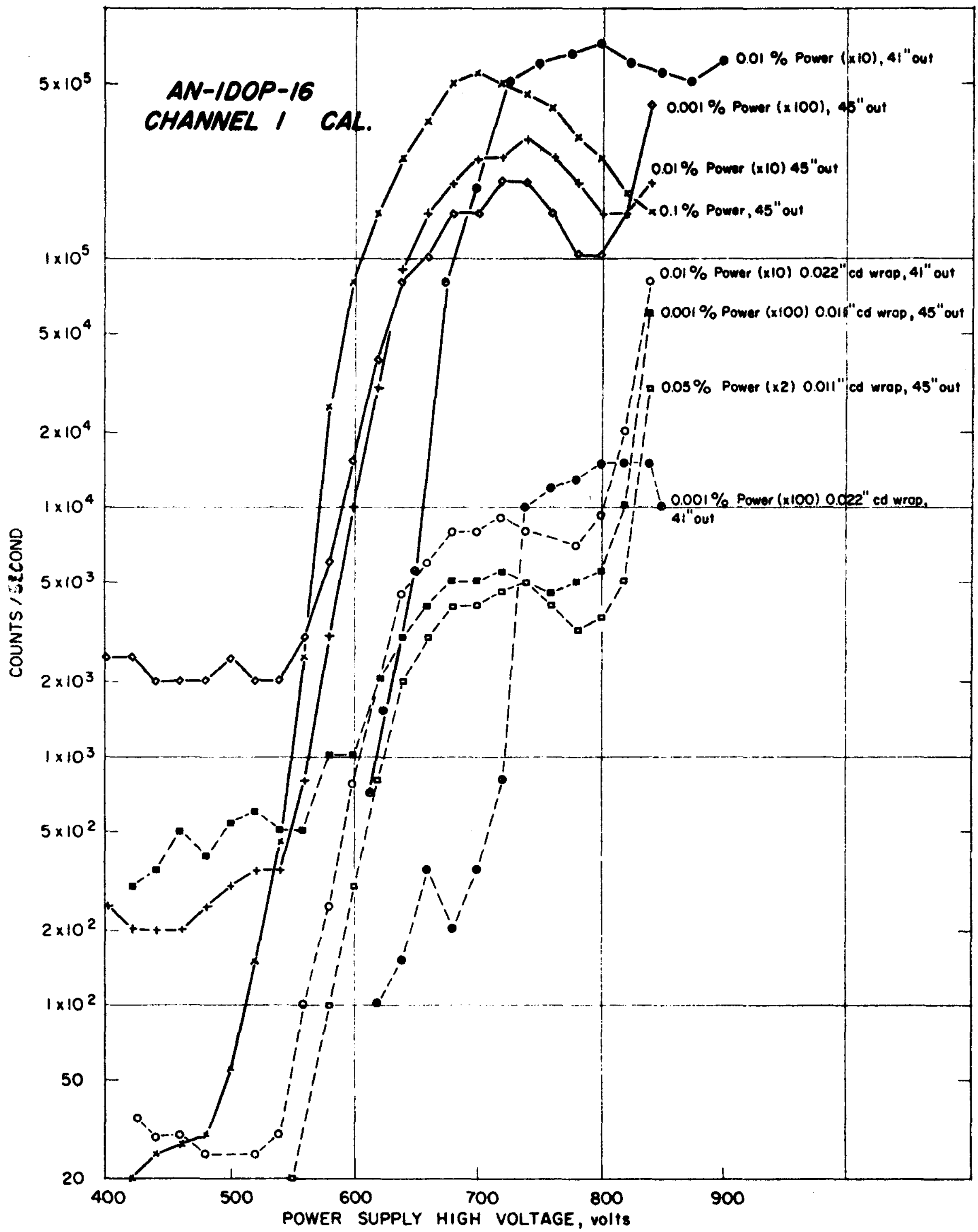

AN-IDOP-16
CHANNEL I CAL.
0.01 % Power (x10), 41" out
0.001 % Power (x100), 45" out
0.01 % Power (x10) 45" out
0.1 % Power, 45" out
0.01 % Power (x10) 0.022" cd wrap, 41" out
0.001 % Power (x100) 0.018" cd wrap, 45" out
0.05 % Power (x2) 0.011" cd wrap, 45" out
0.001 % Power (x100) 0.022" cd wrap, 41" out
COUNTS / SECOND
POWER SUPPLY HIGH VOLTAGE, volts
5 x 10^5
1 x 10^5
5 x 10^4
2 x 10^4
1 x 10^4
5 x 10^3
2 x 10^3
1 x 10^3
5 x 10^2
2 x 10^2
1 x 10^2
50
20
400
500
600
700
800
900

FIGURE 1

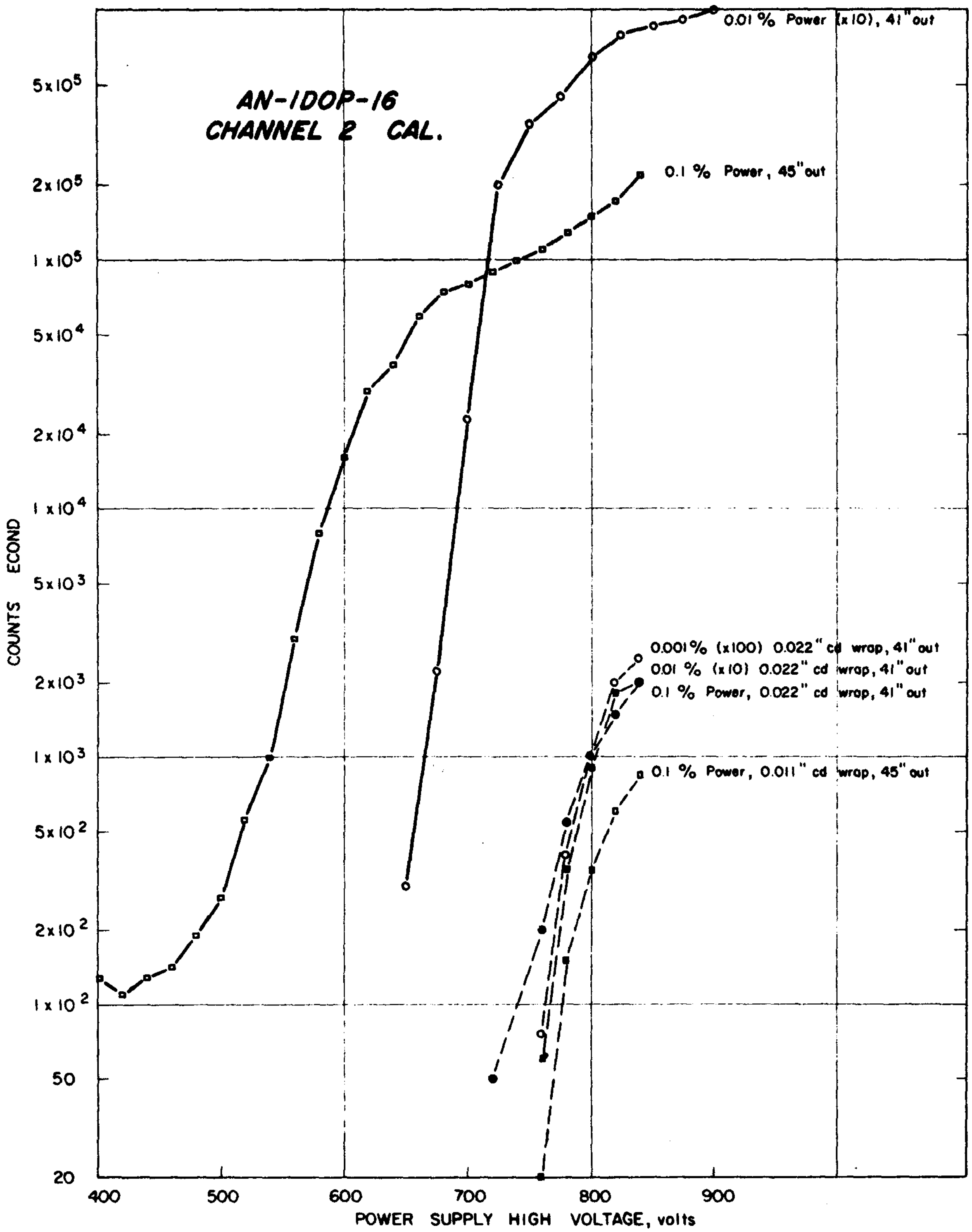

AN-IDOP-16
CHANNEL 2 CAL.
0.01 % Power (x10), 41" out
0.1 % Power, 45" out
0.001% (x100) 0.022" cd wrap, 41" out
0.01 % (x10) 0.022" cd wrap, 41" out
0.1 % Power, 0.022" cd wrap, 41" out
0.1 % Power, 0.011" cd wrap, 45" out
COUNTS ECOND
5x10^5
2x10^5
1x10^5
5x10^4
2x10^4
1x10^4
5x10^3
2x10^3
1x10^3
5x10^2
2x10^2
1x10^2
50
20
400
500
600
700
800
900
POWER SUPPLY HIGH VOLTAGE, volts

FIGURE 2

The amplifier gain, which had been set approximately correct initially, was then adjusted for proper overlap. With Channels 1 and 4 detectors at 41 inches from the reactor centerline, the gain was set so that Channel 1 indicated 7×10^5 cps when Channel 4 indicated 5×10^4 nv. Then Channel 2 detector was substituted for the Channel 1 detector and the gain on Channel 2 was set identically. This overlap is illustrated below:

ML-1 Power (Approximate)	Channels 1 and 2	Channel 4
0.0003 w	3 cps	Off Scale
1. w	4.2×10^4 cps	3×10^3 nv (Bottom of Range)
100 w	1×10^6 cps (Top of Range)	7×10^4 nv

Figures 1 and 2 illustrate that the detectors are sensitive to neutrons at high count rates since the sensitivity is reduced by a factor of about 10^2 when the detectors are wrapped with cadmium foil. However, a demonstration was arranged to show that the detectors are sensitive to neutrons at low count rates also. For this demonstration, the GCRE reactor was shut down after operating at 1.5 Mw to build up an inventory of fission products.

Then substitution tests were conducted to obtain the following data:

Detector Cover	Channel 1	Channel 2
None, bare detector	12 cps	17 cps
2 in. thick lead shield	7	8
0.022 in. thick cadmium wrap	1	-

The gamma field at the detector locations was measured as about 28 r/hr, using a film badge (950 mr for a 2 minute exposure). The detectors are sensitive to this relatively high gamma field since the count rate was reduced by the lead shield. However, the important sensitivity is to neutrons.

The procedure outlined in the ANSOP could not be used in checking the period scram functions on Channels 1 and 2, due to the chamber location with respect to the GCRE reactor vessel and instrumentation. Instead, these scram functions were tested by raising and lowering each detector in its thimble adjacent to the reactor. Upon raising the detectors simulating a reduction in reactor power, a negative period was displayed and no scram indication occurred. Then upon lowering each detector, simulating a fast increase in reactor power, scram indication was observed along with the proper annunciator alarm and short period indication.

B. LOG N CHANNELS

1. Channels 3 and 4.

Channels 3 and 4 are the intermediate channels and operate throughout the range of 3×10^3 to 3×10^{10} nv (neutron flux value approximately at detector location) as Log N channels. These two channels are designed to overlap the startup channels, as shown previously, and to cover the range up to and including full power level. These two intermediate channels have a scram function, short period, which is normally set at 10 sec.period. Channel 4 also actuates the power supply for Channels 1 and 2 so that these startup channels are turned off when they are off scale. The detectors for the intermediate channels are made by the Anton Electronic Laboratories, Inc., and are ANTON Type 807, compensated boron lined ionization chambers.

The test procedure had the following objectives:

a. To determine the optimum power supply high voltage (R16 and S1 controls).

b. To determine the optimum compensating voltage.

c. To set on Channel 4 the power supply switch for Channels 1 and 2.

d. To relate thermal neutron flux to Channels 3 and 4 nv values.

e. To prove that these channels will sense a short period and will actuate the scram system properly.

Compensating voltage vs. nv readout and also power supply high voltage vs. nv readout data were taken with the GCRE reactor at 0.01% power and Channels 3 and 4 detectors located 43 inches away from the reactor centerline. The voltage vs. nv readout are plotted on Figure 3. The striking feature of these plots is the insensitivity of the nv indication to voltage variation. Figure 3 confirms the vendor's recommended values of -40 volts for the compensating voltage and 750 volts for the power supply high voltage. The compensating voltage was further confirmed by placing the GCRE on a steady negative period (inserting the setback rod), and checking that the nv indication is linear with time.

Channels 1 and 2 are turned off when Channel 4 indicates 2.5×10^6 nv; equivalent to about 3.5×10^7 cps, but above the range for readout on Channels 1 and 2.

The neutron flux in the detector positions for Channels 3, 4, and 5 was measured, using cobalt foils, both bare and cadmium covered. These flux measurements were taken when the detector thimbles were positioned about 42 in. from the reactor centerline. Channel indication and flux data are summarized below. The flux were measured to a standard deviation of about 10%.

Channel	Indication	Thermal Neutron Flux
3	7×10^7 nv	4.9×10^7 n/cm^2 sec
4	-	3.4×10^7
5	2%	2.8×10^7

This data compares favorably with the vendor's design prediction.

The period scram functions for Channels 3 and 4 were tested similarly to those for Channels 1 and 2 described previously. Again, upon lowering the detectors for Channels 3 and 4, to simulate a fast increase in reactor power, scram indication was observed along with the proper annunciator alarm and short period indication.

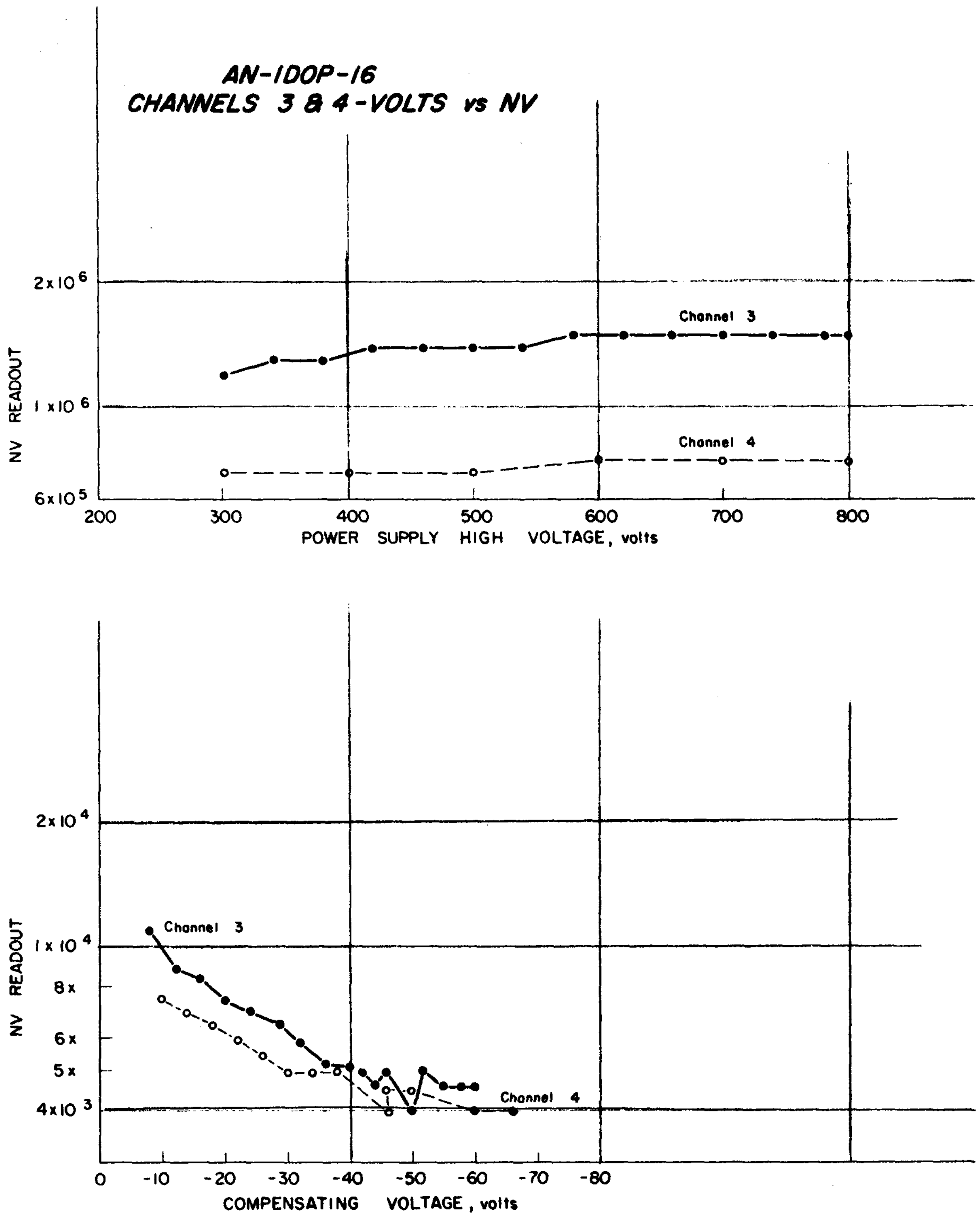

AN-IDOP-16
CHANNELS 3 & 4-VOLTS vs NV
NV READOUT
2x10 6
1 x10 6
6x10 5
Channel 3
Channel 4
200
300
400
500
600
700
800
POWER SUPPLY HIGH VOLTAGE, volts
2x10 4
1x10 4
8x
6x
5x
4x10 3
0
-10
-20
-30
-40
-50
-60
-70
-80
COMPENSATING VOLTAGE, volts

FIGURE 3

C. LINEAR POWER CHANNELS

1. Channels 5, 6, and 7.

The three high-level channels cover the operating range of 0 to 150% of full reactor power and operate as Linear Power channels. These three channels overlap the intermediate channels. The linear power channels have a scram function, high-level safety, which is normally set at 110% of full power. The detectors for these channels are made by the Anton Electronic Laboratories, Inc., and are ANTON Type 813, uncompensated boron lined ionization chambers.

The test procedure had the following objectives:

a. To determine the optimum power supply high voltage, (Tl control).

b. To compare the overlap and linearity between the intermediate Channels 3 and 4, with the linear power Channels 5, 6, and 7.

c. To test the high-level safety scram function on each of the linear power channels.

Not all of the above objectives were attained.

The power supply voltage vs. channel indication data was not taken due to oversight. Thus, the vendor's recommended value of 500 volts was utilized throughout the remainder of the test.

A series of runs were made to compare pairs of channels throughout the allowable operating range for the linear power channels. These runs are summarized on page 10. (Distance is from the thimble to the lead reflector on the GCRE.)

The high-level scram function for Channel 5 was tested repeatedly. However, the detector for Channel 6 is not as sensitive as Channel 5, and the detector for Channel 7 could not be placed in high enough flux to test out their scram function. Thus, the one-out-of-three and also the two-out-of-three coincidence trip circuits could not be demonstrated with all possible combinations of channels.

Malfunctioning of the linear power meter makes the data somewhat questionable and could account for some of the inconsistency and non-linearity observed.

Channel	Thimble and Distance	Channel	Thimble and Distance	Results
3	2, 12"	5	1, 12"	3 points plotted on Figure 4, Scram at 106% on Channel 5.
3	2, 12"	5	1, 18"	3 points plotted, Scram at 106% on Channel 5.
3	2, 12"	6	1, 12"	4 points plotted, no scram test possible.
3	2, 12"	7	7	1 point taken, thimble 7 in too low a flux field to make useful data.
4	2, 12"	5	1, 12"	3 points plotted, Scram at 106% on Channel 5.
4	2, 12"	6	1, 12"	3 points plotted, no scram test possible.
4	1, 12"	6	2, 12"	4 points plotted, no scram test possible.

The data from the series of runs are plotted on Figure 4 to illustrate the degree of linearity and overlap available from Channels 3, 4, 5, and 6. These channels overlap satisfactorily and also exhibit satisfactory linearity. The non-linearity could as well be due to the GCRE instrumentation as due to the ML-1 instrumentation.

D. ML-1 STARTUP INSTRUMENTATION

Though not required by the test procedure, the BF_3 detectors and associated counting equipment to be used in the forthcoming "Initial Critical Experiment", ANSOP 16200, were tested in conjunction with the other ML-1 instrumentation. For this purpose, the BF_3 detectors were connected to the John Fluke power supply, the Bendix pre-amplifiers, the Bendix linear amplifiers, and to a Hamner scaler as described by Step A-6, ANSOP 16200. The three BF_3 detectors were placed in two thimbles which were positioned adjacent to the GCRE reactor. Detector Channels 1 and 3 were in one thimble, while detector Channel 2 was in a second thimble. Power supply voltage to the detectors was set at 2000 volts, and the discriminators on the scalers were set to give a background

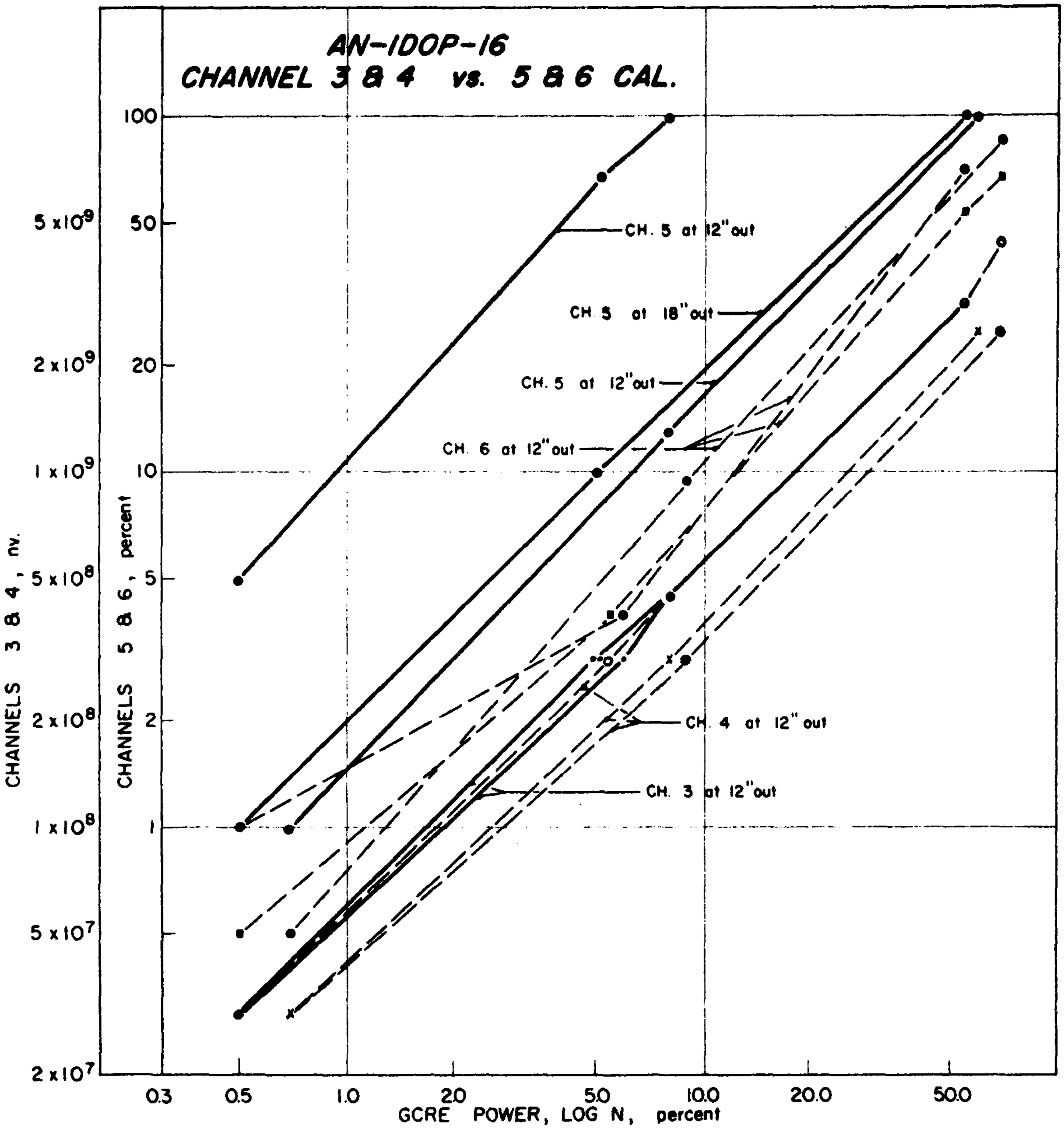

AN-IDOP-16
CHANNEL 3 & 4 vs. 5 & 6 CAL.
CH. 5 at 12" out
CH 5 at 18" out
CH. 5 at 12" out
CH. 6 at 12" out
CH. 4 at 12" out
CH. 3 at 12" out
CHANNELS 3 & 4, nv.
CHANNELS 5 & 6, percent
GCRE POWER, LOG N, percent
5 x 10^9
2 x 10^9
1 x 10^9
5 x 10^8
2 x 10^8
1 x 10^8
5 x 10^7
2 x 10^7
100
50
20
10
5
2
1
0.3
0.5
1.0
2.0
5.0
10.0
20.0
50.0

FIGURE 4

of 300-400 cpm before the test was begun. The test consisted of taking counts on each detector channel when the detectors were positioned at various heights in the thimble and at various GCRE low-power levels. For the most part, three one-minute counts were taken at each position and power level. The three counts are averaged and reported to the nearest standard deviation magnitude in the results listed below:

Position	GCRE Power (Ch. 3), %	BF_3 Channel 1 cpm	BF_3 Channel 2 cpm	BF_3 Channel 3 cpm
One	0.065	136,300	120,000	77,300
One	0.030	69,300	66,100	42,300
(Ratio)	(2.17)	(1.97)	(1.82)	(1.83)
Two	0.030	2,014,000	1,296,000	1,060,000
Two	0.100	5,234,000	3,838,000	3,103,000
(Ratio)	(3.33)	(2.60)	(2.97)	(2.93)
Three	0.100	4,257,000	12,312,000	5,318,000
Three	0.200	6,170,000	13,646,000	7,364,000
(Ratio)	(2.00)	(1.45)	(1.11)	(1.39)
On Bridge Floor -	Zero (Background)	13,100	6,600	3,700

These data indicate that detector Channel 2 would saturate at about 14.5×10^6 cpm and would give false count rates at higher levels of neutron flux;probably the other detector channels would do likewise. In general, this startup instrumentation appears to follow the GCRE power increase satisfactorily up to a counting rate of about 6×10^6 cpm. It appeared that the connections for detector Channel 1 were slightly dirty so that a high spurious background count was recorded, although the counting seemed satisfactory at high count rates. Thus, this startup instrumentation can be utilized with confidence for the initial critical experiment.

File: AN-IDOP-20, Page 1 of 18
31 March 1961
Standard Distribution

M E M O R A N D U M

TO: R. H. Chesworth

FROM: R. D. Peak and R. E. Lightle

SUBJECT: INITIAL CRITICAL EXPERIMENT FOR ML-1

SUMMARY

Preparations for the initial critical experiment on the ML-1 reactor were completed on 28 March 1961. The procedure, ANSOP 16200, was initiated at 0830 hours, 29 March 1961, and fuel loading into the reactor commenced at 1530 hours. The fuel was loaded into dry gas coolant passages;the moderator water system was filled with demineralized water,and the shield water tank was dry. The charging operation was monitored by three separate BF_3 detector channels (detectors located at peripheral blank fuel positions) in addition to the standard ML-1 instrumentation. Fuel loading continued without major interruption until criticality was attained at 1355 hours, 30 March 1961. Forty-seven standard fuel elements were required for criticality with five control blades fully withdrawn and Shim 2 withdrawn to 65 degrees (80 degrees is full out).

The successful conclusion of this experiment on 30 March bettered the ML-1 test schedule by two days, the date for criticality of 1 April 1961 having been originally established in July 1959. The critical loading of 47 elements was extremely close to the prediction of 48 $\pm$ 4 fuel elements.

PREPARATION

A. INSTRUMENTATION

The ML-1 nuclear instrumentation was checked out and proof tested in February at the GCRE facility. For this purpose, the ML-1 control cab was sited near the GCRE reactor pool and the test operations utilized the GCRE as a source of neutrons. The ML-1 detectors were placed in watertight thimbles adjacent to the GCRE reactor core. The GCRE was operated at various power levels so that the successive channels of the ML-1 instruments, the channel overlaps,the period scram functions,and the high level scram functions could be tested and adjusted. Also at this time, the BF_3 detector systems to be used in the critical experiment were checked out. All this testing was quite successful and was reported by R. Peak, "ML-1 Nuclear Instrumentation Test at the GCRE," AN-IDOP-16, 7 March 1961.

At the conclusion of the above instrument tests, the ML-1 control cab was moved to its permanent location adjacent to the auxiliary control building at the ML-1 facility. The nuclear instruments in the cab were connected to the detectors installed in the reactor package, some 500 feet distant in the test building, through cables supplied by Stromberg-Carlson specially for use with the ML-1. However, since the other ML-1 cables for power, control, and alarm transmission between the cab and the reactor package have not arrived, extra cables, connectors, and jumpers were made up so that the cab was connected to the reactor through the cables which had been installed for the analysis instrumentation on the power conversion (P.C.) package. Only the functions essential to the initial tests and experiments were thus rigged, the connections being run through a connector panel especially prepared for the reactor during the absence of the P.C. package.

B. MODERATOR SYSTEM

The moderator water system was visually checked and then temporarily repiped to minimize the quantity of water in the reactor circuit. A jumper line was installed to complete the circuit in the absence of the P.C. package and the moderator water-to-air heat exchanger. The upper surge tank was removed from the reactor shield tank and placed aside. The lower surge tank was bypassed by temporary lines as was also the shield water-to-moderator water heat exchanger. Other temporary lines provided water subcircuits essential for the neutron detector chambers and for the control blade actuator dashpots. Finally, a one-gallon surge tank having a low-level alarm switch was installed at the high point of the moderator water circuit.

The modified moderator water system was filled with demineralized water and circulated using the auxiliary moderator water pump, 15 gpm capacity. One of the mixed bed demineralizer tanks on the reactor package was filled with resin and the water was circulated through this bed. Several cycles of filling, circulation, and draining of the moderator water were required to completely cleanse the circuit. Finally, the system was filled with water and circulated until all bubbles had been vented from the circuit. During the critical experiment, the moderator water was circulated using the auxiliary pump with half the flow through the reactor core, and half through the demineralizer bed.

C. RADIATION DETECTION INSTRUMENTS

The "Site Area Monitoring" system (SAM) was connected and checked out. In the absence of the P.C. package, six ion chamber detectors for this system were placed under and about the reactor package in the test building; one detector was located in the control cab. This system was calibrated using a 5 R cobalt source. The hand and foot counter and the portal monitor in the test building, and the portal monitor in the entrance between the cab and control building were checked and calibrated. All the portable survey instruments (beta, gamma, alpha, fast neutron, and thermal neutron units) were checked and calibrated. Two dozen sets of radiation protective clothing, 17 respirators with activated charcoal filters, and 7 Scott Air Packs were procured and stored in the control building ready for emergency use. Finally, a Continuous Air Monitor was placed in the test building, checked and calibrated.

D. CONTROL ROD SYSTEM

The complete control rod system was checked out per ANSOP 16112 to ensure satisfactory operation. Some troubles were discovered during this system checkout which were corrected. Mis-connections, shorts, and improper grounds in the wiring in the cab and cabling were located and eliminated. The dashpot orifice rings on all blade actuators were ground and honed to alleviate certain rough surfaces which were causing the blades to stick. At first during the checkout, the safety and shim blades could not be fully withdrawn; the clutches slipped against the insertion torque of the scram springs. This slippage was alleviated by boosting a transformer tap supplying current to these clutches, by adjusting the shaft holding springs to lessen tension, and by replacing one clutch having an excessive air gap clearance. Finally, the blade position indicators were calibrated and the scram times for each pair of blades were measured. The measured times were all less than the specified maximum time permissible: 0.350 sec. The conclusion of the checkout indicated that all blade actuators and blade position indicating circuitry were operating normally and satisfactorily. A memorandum detailing the results of this checkout and the correction work accomplished is being prepared.

E. TRAINING

The training of the ML-1 operating personnel had been started in September 1960, with the initiation of informal discussions and formal lectures and periodic written quizzes. Finally, on 24 March, a formal briefing was held with all these operating personnel on the Initial Critical Experiment, ANSOP 16200 and on the Master Emergency Plans, ANSOP 3950. Both procedures were covered in step-by-step detail and the various responsibilities and job assignments were noted. This training culminated in a reactor operator qualification test given to the military personnel and the AGN reactor technicians. All personnel passed this written test.

THE CRITICAL EXPERIMENT

The general course of work conducted during the critical experiment is outlined in the procedure, "Initial Critical Experiment," ANSOP 16200. However, this work entailed the following subsidiary procedures that were cited or generally applicable.

ANSOP 0800 - Power Plant and Facility Modifications

ANSOP 14030 - New Fuel Element Handling

ANSOP 16068 - Initial Critical Moderator System Test

ANSOP 14360 - Site Area Monitoring (SAM) System Startup

ANSOP 14060 - Nuclear Instrumentation Pre-Startup Check

ANSOP 14080 - Control Blade System Pre-Startup Check

ANSOP 14300 - Battery-Inverter System Pre-Startup Check

ANSOP 2302 - Personnel Control ML-1 Facility

ANSOP 12000 - ML-1 Facility Pre-Reactor Operation Startup Checks

ANSOP 1600 - ML-1 Special Materials Vault

ANSOP 2200 - Special Work Permit

Once the experiment was completed, the "Low Power Reactor Shutdown,"ANSOP 14023, and "ML-1 Facility Overnight Shutdown,"ANSOP 12004,were initiated.

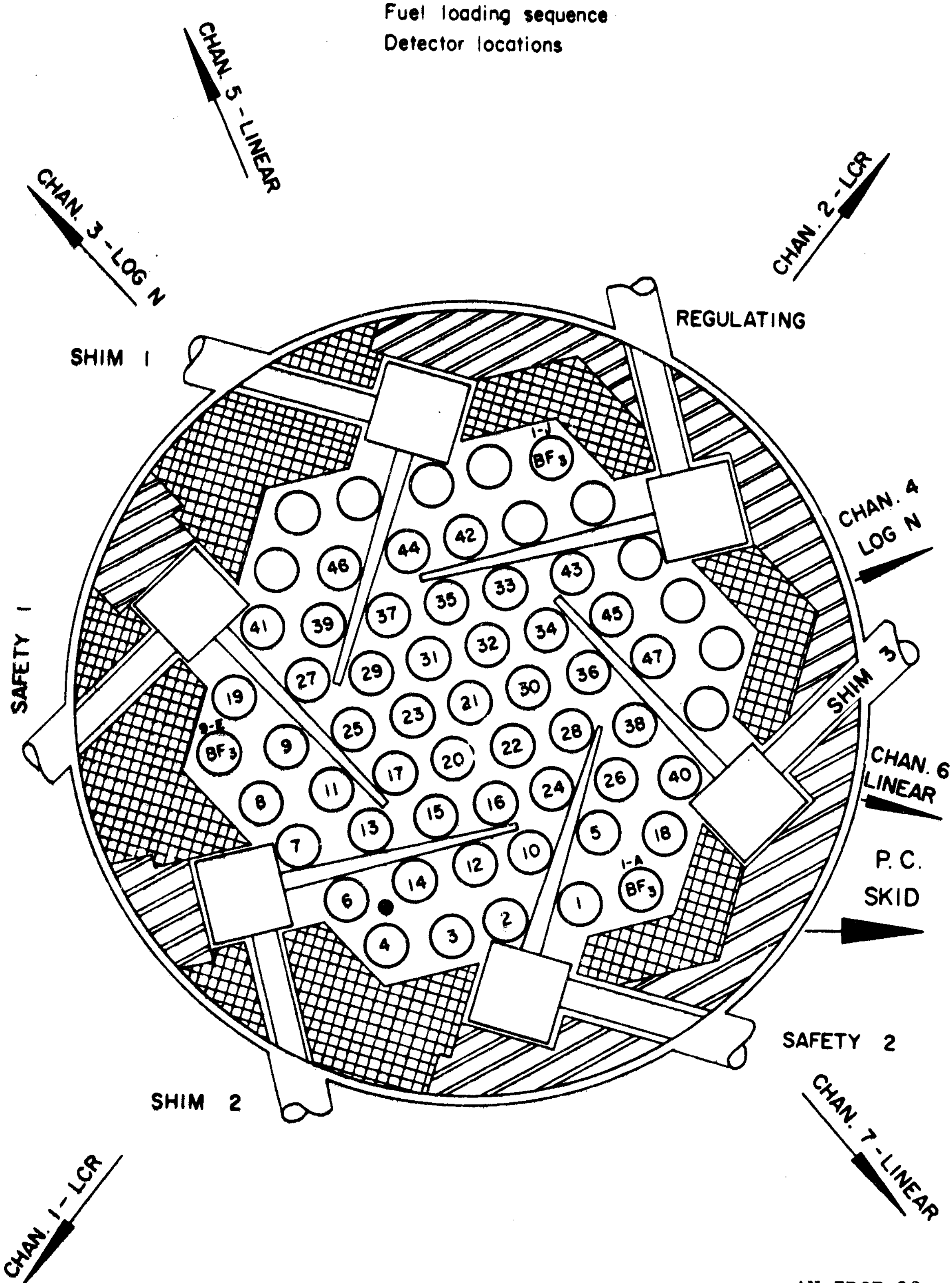
The experiment deviated from the procedure in one significant respect; a different fuel loading sequence was followed. The sequence was revised to conform to the several criteria: to load fuel first near the source and BF_3 detectors (surround the detectors as soon as possible) and to load fuel in a compact array. The objective of the revision was to produce a smooth, regular curve on the 1/M plots so that criticality could be predicted with confidence. The loading sequence is shown in Figure 1 and is tabulated in the Appendix along with the counting data.

Fuel loading into the dry gas coolant passages was begun at 1530 hours, 29 March 1961. First a block of nine elements was loaded around the neutron source and the BF_3 detector positions at 1-A and 9-E. Then successive pairs of elements were loaded without moving the control blades until 17 elements in all had been charged. The procedural criteria for stopping this mode of loading was at either 17 elements or the attainment of a 1/M of 0.20. However, at the 17th element, the 1/M values were 0.45, 0.47, 0.52, 0.58, and 0.65.

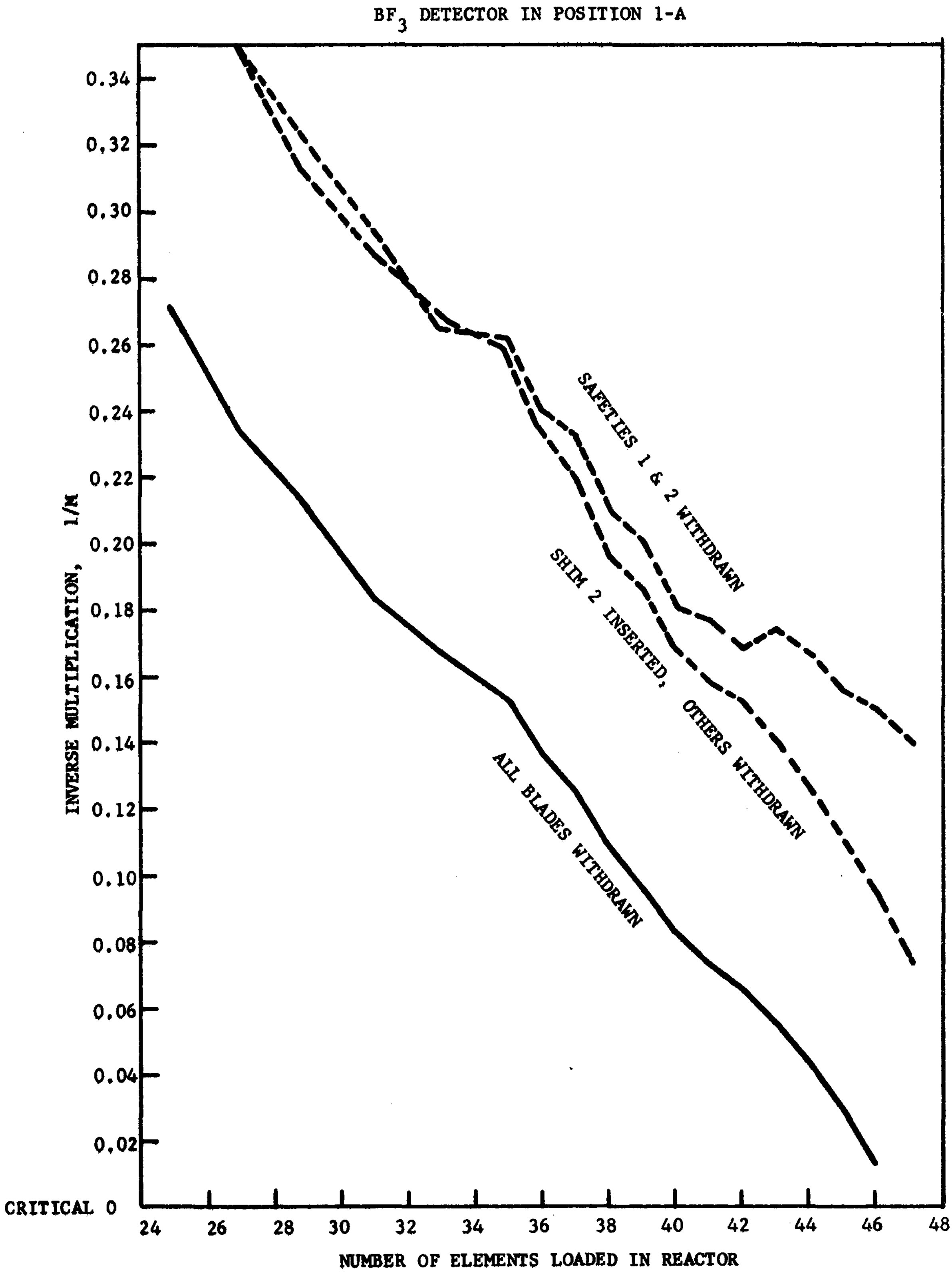
Pairs of elements continued to be loaded up to the 35th element, but with counting being done after withdrawing sets of control blades. For instance, up to element 25, the Regulating and Shim 2 blades were inserted for the loading, and then withdrawn in sequence for the counting. For successive pairs of elements, the Regulating and Shim 1 and 2 blades were inserted for the loading and then withdrawn for counting. The 1/M graphs included in this memorandum begin with element 24 and are shown as Figures 2 through 6.

ML-1 REACTOR

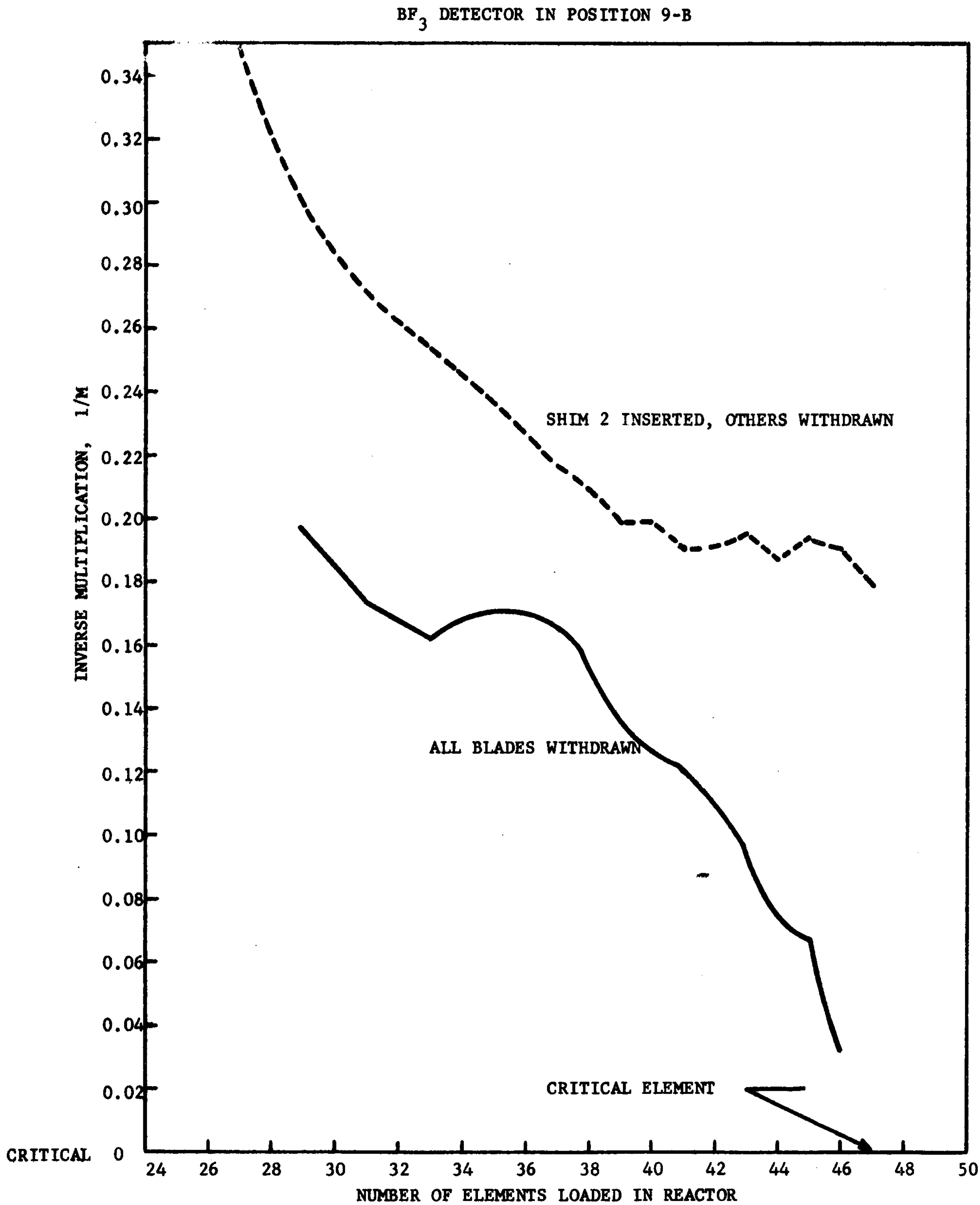
Fuel loading sequence
Detector locations



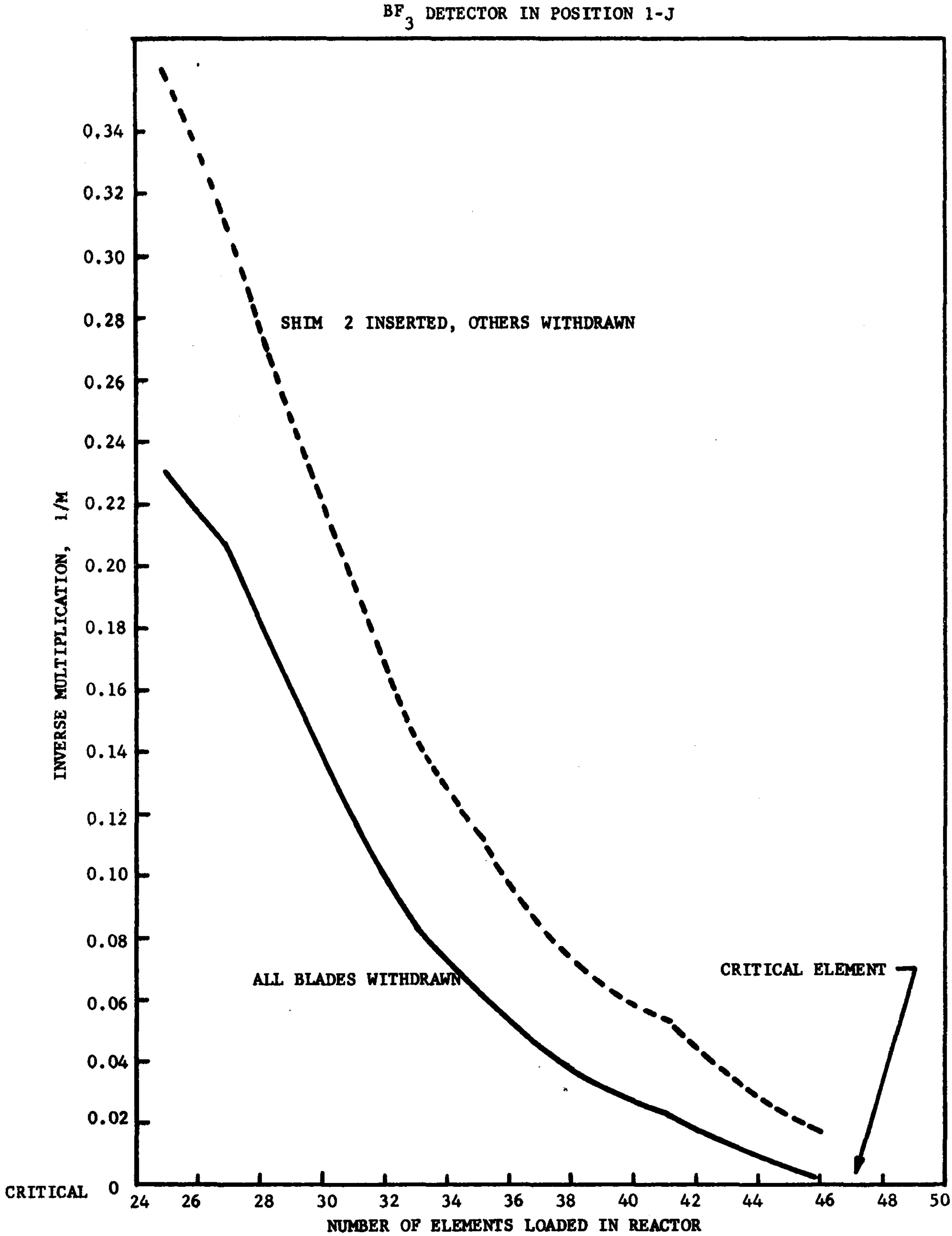
AN-IDOP-20
FIGURE 1



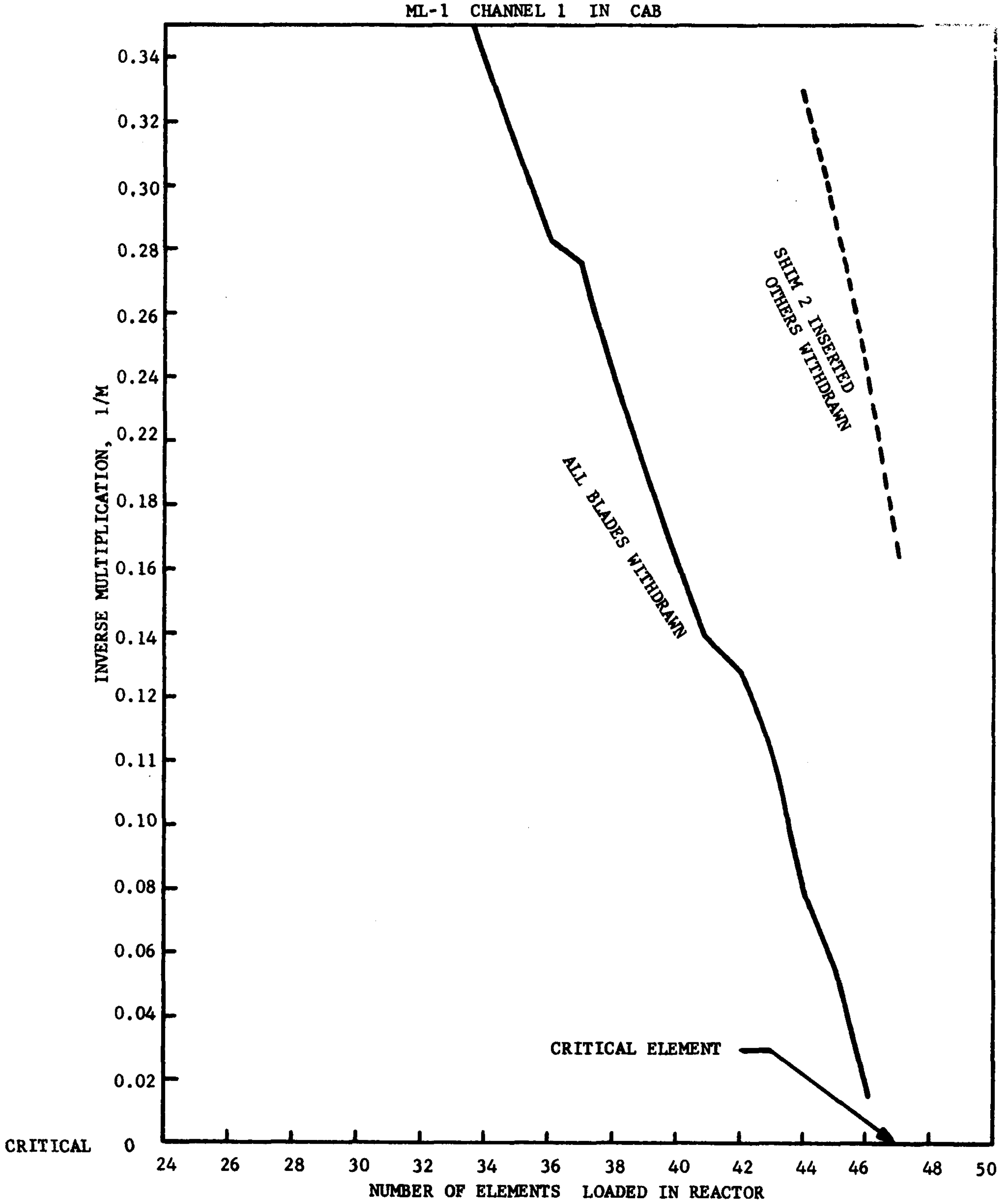
AN-IDOP-20
FIGURE 2



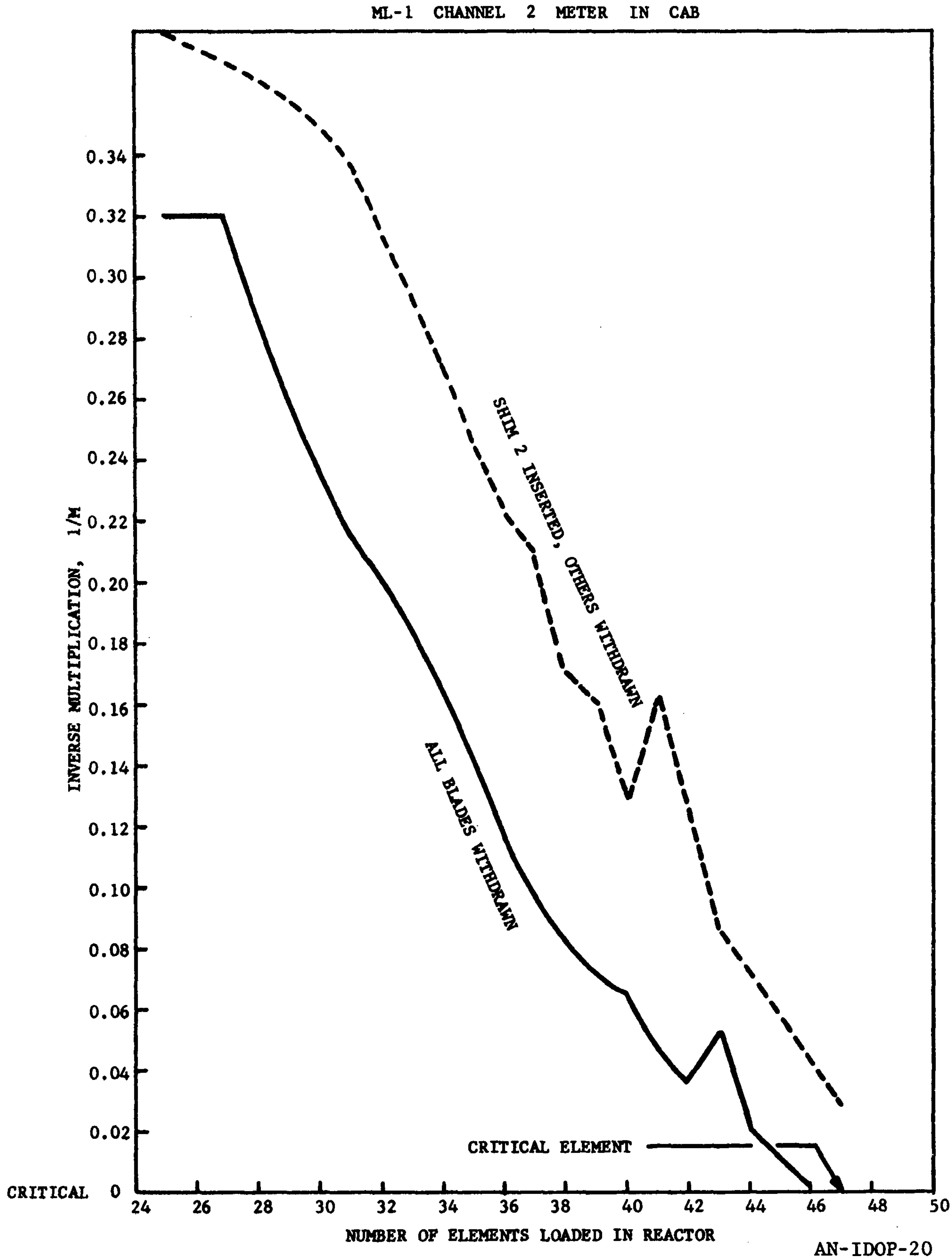
AN-IDOP-20
FIGURE 3



AN-IDOP-20
FIGURE 4



AN-IDOP-20
FIGURE 5



AN-IDOP-20
FIGURE 6

The procedural stop point for adding elements in pairs was overrun at element 33 by adding another pair. The information available at the ending of counting and plotting data on element 33 is summarized below:

Detector Position	1/M Value	Additional Elements Required for Critical, Predicted, X	Extrapolated Worth of Reg. and Shims 1 and 2 Blades, Y	Ratio: Y/X
1-A, BF_3	0.167	13-15	9-11	0.69-0.73
9-E, BF_3	0.162	12-18	4-5	0.28-0.33
1-J, BF_3	0.083	3-5	1-2	0.33-0.40
Ch. 1	0.37	10	5	0.50
Ch. 2	0.186	10	3	0.30

The procedural criteria for stopping element loading two at a time was if either 1/M value dropped below 0.10 or if the ratio Y/X became greater than 0.67. The data was in conflict; the detector data of position 1-A meeting one criteria, and detector in position 1-J the other. The additional number of elements required for criticality ranged 3-18, the minimum number being predicted from the 1-J data. A close study of this particular position showed the beginning of a concave upward curve, each successive 1/M increment being less than the preceding increment, indicating that probably many more than 3 elements would have to be loaded to attain criticality. On this basis, the experiment was expedited by loading one more pair of elements. Then commencing with the 36th element, fuel was loaded one element at a time.

No serious difficulty was encountered with this experiment. The several instrument scrams experienced beginning with the 31st element only delayed the procedure. These scrams appeared as spurious fast periods (internally) in Channels 1, 2, and 4 as either Shims or Safety blades began or ended their motion. Presumably these scrams were caused by noise in the nuclear instrument channels as the limit switches were triggered on these control blades. Since the early scrams were caused at the time Shim 2 reached the full out position, the condition was alleviated commencing with the 35th element, by requiring the Shims and Regulating blades to be withdrawn to only 70-76 degrees instead of the full out position of 80 degrees.

Commencing with the 43rd element, each successive element was loaded with the Regulating and all three Shim blades inserted. By this time, the Regulating and Shims 1 and 2 were beginning to be surrounded by fuel elements and were worth a significant 1/M value of shutdown reactivity. On the 45th element, the multiplication of Channel 2 threatened an instrument scram from the high level safety switch positioned on the Spare recorder (indicating Channel 2 in the control building) at 5×10^4 cps. This high level switch was moved to 5×10^5 cps to coincide with the high level switch of Channel 1 on the Log Count Rate recorder.

The counting and 1/M data for the 46th element showed clearly on all graphs that criticality would be reached on the 47th element. The 47th element was loaded and the counting with blades inserted was performed. Then the Regulating and Shim 1 and 3 blades were withdrawn to the 75 degree position and counting at this point was done. After a few trials with increments of Shim 2 withdrawal, the critical point was proven by first inserting the Regulating blades and withdrawing Shim 2 to 65 degrees, and then withdrawing the Regulating blades. At this time, 1355 hours, 30 March 1961, the reactor experienced a sustained positive period with a power rise of one decade before the experiment was terminated by a manual scram at 4×10^{-5} cps on Channel 2. The moderator water temperature was 70°F. The 47 element loading held 37.96515 Kg of U^{235}. The critical loading of 47 elements agrees closely with the predicted number of 48 elements.

The last two elements loaded into the reactor, numbers 46 and 47, were unloaded and placed in the ML-1 fuel vault. Due to the low power exposure during the critical, each element showed about 40 mr/hr activity on the surface.

DISCUSSION

The loading, control blade movements, and counting for each element or pair of elements took, on the average, 41 minutes when instrument scrams did not delay the procedure.

A perusal of the 1/M graphs for the five channels of neutron detectors shows some interesting facets.

The 1/M graph for the BF_3 detector in position 1-A, Figure 2, shows fairly straight lines. This detector position was surrounded early in the loading sequence; successive elements then just added to the core away from the detector. A critical loading of 45-47 elements could be predicted on the 31st element and this prediction did not change much during the remainder of the loading. Elements 36, 38, and 40, loaded near the detector, appear to be worth a bit more than elements 37, 39, and 41 which were loaded far from the detector. The incremental worth of Shim 3 appears large between the 42nd and 43rd element due to the close proximity of this control blade. This effect appeared because of the change in standard control blade positions during loading of an element. The Shim 2 blade appears to be worth as much as the other five blades together on the basis of these 1/M lines.

The data from the BF_3 detector in position 9-E is shown in Figure 3 as most unusual curves. Due to its location, one could expect lines similar to those shown for position 1-A. The scaler used with this detector failed on the 25th element and had to be serviced. When the scaler was on line again, the count rate had approximately doubled compared to the previous trend of data. On the 27th element, an arbitrary base count rate was selected to normalize the new counting data to the 1/M value of the 1-A position. Thus, all points shown on Figure 3 have the same arbitrary base and should be comparable for trend with the data on Figure 2. Shim 2, inserted, lies between the neutron source and the 9-E detector and shows as a large absorber. On the 35th element and later, Shim 2 was withdrawn to only 75 degrees (80 degrees is full withdrawn) for status as all blades withdrawn. Thus, the bump at 33-35 element is due to this partial insertion of Shim 2. Elements 37, 39, 42, 44, and 46, loaded near the detector position, show up as worth a bit more than the elements in between which were loaded far away from the detector. Element 41 counters this general trend of element worth.

The 1/M graph for the BF_3 detector in position 1-J, Figure 4, shows fairly smooth curves, concave upward so that the critical element is approached asymptotically. The loading sequence utilized builds towards this detector position. In general, based on previous GCRE critical experiments, this loading pattern and detector position always produce a concave curve. The curve always predicts a low number of elements for criticality, the prediction always increasing as more elements are loaded until criticality is attained.

The data from the Channel 1 meter in the control cab is shown in Figure 5. These 1/M points, in general, fall in a straight line (the two jogs have unknown cause), and 45-47 elements for criticality could be predicted from element 36. This detector is located outside the lead shielding behind the neutron source (see Figure 1) and so the core loading built away from this detector somewhat similarly to the 1-A detector, and produced a similar 1/M plot.

The data from the Channel 2 meter is shown in Figure 6 and resembles the concave curves for the detector in the 1-J position. The Channel 2 detector is located outside the lead shielding behind the 1-J detector, hence the similarity (the breaks have unknown cause). This channel predicted a low number of elements for criticality, the number again increasing as loading continued until criticality was attained.

The apparent worth of the Shim 2 control blades depends on which 1/M graph is extrapolated. The straight-line graphs, position 1-A and Channel 1 show Shim 2 to be worth 4.3-4.4 fuel elements. The concave curve graphs, position 1-J and Channel 2 show Shim 2 to be worth 2.5-2.9 elements. Based on the proven predictability of 1/M straight lines, 4 or 5 elements will have to be added to the present 47-element core loading for the next experiment, "Preliminary Control Blade Calibration," ANSOP 16202. At or near criticality, 1/M is about the same as $1-k_{eff}$. On this basis, Shim 2 is worth 7.8% (BF_3 in 1-A), 1.4% (BF_3 in 1-J), 21.6% (Ch. 1) or 3.7% $\Delta k/k$ (Ch. 2). Critical experiments at Battelle Memorial Institute showed a Shim worth of about 1.6% Δ k/k in comparison.

STATUS POINT AND DATA SUMMARY

Date	Time	Element Sequence Number	Core Position Loaded	Status Point	BF_3 Detector in 1-A Avg. CPM	1/M	BF_3 Detector in 9-E Avg. CPM	1/M	BF_3 Detector in 1-J Avg. CPM	1/M	ML-1 Channel 1 CPS	1/M	ML-1 Channel 2 CPS	1/M
3-29-61	0830			Initiated ANSOP 16200										
				Checked BF_3 counting systems.										
				Checked shield tank dry, drain line open, and outlet gas duct open.										
	through			Checked moderator water system per ANSOP 16068										
				Checked SAM system per ANSOP 14360.										
				Checked nuclear instruments per ANSOP 14060.										
				Checked control blade system per ANSOP 14080.										
				Checked battery-inverter emergency power supply per ANSOP 14300.										
	1450			Secured facility and assigned personnel.										
	1516			All blades withdrawn, background count without neutron source present.	147	-	114	-	133	-	-	-	-	-
	1523			All blades withdrawn, background count with source present.	1,504	-	2,891	-	1,037	-	700	-	60	-
	1600	1,2,3,4, 5,6,7,8, 9	2-A,3-A, 4-A,5-A, 2-B,6-B, 7-C,8-D, 8-E	Nine elements loaded, Reg., Shims inserted	2,855	-	4,923	-	1,252	-	1,000	-	65	-
	1625	-		Base count, all blades withdrawn	3,174	1.00	4,876	1.00	1,539	1.00	1,100	1.00	65	1.0
	1710	10, 11	3-B,7-D	Two elements loaded - Reg., Shims inserted (See Note 1)	3,280	0.97	4,820	1.01	1,380	1.12	1,100	1.00	80	0.81
	1800	12, 13	4-B,6-C	Two elements loaded, Reg., Shims inserted	3,920	0.81	5,920	0.82	1,540	1.00	1,200	0.92	75	0.86
	1815	14, 15	5-B,5-C	Two elements loaded, Reg., Shims inserted	4,750	0.67	7,040	0.69	1,904	0.81	1,600	0.69	90	0.72
	1828	16, 17	4-C,6-D	Two elements loaded, Reg., Shims inserted	5,500	0.58	7,380	0.66	2,200	0.70	1,700	0.65	85	0.76
	1842	-		Only Shim 2 inserted	5,540	0.57	8,270	0.59	2,240	0.69	1,700	0.65	85	0.76
	1855	-		All blades withdrawn	7,020	0.45	10,280	0.47	2,980	0.52	1,900	0.58	100	0.65
	1922	18, 19	1-B,8-F	Two elements loaded, Reg., Shims inserted	6,030	0.53	8,800	0.55	2,300	0.67	1,700	0.65	90	0.72
	1936	-		Only Shim 2 inserted	6,070	0.52	8,840	0.55	2,360	0.65	1,700	0.65	100	0.65
	1946	-		All blades withdrawn	8,100	0.39	12,200	0.40	3,220	0.48	1,900	0.58	140	0.46
	2010	20, 21	5-D,5-E	Two elements loaded, Reg., Shim 2 inserted	6,620	0.48	12,220	0.40	2,804	0.55	-	-	-	-
	2015	-		Only Shim 2 inserted	6,580	0.48	12,280	0.38	2,860	0.54	1,700	0.65	120	0.54
	2023	-		All blades withdrawn	8,680	0.37	17,700	0.274	4,040	0.38	2,000	0.55	160	0.41
	2057	22, 23	4-D,6-E	Two elements loaded, Reg., Shim 2 inserted	7,270	0.44	15,070	0.32	3,440	0.45	1,700	0.65	140	0.46
	2106	-		Only Shim 2 inserted	7,470	0.42	14,680	0.33	3,620	0.42	1,700	0.65	140	0.46
	2115	-		All blades withdrawn	9,860	0.32	19,680	0.248	5,040	0.30	2,000	0.55	170	0.38
	2138	24, 25	3-C,7-E	Two elements loaded, Reg., Shim 2 inserted	8,170	0.39	18,940	0.257	4,180	0.37	1,800	0.61	150	0.43
	2144	-		Only Shim 2 inserted	8,210	0.39	19,500	0.250	4,320	0.36	1,800	0.61	170	0.38
	2153	-		All blades withdrawn	11,770	0.270	See Note 2		6,700	0.230	2,300	0.48	200	0.32
	2215	26, 27	2-C,7-F	Two elements loaded, Reg., Shims 1,2 inserted	9,040	0.35	37,370	0.35	4,700	0.33	1,800	0.61	160	0.41
	2225	-		Only Shim 2 inserted	9,110	0.35	-	-	4,980	0.31	1,800	0.61	150	0.43
	2236	-		All blades withdrawn	13,630	0.233	-	-	7,470	0.206	2,500	0.44	200	0.32
	2300	28, 29	3-D,6-F	Two elements loaded, Reg., Shims 1,2 inserted	10,000	0.32	42,500	0.31	5,750	0.268	1,900	0.58	160	0.41
	2310	-		Only Shim 2 inserted	10,100	0.31	43,300	0.30	6,200	0.248	1,900	0.58	180	0.36
	2317	-		All blades withdrawn	15,150	0.210	66,400	0.197	9,690	0.159	2,800	0.39	250	0.26

Date	Time	Element Sequence Number	Core Position Loaded	Status Point	BF_3 Detector in 1-A Avg. CPM	1/M	BF_3 Detector in 9-E Avg. CPM	1/M	BF_3 Detector in 1-J Avg. CPM	1/M	ML-1 Channel 1 CPS	1/M	ML-1 Channel 2 CPS	1/M
3-29-61	2341	30, 31	4-E,5-F	Two elements loaded, Reg., Shims 1,2 inserted	10,840	0.293	46,400	0.282	7,460	0.206	2,000	0.55	190	0.34
	2348	-		Scram, See Note 3	-		-		-		-		-	
3-30-61	0005	-		Only Shim 2 inserted	11,080	0.287	48,000	0.272	7,840	0.196	2,000	0.55	190	0.34
	0012	-		All blades withdrawn	17,370	0.183	75,500	0.173	13,130	0.117	3,000	0.37	300	0.217
	0034	32, 33	4-F,3-G	Two elements loaded, Reg., Shims 1,2 inserted	12,000	0.264	50,040	0.261	10,010	0.154	2,000	0.55	200	0.32
	0041	-		Only Shim 2 inserted	11,870	0.267	51,590	0.254	10,760	0.143	2,000	0.55	220	0.295
	0045	-		Scram, See Note 3	-		-		-		-		-	
	0105	-		All blades withdrawn	19,050	0.167	80,560	0.162	18,570	0.0829	3,000	0.37	350	0.186
	0127	34, 35	3-F,4-G	Two elements loaded, Reg., Shims 1,2 inserted	12,200	0.260	53,000	0.247	12,600	0.122	2,000	0.55	220	0.295
	0136	-		Scram, See Note 3	-		-		-		-		-	
	0153	-		Only Shim 2 inserted	12,320	0.258	55,150	0.237	13,640	0.113	-		-	
	0155	-		Scram, See Note 3	8,540	0.37	38,670	0.34	8,400	0.183	-		-	
	0414	-		All blades withdrawn: Shim 1 to 70 deg., Shims 2, 3 and Reg. to 75 deg.	20,850	0.152	76,440	0.171	24,800	0.0620	3,500	0.314	450	0.144
	0430	36	3-E	One element loaded, Reg., Shims 1,2 inserted	13,190	0.240	54,920	0.238	14,460	0.106	2,000	0.55	250	0.260
	0442	-		Only Shim 2 inserted: Shim 1 at 70 deg. Shim 3 and Reg. at 75 deg.	13,580	0.234	57,670	0.227	16,050	0.0959	2,100	0.52	290	0.224
	0452	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 and Reg. to 75 deg.	23,350	0.136	76,920	0.170	29,120	0.0528	3,900	0.282	550	0.118
	0507	37	5-G	One element loaded, Reg., Shims 1,2 inserted	13,640	0.233	57,240	0.228	16,250	0.0947	2,200	0.50	290	0.224
	0514	-		Only Shim 2 inserted; Shim 1 at 70 deg., Shim 3 and Reg. at 75 deg.	14,390	0.221	60,750	0.215	18,550	0.0830	2,200	0.50	310	0.209
	0522	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 and Reg. to 75 deg.	25,400	0.125	79,200	0.165	35,000	0.0440	4,000	0.275	650	0.100
	0536	38	2-D	Element loaded, Reg., Shims 1, 2 inserted	15,140	0.210	59,500	0.220	18,500	0.0832	-		-	
	0540	-		Scram, See Note 3	-		-		-		-		-	
	0558	-		Only Shim 2 inserted, Shim 1 at 70 deg., Shim 3, Reg., at 75 deg.	16,180	0.196	62,660	0.209	21,050	0.0731	2,400	0.46	380	0.171
	0607	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 and Reg. to 75 deg.	29,600	0.107	84,740	0.154	41,790	0.0368	4,500	0.244	800	0.081
	0621	39	6-G	Element loaded, Reg., Shims 1, 2 inserted	15,790	0.201	62,170	0.210	20,130	0.0765	2,400	0.46	380	0.171
	0631	-		Only Shim 2 inserted, Shim 1 at 70 deg., Shim 3, Reg. at 75 deg.	16,940	0.187	65,760	0.199	24,030	0.0640	2,500	0.44	400	0.162
	0639	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 and Reg. to 75 deg.	33,250	0.0954	96,620	0.135	50,260	0.0306	5,200	0.212	900	0.072
	0653	40	1-C	Element loaded, Reg., Shims 1, 2 inserted	17,540	0.181	63,170	0.207	21,950	0.0701	2,500	0.44	400	0.162
	0702	-		Only Shim 2 inserted, Shim 1 at 71 deg., Shim 3 at 75 deg., Reg. at 76 deg.	18,860	0.168	65,890	0.198	26,220	0.0587	2,600	0.42	500	0.130
	0709	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 to 75 deg., Reg. to 76 deg.	38,710	0.0820	104,600	0.125	57,110	0.0269	6,000	0.183	1,000	0.065
	0735	41	7-G	Element loaded, Reg., Shims 1, 2 inserted	18,080	0.176	65,150	0.201	23,370	0.0658	2,000	0.55	400	0.162
	0741	-		Only Shim 2 inserted, Shim 1 at 70 deg., Shim 3 at 75 deg., Reg. at 76 deg.	20,040	0.158	68,920	0.190	28,600	0.0538	3,000	0.37	400	0.162
	0747	-		All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 to 75 deg., Reg. to 76 deg.	43,240	0.0734	108,100	0.121	66,540	0.0231	7,000	0.157	1,400	0.046
	0806	42	3-H	Element loaded, Reg., Shims 1, 2 inserted	18,740	0.169	66,090	0.198	29,090	0.0529	1,700	0.65	500	0.130

Date	Time	Element Sequence Number	Core Position Loaded	Status Point	BF_3 Detector in 1-A Avg. CPM	BF_3 Detector in 1-A 1/M	BF_3 Detector in 9-E Avg. CPM	BF_3 Detector in 9-E 1/M	BF_3 Detector in 1-J Avg. CPM	BF_3 Detector in 1-J 1/M	ML-1 Channel 1 CPS	ML-1 Channel 1 1/M	ML-1 Channel 2 CPS	ML-1 Channel 2 1/M
3-30-61	0815	-		Only Shim 2 inserted	20,920	0.152	68,850	0.190	35,150	0.0438	-		-	
	0825			All blades withdrawn, Shim 1 to 70 deg., Shims 2, 3 to 75 deg., Reg. to 76 deg.	48,400	0.0656	121,400	0.108	86,650	0.0178	7,500	0.147	1,790	0.038
	0843	43	2-G	Element loaded, Reg., all Shims inserted	18,200	0.174	66,690	0.196	28,990	0.0531	1,800	0.61	500	0.130
	0902	- -		Scram, three times in succession, See Note 3	-		-		-		-		-	
	0929	-		Only Shim 2 inserted, Reg., Shims 1, 3 at 75 deg.	22,640	0.140	67,580	0.194	44,210	0.0348	2,000	0.55	750	0.086
	0938	-		All blades withdrawn, Reg., Shims 1, 2, 3 to 75 deg.	57,090	0.0556	137,100	0.0954	120,200	0.0128	9,000	0.122	1,290	0.054
	0958	44	4-H	Element loaded, Reg., and all Shims inserted	18,860	0.168	63,840	0.205	33,080	0.0465	2,700	0.41	500	0.130
	1010	-		Only Shim 2 inserted, Reg., Shims 1, 3 at 75 deg.	25,140	0.126	69,800	0.187	55,481	0.0277	3,300	0.33	900	0.072
	1020	-		All blades withdrawn, Reg., Shims 1, 2, 3 to 75 deg.	73,600	0.0431	180,800	0.0723	172,400	0.0089	14,000	0.079	3,100	0.021
	1038	45	2-F	Element loaded, Reg. and all Shims inserted	20,290	0.156	66,160	0.198	37,830	0.0407	2,900	0.36	650	0.100
	1053	-		Scram, twice in succession, See Notes 3 and 4	-		-		-		-		-	
	1127	-		Only Shim 2 inserted, Shims 1, 3 at 75 deg., Reg. at 77 deg.	28,810	0.110	68,150	0.192	69,090	0.0223	3,800	0.29	1,100	0.059
	1137	-		All blades withdrawn, Shims 1, 2, 3 at 75 deg., Reg. at 77 deg.	108,600	0.0291	145,900	0.0668	289,000	0.0053	20,000	0.055	6,000	0.011
	1203	46	5-H	Element loaded, Reg. and all Shims inserted	21,210	0.150	69,360	0.139	42,830	0.0359	3,000	0.37	700	0.093
	1217	-		Only Shim 2 inserted, Shims 1, 3, Reg. at 75 deg.	33,860	0.0937	68,910	0.139	90,230	0.0171	4,500	0.24	1,500	0.043
	1230	-		All blades withdrawn, Shims 1,2,3 and Reg. at 75 deg.	237,000	0.0134	410,100	0.0519	750,000	0.0020	75,000	0.015	20,000	0.003
	1256	47	2-E	Element loaded, Reg. and all Shims inserted	22,560	0.141	70,230	0.136	See Note 5		3,000	0.37	800	0.081
	1311	-		Only Shim 2 inserted, Shims 1, 3 and Reg. at 75 deg.	42,540	0.0746	73,490	0.178	-		6,000	0.183	2,100	0.031
	1355	-		Reactor critical on sustained positive period, Reg Shim 1 and 3 at 80 deg., Shim 2 at 65 deg. Terminated by manual scram	-		-		-		-		-	
	1412	-		Removed two elements from reactor leaving subcritical loading of 45 elements.	-		-		-		-		-	

NOTES

General

Scaler	BF_3 Detector Position
Hamner Electronics Co., Model N-240	1-A
Radiation Instrument Development Laboratory	9-E
Tracerlab Superscaler	1-J

1. Testing of the BF_3 channels and the base counting was done when the John Fluke power supply was connected into an unregulated source. Since the counting then showed randomness in excess of the expected Poisson distribution, the power supply was reconnected into a regulated source. The 1/M value of 1.01 for the BF_3 detector in 9-E is within the 95 percentile, the 1/M value of 1.12 for the 1-J position is outside the 95 percentile and must be due to the difference in power supply source.

2. The Radiation Instrument Development Laboratory scaler, after a history of apparently satisfactory operation, quit counting altogether at this time. The fault was remedied by installing new tubes in the amplifier section of the scaler. When the count rate for the 27th element was taken, the result was high, almost double the count to be expected based on extrapolation of the 1/M graph. For the remainder of the counting, an arbitrary new base count rate was selected to normalize the 27th element to a 1/M value of 0.35, a value identical to that shown by the detector in 1-A position. Thus all points shown on Figure 3 are computed on the arbitrary base count rate of 13,079 cpm.

3. A total of 15 instrument scrams are noted in the Control Cab Log by the cab operator. These scrams were indicated as fast periods on Channel 1 (seven times), Channel 2 (four times), Channel 4 (twice) and unassigned (twice). For the most part, these scrams were not indicated on the period meter or the recorder in the control building but just on the annunciator panel. Each scram went through to completion; all control blades inserted automatically, the usual consequence of a scram signal. An attempt to determine cause for these scrams showed some correlation between a control blade triggering either the "In" or "Out" limit switch and the scram; both safeties and shims seemed prone to this sort of scram. Proceedings on the 35th element were held up while the cables at the reactor, junction box, and control cab wer rerouted to separate the nuclear channel wires from the control blade wires. This attempt to reduce the limit switch-induced noise in the nuclear channels was partially successful, but a few more scrams were experienced. Also on the 35th and subsequent elements, only the two Safety blades were withdrawn fully; all other control blades were withdrawn to only 70-76 degrees to eliminate the "Out" limit switch noise.

4. Multiplication, due to the core loading at the 45th element, had risen enough to threaten an instrument scram from the high level safety switch positioned on the Spare recorder at 5×10^{-4} cps. This recorder indicated Channel 2 in the control building and was calibrated (inadvertently) to indicate about twice the Channel 2 meter value in the control cab. During this scram, this high level switch was repositioned to 5×10^{-5} cps.

5. The Tracerlab Superscaler, which had a history of skipping digits in the 1,000 and 10,000 cpm range, finally ceased to operate. Since the experiment was just about completed, no attempt was made to repair this scaler; the two remaining scalers being sufficient to satisfy the safety requirements of the procedure.

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Date: 9 May 1961
Standard Distribution

M E M O R A N D U M

TO: R. H. Chesworth

FROM: R. D. Peak

SUBJECT: OPERATING CORE DETERMINATION FOR ML-1 (ANSOP 16208)

SUMMARY

During the period of 17 and 18 April 1961, the number and location of shim liners required to attain the desired excess reactivity was determined for the clean, cold, operating core loading of 61 fuel elements. This experiment was terminated with 28 heavy shim liners (0.0095 inch thick steel tubing with 0.0046 inch of silver plating) loaded about the center of the core. The final excess reactivity was estimated to be 1.20 - 1.44% Δ k/k for a moderator water temperature of 73°F. The excess reactivity quoted is preliminary and includes the reactor cover (tungsten baffle) worth of 0.14 - 0.20% Δ k/k. The 61 element core loading contained 49.25154 kgs. of U^{235}.

INTRODUCTION

The ML-1 reactor must be operated with 61 fuel elements to minimize the gas coolant pressure drop through the core and obtain the required amount of heat transfer area. At the beginning of the core lifetime (clean core), the desired excess reactivity is 3.7% Δ k/k at operating temperature and pressure to accommodate uranium fuel burnup, fission product poison accumulation, etc., during the lifetime of the core. The design philosophy of the fuel elements was to use extra fuel in the core by overloading each element to assure achievement of this desired excess reactivity should criticality calculations be in error. The "overloaded" excess reactivity was to be poisoned by silver-plated, stainless steel shim liners surrounding the outer liner of one or more fuel elements. By varying the number of shim liners installed in the core, the initial excess reactivity could be varied to attain the desired value.

The operating excess reactivity of 3.7% Δ k/k is equivalent to a cold excess reactivity of about 1.5% Δ k/k (at a moderator water temperature of 68°F) due to the influence of temperature and pressure coefficients of reactivity. This cold excess reactivity is predicated based upon the shield tank full of boric acid solution and the reactor cover (with tungsten baffle) in place. The "Operating Core Determination," ANSOP 16208, required the shield tank to be one-half full of 2% boric acid solution and the reactor cover to be off to allow fuel element and shim liner loading and installation operations in the core.

The worth of the reactor cover and a half tank of shield water solution was determined in a preliminary experiment reported by D.R. Mathews and R.D. Peak.[1] Using minimum and maximum worths of Shim 2 determined by the rod drop method, the installation of the reactor cover was worth +0.11 to +0.15% $\Delta k/k$ and the filling of half the shield tank was worth less than -0.01% $\Delta k/k$ for the 47 element core loading. For the final 61 element core loading, reflector area considerations indicated that the reactor cover might be worth +0.14 to +0.20% $\Delta k/k$ and the worth of the remaining half tank of shield water solution could be neglected. Thus, the excess reactivity desired at the termination of this experiment was about 1.50% - 0.14 to -0.20% = 1.30 to 1.34% $\Delta k/k$ with a moderator water temperature of about 68^{o}F.

CONDUCT OF THE EXPERIMENT

The reactor had been shutdown following the termination of ANSOP 16204, "Reactivity Worth of Tungsten Baffle and Shield Water," on 7 April 1961. For safety considerations during the week-long shutdown, the reactor was maintained with the reactor cover off and a core loading of 45 fuel elements.

This procedure, ANSOP 16208, was initiated in the morning of 17 April. The BF_3 detectors which had been located about the reactor for the rod drop measurements were rewrapped with cadmium foil and replaced in the three peripheral fuel element positions: 1-A, 9-E, and 1-J. The scalers for these three detectors are listed in Appendix A. With the remainder of the checkout complete, fuel loading was initiated at 1430 hours to reattain the initial critical loading of 47 fuel elements, the starting condition for the operating core determination experiment.

As an aside, a recheck of the control rod positions for criticality with the 47 element core was made. These data, which are tabulated along with the status and counting data in Appendix A, indicated that criticality was attained (LCR at 1.7 x 10^5 cps) with all rods out but Shim 2, which was at 69.4^o, and the moderator water temperature was 74^{o}F. This Shim 2 position was significantly different from the similar criticality with the shield tank half full on 7 April 1961. At this time Shim 2 was at 54.7 degrees, with the moderator water temperature at 73.3^{o}F.

To resolve the differences between these two critical determinations, the core loading was rechecked. At this time, the Control Center Supervisor discovered that the element, ML-1-46, had been loaded into position 2-H instead of position 5-H, an operator error with the "Fuel Element Handling Schedule," ANSOL 5758. With element 46 in the 5-H position (see Figure 1), criticality was attained with Shim 2 at 62.9 degrees with the moderator water temperature of 70^{o}F. Further resolution of the differences took cognizance of the cadmium foils around the three BF_3 detectors in the peripheral core positions. These foils, present on 17 April but not on 7 April were localized poisons which required the additional withdrawal of Shim 2.

FUEL ELEMENT NUMBERS
ML-1-XX

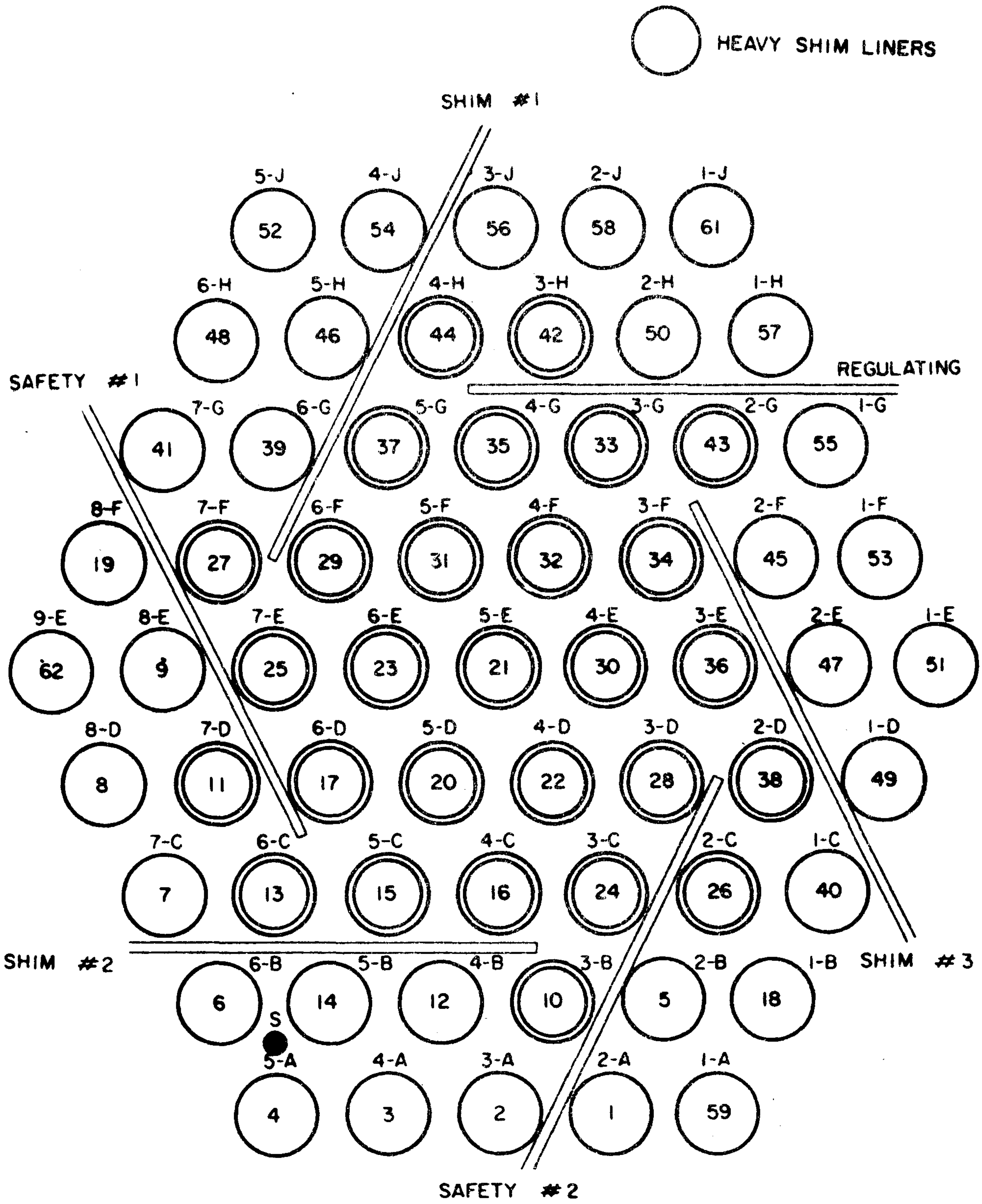

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FIGURE 1

With the criticality differences resolved and procedure step B-6 counting complete, shim liner installation was begun. The number of shim liners had been initially estimated by L. M. Maki[2] to be 30-34 heavy silver (0.0095 inch thick stainless steel with silver plating of 0.0046 inch thickness) liners based on an initial critical loading of 47 elements. However, a later estimate by L. M. Maki[3] using PDQ computer problems, was that only 24 heavy liners would be required. Thus as a start, 22 heavy shim liners were installed around the 22 central fuel elements as shown in Figure 1. The first base count (Regulating and Shim rods in) was taken according to procedure step B-8.

Fuel loading commenced and continued by loading two elements at a time until criticality was attained with the 57th element with all rods out but Shim 2 which was at 63.8 degrees. This criticality was not predicted by the 1/M plots of the counting data with all detectors; only the BF_3 detector in 1-J and Channel 2 predicted with accuracy as shown in Figures 2 and 3.

Two more heavy shim liners were installed and the rod positions for the previous criticality was repeated (all rods out but Shim 2 at 63.3 degrees) for counting purposes. Interpretation of the 1/M data indicated that 2 heavy shims were equivalent to 0.8 element (BF_3 in 1-A), 0.7 element (BF_3 in 9-E), 0.7 element (Channel 1) and 0.5 element (Channel 2).

The 58th element was loaded. Interpretation of the 1/M data for the condition of all rods out but Shim 2 indicated that 2 heavy shims were equivalent to 0.4 element (BF_3 in 1-A), 0.5 element (BF_3 in 9-E), 0.5 element (BF_3 in 1-J), 0.6 element (Channel 1) and 0.7 element (Channel 2). Roughly then, 3 heavy shim liners would compensate for one additional fuel element.

Criticality was attained with the 58th element with all rods out but Shim 2 at 51.1 degrees. No further fuel elements could be loaded without removing the BF_3 detectors from the last peripheral core positions. Because of the cadmium foil wrappers about the BF_3 detectors, the procedure at step B-30 was altered so that the BF_3 detectors were removed all at once instead of one at a time.

The BF_3 detectors were relocated as follows: one BF_3 detector was installed in a pipe well on the power conversion side of the shield tank (P.C. Side) about 51 inches from the core centerline; one BF_3 detector was installed in a pipe well on the opposite side of the shield tank (Rear Side) about 51 inches from the core centerline. These two positions were identical with those used previously during the preliminary control rod calibration experiment. The third BF_3 detector was slid up the outlet gas duct and around the first elbow out of sight to place it under the reactor (Outlet Gas Duct) but not directly under the core, a new and different position.

BF_3 DETECTOR POSITIONS

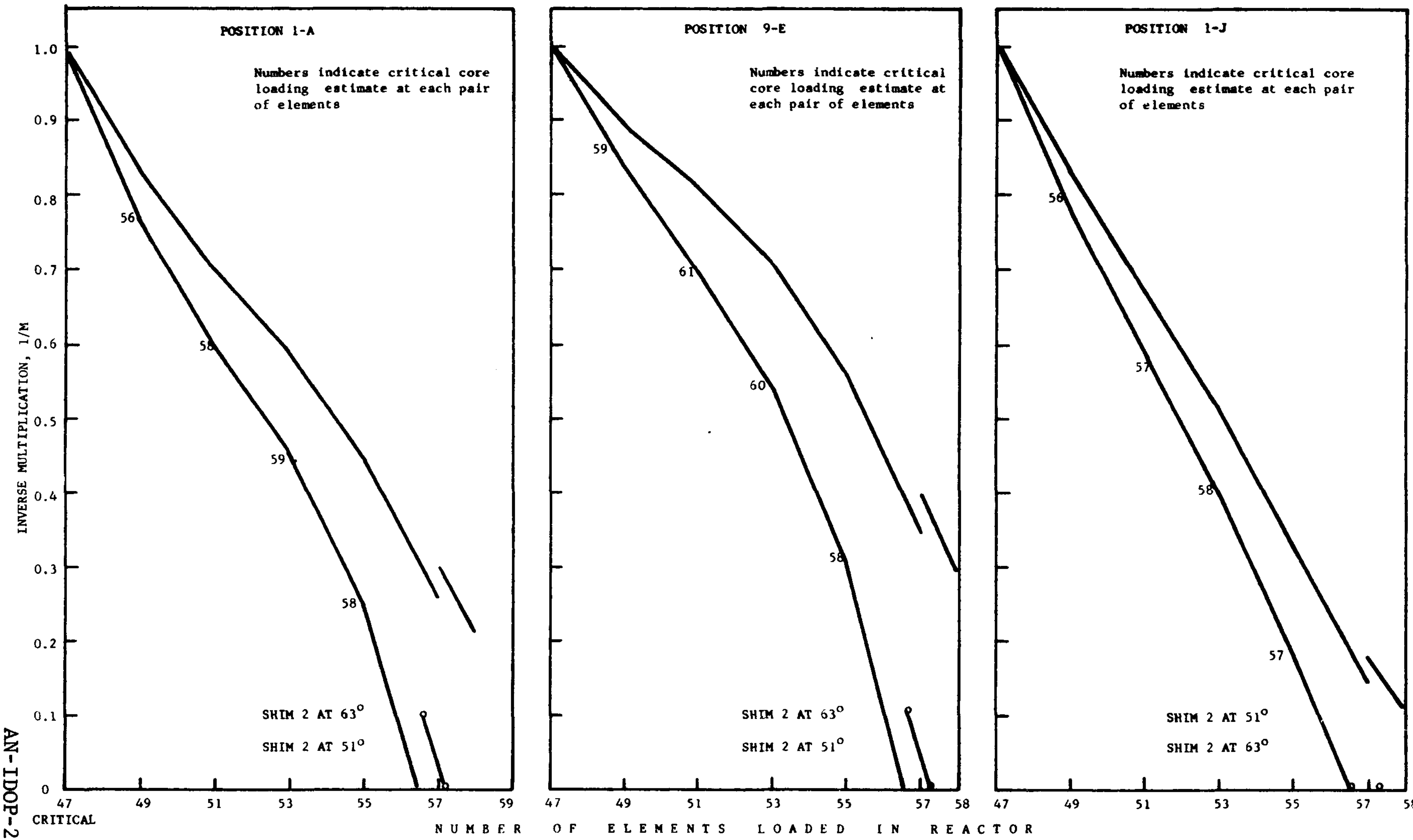
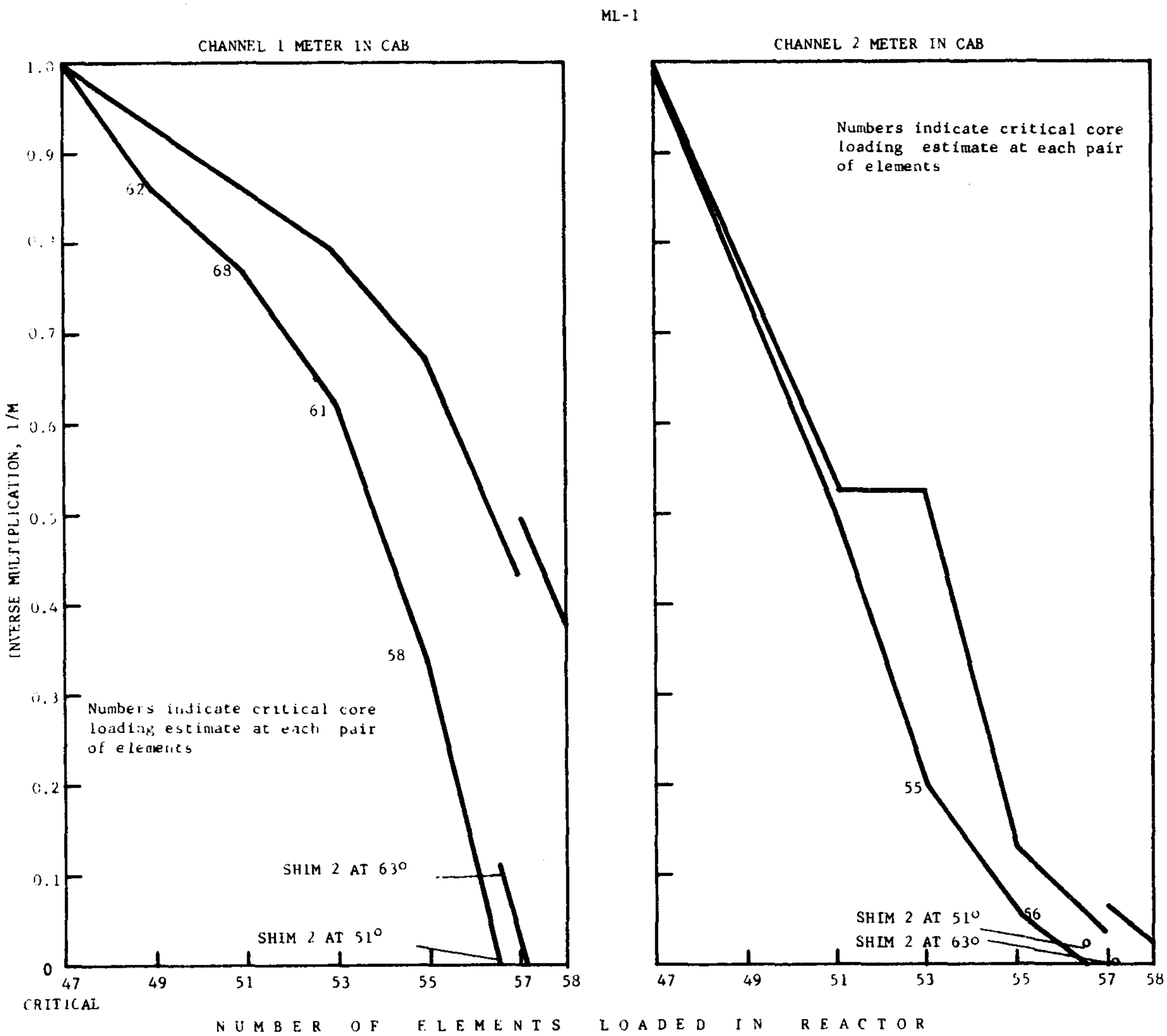


FIGURE 2
AN-IDOP-29



AN-IDOP-29
FIGURE 3

With the BF_3 detectors relocated, the 1/M plots could not be used for prediction and evaluation purposes during subsequent fuel loading and shim installations. Instead, the remaining work was based on the results of rod drop worth measurements after each criticality was attained.

Element 59 was loaded concurrent with the installation of the 25th shim liner. Then, a rod drop of Shim 2 was run which resulted in the interruption of the experiment described in the next two paragraphs. Once the experiment was resumed, element 60 was loaded and the worth of Shim 3 was measured with a rod drop. Element 61 was loaded concurrent with the installation of shim liners 26 through 31. The results of two more rod drops indicated that about 3 too many shim liners had been installed. These 3 liners were removed leaving only 28 installed in the core. The final criticality was terminated in a scram rod drop of all rods to measure the shutdown margin of reactivity of the final core loading.

The experiment was interrupted after the first rod drop at 0357 hours, 18 April. At this time, the Shim 2 rod was scrammed from the clutch power switch box in the auxiliary control building (box installed especially for rod drop tests as described in ANSOP 16202) and then the Regulating and Shims 1 and 3 were similarly scrammed. For some undetermined reason, the position indicators in these latter three rods showed 15 degrees at the end of their scram actuation whereas the "Rod In" limit lights glowed. A test of the Regulating rod showed 13 seconds to actuate full out and 13 seconds to actuate full in, the nominal stroke time for this rod. "Low Power Reactor Shutdown," ANSOP 14023 was initiated at 0500.

Beginning with a fresh crew at 0800, the position indicators for the Regulating and Shims 1 and 3 were readjusted to read correctly. Then the checkout of ANSOP 16208 was completed so that the previous criticality and rod drop could be duplicated. However, the rod drop at 1833 was voided; no scalers started correctly when Shim 2 was scrammed. This electrical relay fault was repaired and the 60th element loaded.

The experiment was terminated with the rod drop of all rods. "Final Control Rod Calibration," ANSOP 16210, was initiated immediately, since the essentials of the necessary checkout had been completed and the three BF_3 detectors were located in favorable positions for rod drop measurements. The results of the final control rod calibration will be reported in a later document.

DISCUSSION

The description of the method and evaluation of rod drop data has already been reported by D.R. Mathews and R.D. Peak[1] in connection with the preliminary calibration of Shim 2. This prior experience with the method may be compared with the rod drop data obtained during this experiment when elements 59 to 61 were loaded. These data, tabulated in Appendix A, are summarized below.

ROD DROP REACTIVITY DATA

Data at Critical						Reactivity Worth at Each Detector Position, % $\Delta k/k$		
Time Attained, hours	Core Loading: Elements,	Liners	All Control Rods Out Except Shim;	Position, Degrees	Rods Dropped	P.C. Side	Rear Side	Outlet Gas Duct
0346	59;	25	Shim 2	31.4	Shim 2	0.55	0.44	0.58
1924	60;	25	Shim 2	12.2	Shim 3	1.69	1.06	1.52
2047*	61;	31	Shim 2	30.4	Shim 1	1.40	1.28	1.34
2116	61;	31	Shim 1	34.8	Shim 2	1.36	1.16	1.52
2253	61;	28	Shim 2	13.2	All rods	4.55	4.92	5.24

*Moderator water temperature at 73°F.

The bias of each detector position noted previously during the preliminary rod calibration is evident in these data; the Rear Side detector continued to give a low value for the worth but now the Outlet Gas Duct alternates with the P.C. Side detector for the high value of worth. In view of these biases, no definite worth was attributed to each drop measurement. Instead the minimum and maximum values were considered to bracket the probable true worth and are utilized in the following evaluation.

The worth of individual shim rods, ranging between 1.06 and 1.69% $\Delta k/k$ is significantly smaller in this shimmed 61 element core than the worth of Shim 2 had been measured to be in the 51 element core (worth of 1.91 - 2.33% $\Delta k/k$). Although the worths of these rods were different, the shape of the worth-position curve was assumed to be similar to that determined in the preliminary rod calibration. For example, the first rod drop measured the worth of Shim 2 from 31.4 degrees to be 0.44 - 0.58% $\Delta k/k$, whereas the preliminary calibration gave the worth of Shim 2 at the same position as 0.86 - 0.92% $\Delta k/k$. Since the shape of the worth-position curves are similar, simple ratio indicates that the worth of Shim 2 in this core is 1.06 - 1.46% $\Delta k/k$ and by difference, the excess reactivity of the 59 element, 25 liner core is 0.62 - 0.88% $\Delta k/k$. Computations of this nature were carried out to determine the excess reactivity for each criticality. The excess reactivities were also related to the differences in core loadings as shown in the summary on the following page.

Criticality Status

Time, hours	Core Loading: Elements;	Liners	Excess Reactivity, + % $\Delta k/k$	Worth of Elements and Shim Liners, % $\Delta k/k$
0346	59;	25	0.62 to 0.88	--
--				Element worth +0.32 to +0.57
1924	60;	25	0.94 to 1.45	--
--				Element and 6 liners worth -0.17 to -0.58
--				2 elements and 6 liners worth +0.15 to -0.01
2047	61;	31	0.77 to 0.87	--
--				Element and 6 liners worth -0.31 to -0.63
--				2 elements and 6 liners worth +0.01 to -0.06
2116	61;	31	0.63 to 0.82	--
--				Element and 3 liners worth +0.12 to -0.21
--				2 elements and 3 liners worth +0.44 to +0.36
2253	61;	28	1.06 to 1.24	--

These data confirm to a great extent the preliminary worth of a peripheral fuel element[1] as being about +0.42% $\Delta k/k$. Also these data confirm the previous 1/M evaluation that 3 heavy shim liners will approximately compensate for the addition of one fuel element.

As noted in the introduction, the installation of the reactor cover (with tungsten baffle) is worth +0.14 to +0.20% $\Delta k/k$; the filling of the remaining half tank of shield water solution is a worth value that could be neglected. Thus, the final excess reactivity of the 61 element core having 28 shim liners, reactor cover in place and a full shield tank, is estimated to be +1.20 to +1.44% $\Delta k/k$. A better value of this excess reactivity will be determined during the final control rod calibration experiment. At this time, the excess reactivity is probably within the limits set by the procedure, viz., +1.30 to +1.70% $\Delta k/k$.

The final loading of 61 fuel elements contained 49.25154 kgs. of U^{235} in 58 standard fuel elements and 3 instrumented fuel elements. The instrumented elements were required to fill out the complete loading since not enough extra standard elements were available. These instrumented elements were loaded into peripheral positions as noted in Appendix B. This loading was an expedient for the purposes of approximating the operating core loading desired. Actually the fuel element positions will be altered somewhat during subsequent experiments but prior to August 1961, the ten instrumented elements will be loaded according to the pattern by D.M. Elliott.[5]

A, DATA SUMMARY

1. All counting for 1/M plots was taken with the BF_3 detectors in the peripheral core positions of 1-A, 9-E, and 1-J, identical with the initial critical experiment. Before reinstalling these detectors into these core positions, each detector was wrapped with one 0.020 inch thick cadmium foil on top of any previous foil wraps. The scaler connections and accumulated foil wraps are summarized below.

BF_3 Position	Cadmium Foil	Scaler Connections
1-A	One wrap of foil	Hamner Electronics Co., Model N-240
9-E	One wrap on top of 3/4 wrap of foil	Radiation Instrument Development Laboratory
1-J	Two wraps of foil	Tracerlab Superscaler

2. All counting for the rod drop tests were taken after the BF_3 detectors had been relocated and in most cases after the cadmium foil wraps[3] had been removed. The P.C. Side detector position and the Rear Side detector position were identical with the positions previously described by D.R. Mathews and R.D. Peak[1], in pipe wells about 51 inches radially from the core centerline. However, the third detector was slid up the outlet gas duct and around the elbow. This places the detector somewhere under the side of the core, downstream of the elbow below the lower tungsten baffle. The cadmium foil wraps and scaler connections are as follows:

BF_3 Position	Cadmium Foil	Scaler Connections
P.C. Side	None, all removed	Hamner Electronics Co., Model N-240
Rear Side	One wrap removed leaving only 3/4 wrap	Radiation Instrument Development Laboratory
Outlet Gas Duct	None, all removed	Tracerlab Superscaler

3. The first rod drop at 0357 preceded an interruption of the experiment due to malfunction of the position indicators of the Regulating and Shims 1 and 3. This shutdown was discussed in the text of the memorandum.

B, FINAL CORE LOADING

The reactor core loading at the termination of the operating core experiment is summarized below. Fuel element serial numbers, shim liner locations, uranium loading, etc., are noted for each core position. Note that three instrumented fuel elements, No's 59, 61, and 62 were loaded in peripheral positions for convenience during the subsequent low power critical experiments. Thus this core loading is not final, the operating core for

STATUS POINT AND DATA SUMMARY

Date	Time, hours	Element, Liner Sequence Number	Core Position Loaded	Status Point	BF$_3$ Detector in 1-A Avg. cpm	BF$_3$ Detector in 1-A 1/M	BF$_3$ Detector in 9-E Avg. cpm	BF$_3$ Detector in 9-E 1/M	BF$_3$ Detector in 1-J Avg. cpm	BF$_3$ Detector in 1-J 1/M	ML-1 Channel 1 cps	ML-1 Channel 1 1/M	ML-1 Channel 2 cps	ML-1 Channel 2 1/M
4-17-61	0830			Initiated ANSOP 16208 with reactor cover off and a 45 fuel element core loading										
				Installed BF$_3$ detectors										
				Checked shield tank was 1/2 full of 2% boric acid solution										
				Startup up moderator water system										
				All rods in, background count	33,500		68,500		38,500		-		-	
	1440	46, 47	2-H, 2-E	Two elements loaded, Safety 1 & 2 out	37,760		71,670		48,460		-		-	
	1512	-		All rods in	19,440		42,100		25,950		200		3	
	1641	-		Only Safety 1 and 2 out	37,810		71,360		48,470		370		10	
	1738	-		Critical, all rods out except Shim 2 at 69.4 deg., moderator water temperature 74° F	-		-		-		1.7 x 10^5		1.5 x 10^3	
	1837	46	5-H	Moved element from 2-H to 5-H, Safety 1 and 2 out	23,840	-	73,460	-	48,450	-	390	-	9	-
	1900	-		Critical, all rods out except Shim 2 at 62.9 deg., moderator water temperature 70° F							2 x 10^5		5 x 10^3	
	1950	Liners 1 thru 22	5-E, 5-D, 4-D, 4-E, 4-F, 5-F, 6-E, 6-D, 5-C, 4-C, 3-C, 3-D, 3-E, 3-F, 3-G, 4-G, 5-G, 6-F, 7-E, 2-G, 3-B, 7-F	Twenty two heavy shim liners installed, Safeties 1 and 2 out, base count of Step 8	15,890	1.00	43,300	1.00	20,050	1.00	260	1.00	8	1.00
	2013	-		Only Shim 2 in, base count of Step 13	20,070	1.00	51,740	1.00	30,780	1.00	-		-	
	2019	-		All rods out, base count of Step 15	37,180	1.00	89,420	1.00	56,910	1.00	500	1.00	25	1.00
	2055	48, 49	6-H, 1-D	Two elements loaded, Reg. and Shims in	18,070	0.88	45,920	0.95	22,580	0.89	-	-	-	-
	2111	-		Only Shim 2 in; Reg., Shims 1 and 3 at 75 deg.	24,050	0.83	57,840	0.89	37,330	0.82	-	-	-	-
	2122	-		All rods out; Reg., and Shims at 75 deg.	47,930	0.78	107,600	0.83	72,920	0.78	580	0.86	15	1.66
	2142	50, 51	2-H, 1-E	Two elements loaded, Reg. and Shims in	20,010	0.79	48,180	0.91	25,310	0.79	-	-	-	-
	2155	-		Only Shim 2 in; Reg., Shims 1 and 3 at 75 deg.	28,710	0.70	63,790	0.81	45,790	0.67	350	0.86	25	0.52

STATUS POINT AND DATA SUMMARY

Date	Time, hours	Element, Liner Sequence Number	Core Position Loaded	Status Point	BF_3 Detector in 1-A Avg. cpm	BF_3 Detector in 1-A 1/M	BF_3 Detector in 9-E Avg. cpm	BF_3 Detector in 9-E 1/M	BF_3 Detector in 1-J Avg. cpm	BF_3 Detector in 1-J 1/M	ML-1 Channel 1 cps	ML-1 Channel 1 1/M	ML-1 Channel 2 cps	ML-1 Channel 2 1/M
4-17-61	2205	- -		All rods out; Reg. and Shims at 75 deg.	61,660	0.60	128,700	0.70	96,810	0.59	650	0.77	50	0.50
	2223	52, 53	5-J, 1-F	Two elements loaded, Reg. and Shims in	21,650	0.73	50,560	0.87	29,220	0.69	-	-	-	-
	2239	-		Only Shim 2 in; Reg., Shims 1 and 3 at 75 deg.	33,900	0.59	72,960	0.71	59,480	0.52	380	0.79	25	0.52
	2247	-		All rods out; Reg. and Shims at 75 deg.	81,460	0.46	164,700	0.54	141,600	0.40	800	0.62	125	0.20
	2309	54, 55	4-J, 1-G	Two elements loaded, Reg. and Shims in	23,820	0.67	53,300	0.82	36,700	0.55	300	0.87	20	0.40
	2314	-		Only Shim 2 in; Reg., Shims 1 and 3 at 75 deg.	44,870	0.45	92,230	0.56	93,700	0.33	450	0.67	100	0.13
	2324	-		All rods out; Reg. and Shims at 75 deg.	143,600	0.250	290,800	0.308	307,300	0.185	1,500	0.33	400	0.062
	2355	56, 57	3-J, 1-H	Two elements loaded, Reg. and Shims in	26,890	0.59	57,910	0.76	49,610	0.40	320	0.81	65	0.12
4-18-61	0013	-		Only Shim 2 in	78,400	0.256	151,700	0.34	208,800	0.147	700	0.43	350	0.037
	0020	-		Critical, all rods out except Shim 2 at 63.8 deg. moderator water temperature 71° F	-		-		-		1×10^5	-	3.2×10^4	-
	0051	Liners 23, 24	4-H, 6-C	Two heavy shim liners installed, Reg. and Shims in	26,110	0.61	54,980	0.80	45,890	0.44	-	-	-	-
	0106	-		Only Shim 2 in	63,070	0.295	129,200	0.40	172,600	0.178	600	0.50	200	0.065
	0116	-		All rods out except Shim 2 at 63.3 deg.	390,100	0.095	735,500	0.121	saturated		4,500	0.11	1,600	0.016
	0135	58	2-J	One element loaded, Reg. and Shims in	27,350	0.58	57,640	0.76	54,170	0.37	320	0.81	30	0.38
	0147	-		Scram when BF_3 detector removed from position 1-A and then replaced	-		-		-		-		-	
	0204	-		Only Shim 2 in	95,960	0.209	181,500	0.285	278,900	0.110	800	0.38	320	0.025
	0210	-		Critical, all rods out except Shim 2 at 51.1 deg.	-		-		-		1×10^5		-	
	0254	-		Scram when only Safety 1 and 2 out during shutdown for relocation of BF_3 detectors in preparation for rod drop measurements	P.C. Side Shld. Tnk.		Rear Side Shld. Tnk.		Outlet Gas Duct		-		-	
	0325	59; Liner 25	1-A; 2-D	One element and one heavy shim liner loaded, Reg. and Shims in	1,140; 60 sec count		-		-		350		150	
	0346	-		Critical, all rods out except Shim 2 at 31.4 deg.	70,880; 60 sec count		54,324; 60 sec count		165,090; 60 sec count		1.1×10^5		2.7×10^4	
	0357	-		Rod drop with Shim 2, post drop count	10,030; 30 sec count		8,919; 30 sec count		22,421; 30 sec count		-		-	
	0500	-		Shutdown interruption of experiment, see Note 3										
	1600	-		Reinitiated ANSOP 16208; relocated Channel 2 detector as far out (inside shield tank) as possible										

STATUS POINT AND DATA SUMMARY (Continued)

Date	Time, hours	Element, Liner Sequence Number	Core Position Loaded	Status Point	P.C. Side of Shield Tank Counts	P.C. Side of Shield Tank Count Time, seconds	Rear Side of Shield Tank Counts	Rear Side of Shield Tank Count Time, seconds	Outlet Gas Duct Counts	Outlet Gas Duct Count Time, seconds	ML-1 Channel 1 cps	ML-1 Channel 2 cps
	1809	-		Critical, all rods out except Shim 2 at 31.4 deg.	198,395	60	102,943	60	362,144	60	3×10^5	1×10^6
	1833	-		Rod drop with Shim 2, no scalers counted post drop	-		-		-		-	-
	1857	60	1-J	One element loaded, Reg. and Shims in, moderator water temp. 72° F	-		-		-		-	550
	1924	-		Critical, all rods out except Shim 2 at 12.2 deg.	110,460	60	60,641	60	206,784	60	1.5×10^5	2.2×10^5
	1932	-		Rod drop with Shim 3, post drop count	6,171	30	5,098	30	12,690	30		
	2021	61; Liners 26, 27, 28, 29, 30, 31	9-E; 4-B, 2-C, 2-F, 3-H, 6-G, 7-D	Last element and six heavy shim liners loaded; Reg. and Shims in, moderator water temperature 73° F	-		-		-		380	250
	2047	-		Critical, all rods out except Shim 2 at 30.4 deg.	57,475	30	38,262	30	102,838	30	2.5×10^5	3.0×10^5
	2108	-		Rod drop with Shim 1, post drop count	7,615	30	5,474	30	14,180	30	-	-
	2116	-		Critical, all rods out except Shim 1 at 34.8 deg.	59,816	30	39,189	30	111,970	30	2.2×10^5	-
	2142	-		Rod drop with Shim 2, post drop count	8,091	30	6,124	30	13,772	30		
	2231	Liners 26, 28, 30	4-B, 2-F, 6-G	Unloaded three heavy shim liners, Reg. and Shims in	-		-		-		400	280
	2253	-		Critical, all rods out except Shim 2 at 13.2 deg.	49,705	30	33,331	30	95,289	30	1.75×10^5	2.1×10^5
	2307	-		Terminated experiment with all rods being dropped, post drop count	2,095	30	1,295	30	3,461	30	-	-

high power runs starting in August, 1961, will have ten instrumented elements located as advised by D.M. Elliott[5]. The U^{235} loading for each element was taken from the data supplied by J. Healy[6] unless otherwise noted. Figure 4 shows the locations of each fuel element and shim liner. Note that only the heavy shim liners described by L.M. Maki[2] were installed in this core; no record was made of liner serial numbers.

Core Position	Fuel Element Serial Number	U^{235} Loading, gms	Heavy Shim Liner	Remarks
1-A	ML-1-59	812.26	no	Instrumented element, loading from Fuel Pin Inspection, 2-17-61
2-A	ML-1-1	809.36	no	
3-A	ML-1-2	812.95	no	
4-A	ML-1-3	806.91	no	
5-A	ML-1-4	806.21	no	
1-B	ML-1-18	806.16	no	
2-B	ML-1-5	810.42	no	
3-B	ML-1-10	806.58	yes	
4-B	ML-1-12	804.71	no	
5-B	ML-1-14	808.53	no	
6-B	ML-1-6	808.86	no	
1-C	ML-1-40	807.65	no	
2-C	ML-1-26	811.97	yes	
3-C	ML-1-24	810.58	yes	
4-C	ML-1-16	806.03	yes	
5-C	ML-1-15	803.03	yes	
6-C	ML-1-13	807.93	yes	
7-C	ML-1-7	810.90	no	
1-D	ML-1-49	804.09	no	
2-D	ML-1-38	805.48	yes	
3-D	ML-1-24	810.58	yes	
4-D	ML-1-22	810.61	yes	
5-D	ML-1-20	811.33	yes	
6-D	ML-1-17	808.03	yes	

Core Position	Fuel Element Serial Number	U^{235} Loading, gms	Heavy Shim Liner	Remarks
7-D	ML-1-11	806.05	yes	
8-D	ML-1-8	808.37	no	
1-E	ML-1-51	802.36	no	
2-E	ML-1-47	806.31	no	
3-E	ML-1-36	806.73	yes	
4-E	ML-1-30	806.66	yes	
5-E	ML-1-21	809.41	yes	
6-E	ML-1-23	810.93	yes	
7-E	ML-1-25	810.25	yes	
8-E	ML-1-9	806.77	no	
9-E	ML-1-62	808.21	no	Instrumented element
1-F	ML-1-53	805.84	no	
2-F	ML-1-45	806.89	no	
3-F	ML-1-34	810.08	yes	
4-F	ML-1-32	806.37	yes	
5-F	ML-1-31	802.08	yes	
6-F	ML-1-29	804.99	yes	
7-F	ML-1-27	808.37	yes	
8-F	ML-1-19	807.88	no	
1-G	ML-1-55	805.24	no	
2-G	ML-1-43	808.71	yes	
3-G	ML-1-33	807.52	yes	
4-G	ML-1-35	807.28	yes	
5-G	ML-1-37	805.15	yes	
6-G	ML-1-39	808.30	no	
7-G	ML-1-41	805.51	no	
1-H	ML-1-57	809.13	no	Element dented 6 inches below top

Core Position	Fuel Element Serial Number	U^{235} Loading, gms	Heavy Shim Liner	Remarks
2-H	ML-1-50	805.59	no	
3-H	ML-1-42	810.11	yes	
4-H	ML-1-44	804.39	yes	
5-H	ML-1-46	809.07	no	
6-H	ML-1-48	803.94	no	
1-J	ML-1-61	805.22	no	Instrumented element
2-J	ML-1-58	808.72	no	
3-J	ML-1-56	806.70	no	
4-J	ML-1-54	804.39	no	
5-J	ML-1-52	800.86	no	

REFERENCES

1. D. R. Mathews and R. D. Peak, "Preliminary Control Rod Calibration, Shield Water and Tungsten Baffle Worth," AN-IDOP-30, 11 May 1961.

2. L. M. Maki, "ML-1 Shim Liners," MEG-716, 20 December 1960.

3. L. M. Maki, in contribution to memorandum, "Weekly Progress Report, Fuel Development Department for Period Ending 14 April 1961," MEG-834, 24 April 1961.

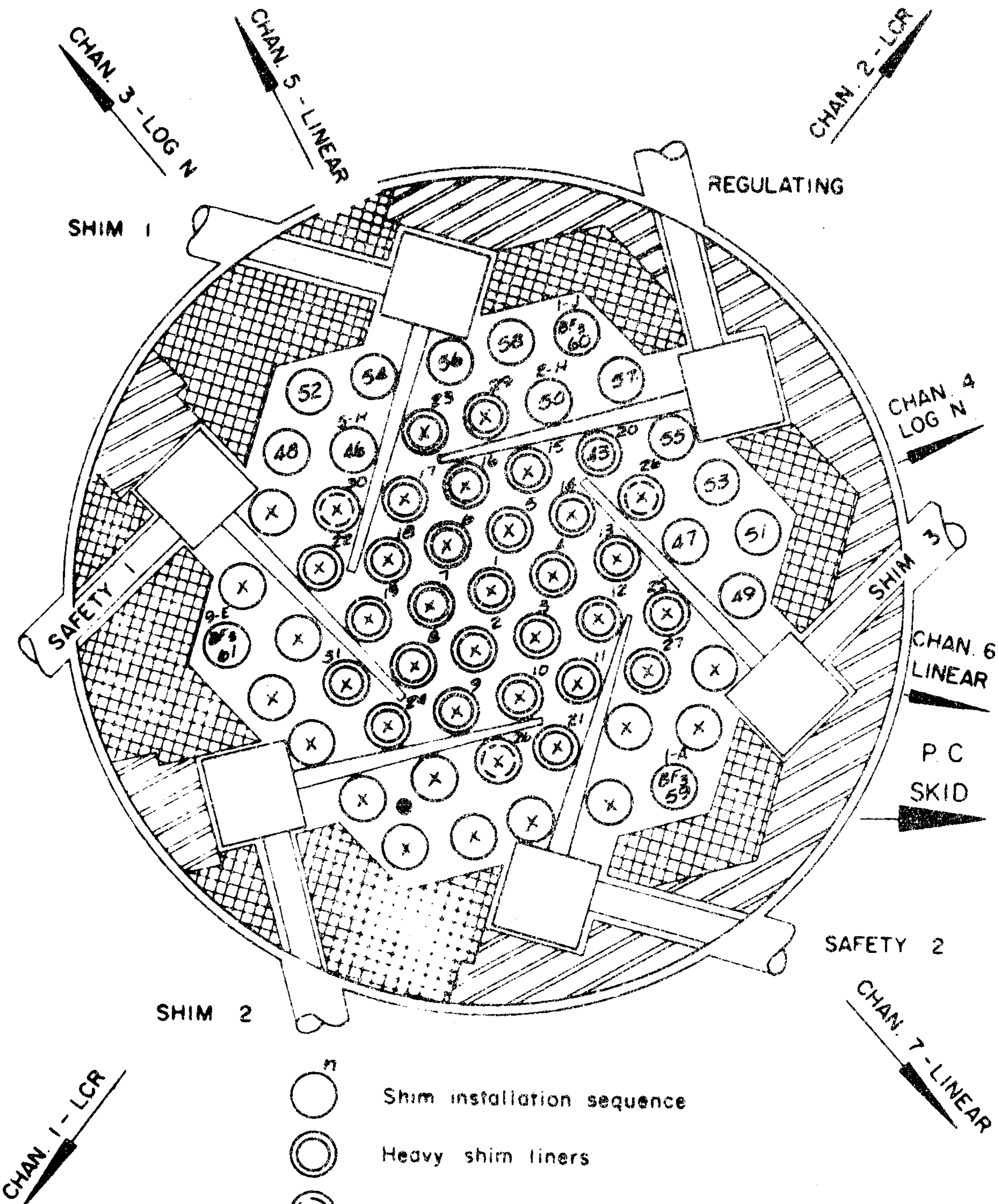
4. R. D. Peak and R. E. Lightle, "Initial Critical Experiment for ML-1," AN-IDOP-20, 31 March 1961.

5. D. M. Elliott, "ML-1 Measured Core Temperatures," MEG-811, 4 April 1961.

6. J. Healy, "ML-1 Fuel Load," IN-16-61, 13 February 1961.

ML-1 REACTOR

Fuel loading sequence
Detector locations



n — Shim installation sequence

Heavy shim liners

Shims installed then removed

X — Elements loaded during initial critical experiment

AN-IDOP-29
FIGURE 4

File: AN-IDOP-30
Date: 17 April 1961
Standard Distribution

M E M O R A N D U M

TO: R. H. Chesworth

FROM: D. R. Mathews and R. D. Peak

SUBJECT: PRELIMINARY CONTROL ROD CALIBRATION, SHIELD WATER AND TUNGSTEN BAFFLE REACTIVITY WORTHS FOR ML-1 (ANSOP 16202 and 16204)

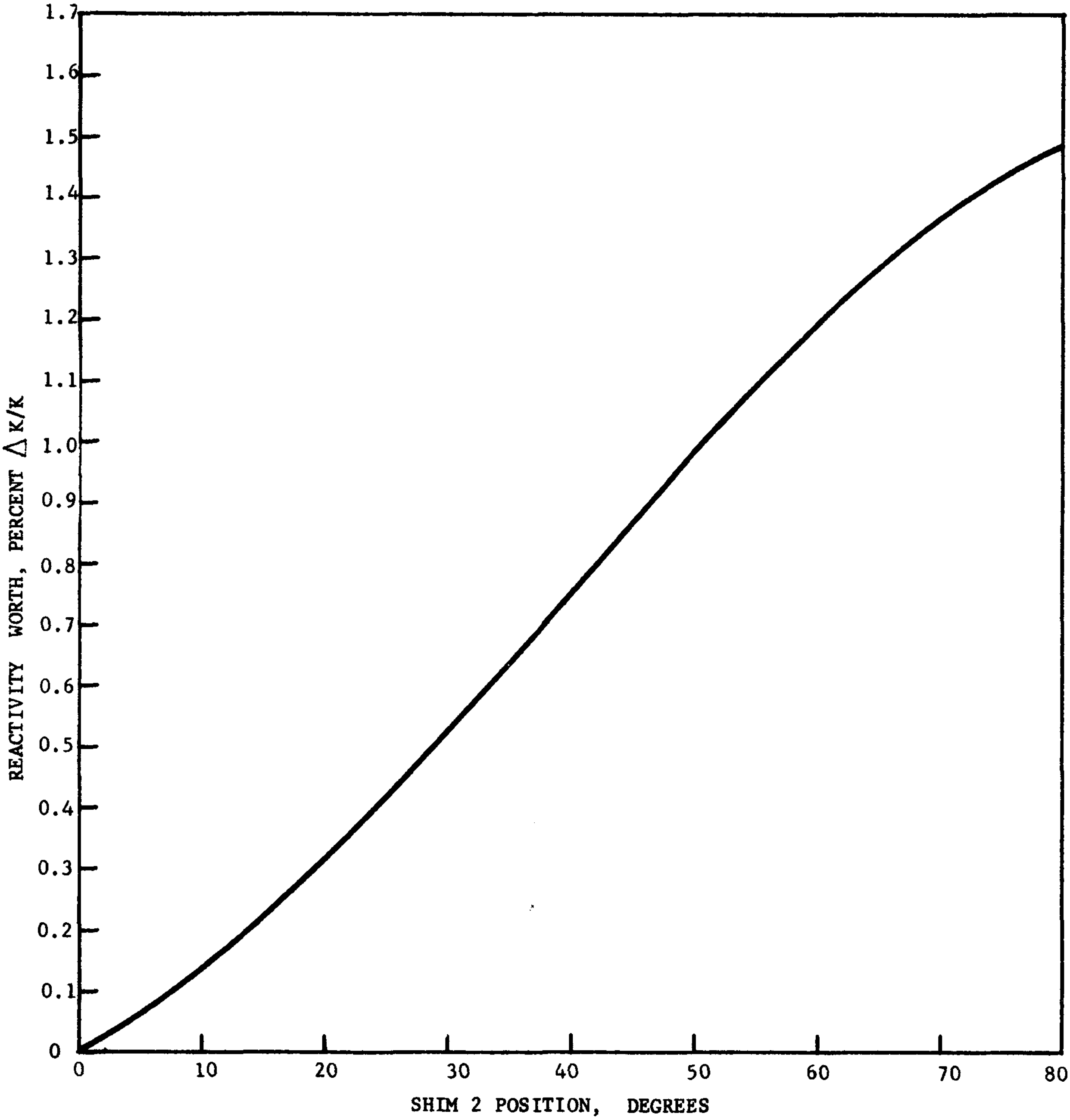
SUMMARY

During the period of 5-7 April 1961, a preliminary calibration of ML-1 Shim Rod 2 was made using the rod drop technique. The rod drop data gave an average worth for Shim 2 of 2.11% $\Delta k/k$ as compared to the BMI calibration of a similar rod of 1.96% $\Delta k/k$. However, the rod drop method showed significant differences in rod worth depending upon the location of the neutron detectors. Further, the neutron source was shown to be a significant contributor to reactor power at a level only one decade below the critical levels used for the rod drops. This source effect and the small working range for power rise below the "High Level" scram settings precluded any satisfactory period measurements to check the rod drop data.

Based on the average value of the rod drop calibration, filling the shield tank half full of 1.97% boric acid solution reduced the reactivity about -0.002% $\Delta k/k$; installing the reactor cover with the tungsten baffle increased the reactivity about +0.13% $\Delta k/k$, and adding four peripheral fuel elements increased the reactivity about +0.42% $\Delta k/k$ per element. A very preliminary temperature coefficient of reactivity was determined to be about 0.019% $\Delta k/k\,^{o}F$. The shutdown margin for the 51 element core loading was determined to be about 5.32% $\Delta k/k$ which compared to the worth shield tank half full of boric acid solution decreased the sensitivity of the log count rate channels by a factor of about 2.44.

SHIM 2 CALIBRATION

ROD DROP DATA



AN-IDOP-30
FIGURE 1

File: AN-IDOP-34
Date: 11 May 1961
Standard Distribution

M E M O R A N D U M

TO: R. H. Chesworth

FROM: R. D. Peak

SUBJECT: FINAL CONTROL ROD CALIBRATION, SHIELD WATER, AND TUNGSTEN BAFFLE REACTIVITY WORTHS FOR ML-1

SUMMARY

During the time period of 18 through 25 April, the experimental procedures, "Final Control Blade Calibration," ANSOP 16210, and "Final Shield Water and Tungsten Baffle Reactivity Determination," ANSOP 16211, were performed.

Both rod drop and period calibration reactivity measurements of Shim 2 and of the Regulating rod were made for comparison.

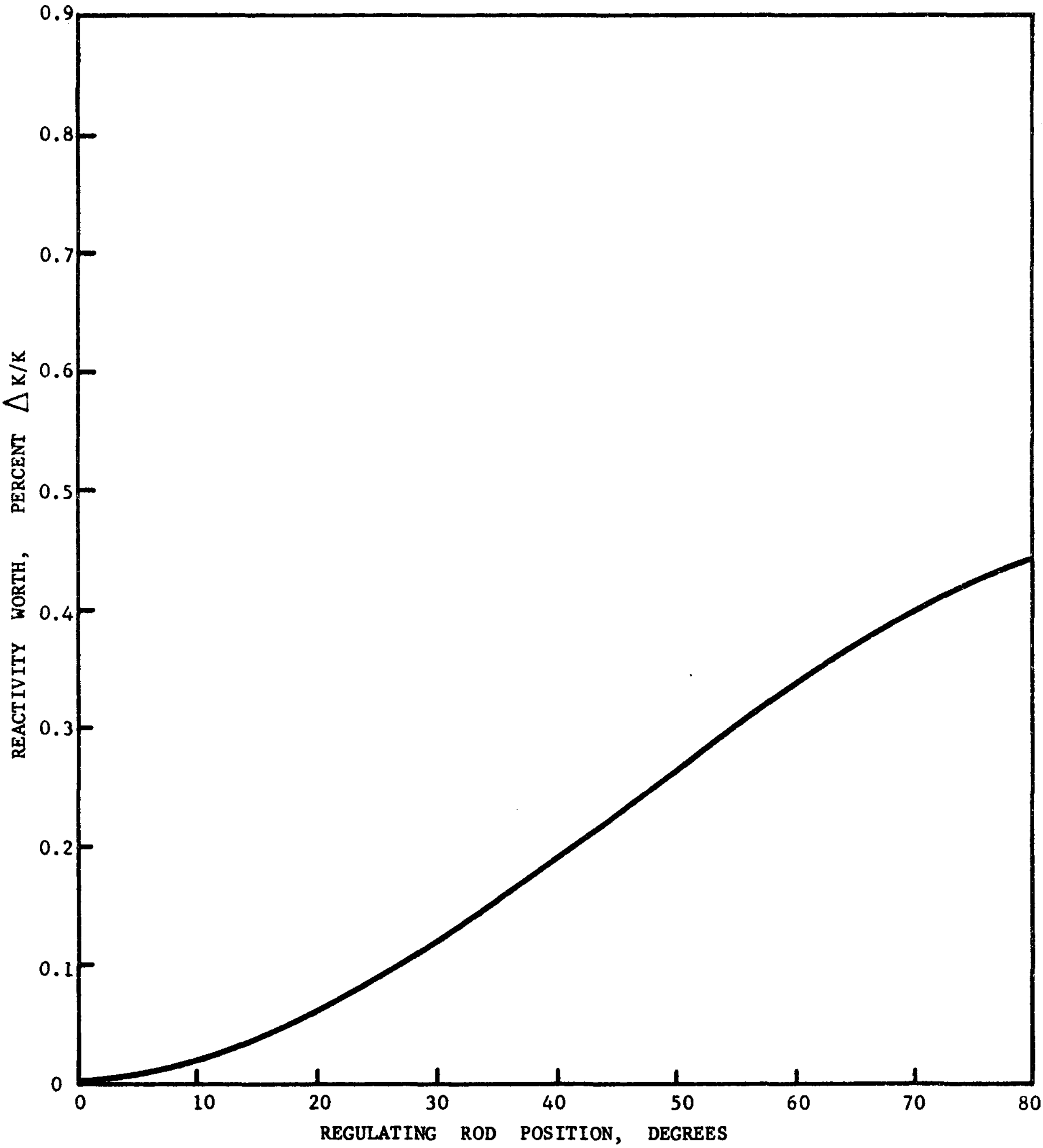
A correlation of the calibration data for Shim 2 showed that the integral worth by rod drop measurements was 1.52% $\Delta k/k$, by period run measurements was 1.43% $\Delta k/k$, and by the combination of all data was 1.48% $\Delta k/k$. A similar correlation of the Regulating rod data gave a worth of 0.44% $\Delta k/k$. Rod drop comparisons of Shims 1, 2, and 3 showed that they were all essentially the same worth, 1.50% $\Delta k/k$. Similar rod drop comparisons of Safety 1 and 2 showed lower worth, about 1.39% $\Delta k/k$, due presumably to shadowing by an adjacent Shim rod in the critical rod configuration.

The "critical" rod position was shown to be dependent upon reactor power level. With an estimate of the reactor power in the shutdown condition, due to the neutron startup source, of 1.7×10^{-4} watts, a power level of about 4 watts was required to avoid any effect of the startup source on rod positions at critical.

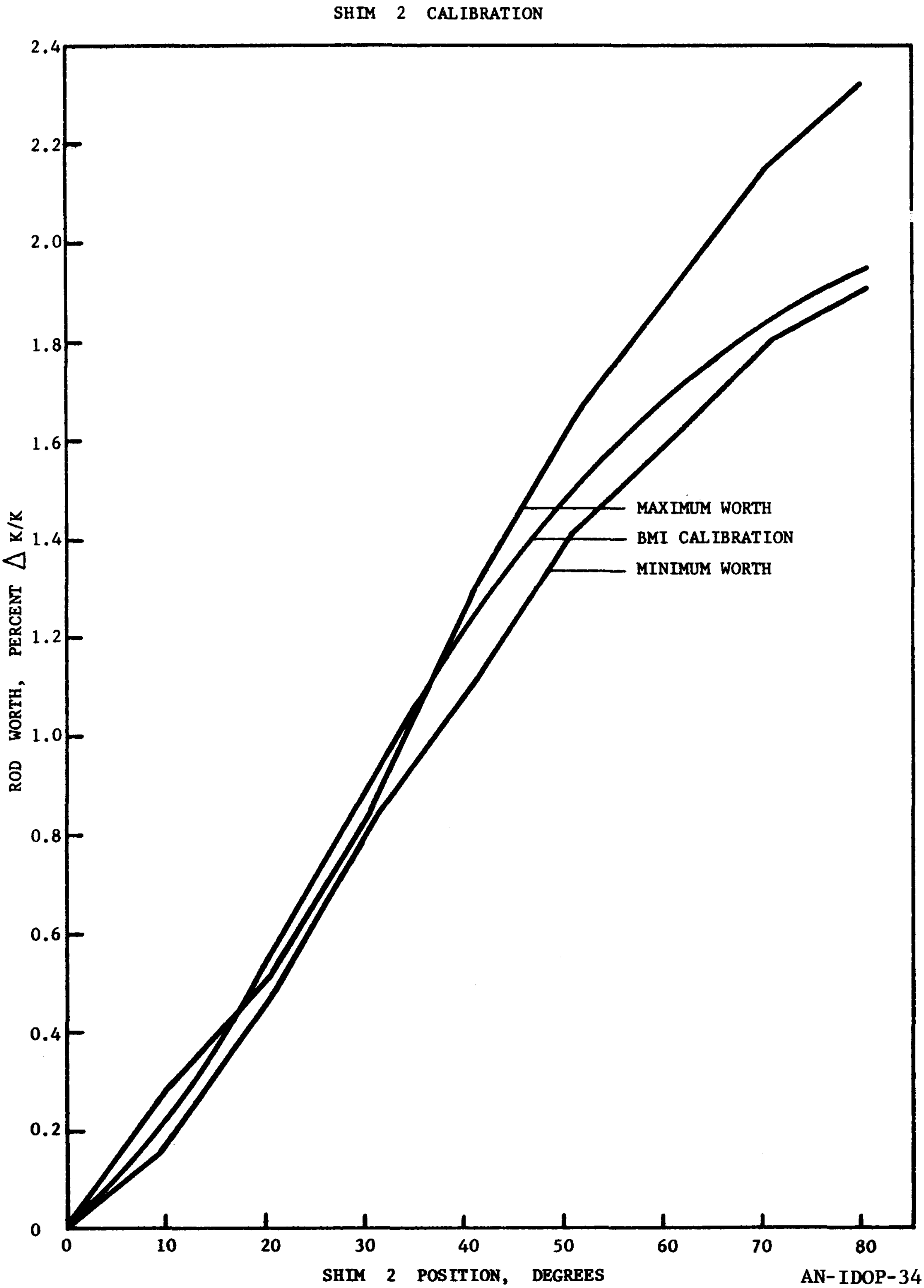
The reactivity worth measurements were correlated to give the following values. Reactivity effect of filling the shield tank with nominal 2% boric acid solution: -0.066% $\Delta k/k$. Reactivity effect of installing reactor cover (with tungsten baffle): +0.20% $\Delta k/k$. Reactivity effect of adding one peripheral fuel element: +0.50% $\Delta k/k$. Reactivity effect of adding one "heavy" shim liner: -0.15% $\Delta k/k$.

The excess reactivity of the cold, clean core in the operating condition with a moderator water temperature of 68°F was determined to be approximately +1.52% $\Delta k/k$. The shutdown margin of reactivity of this reactor was determined to be -4.73% $\Delta k/k$.

REGULATING ROD CALIBRATION



AN-IDOP-34
FIGURE 1



AN-IDOP-34
FIGURE 2

IV. ML-1 PHASE II TEST PROGRAM

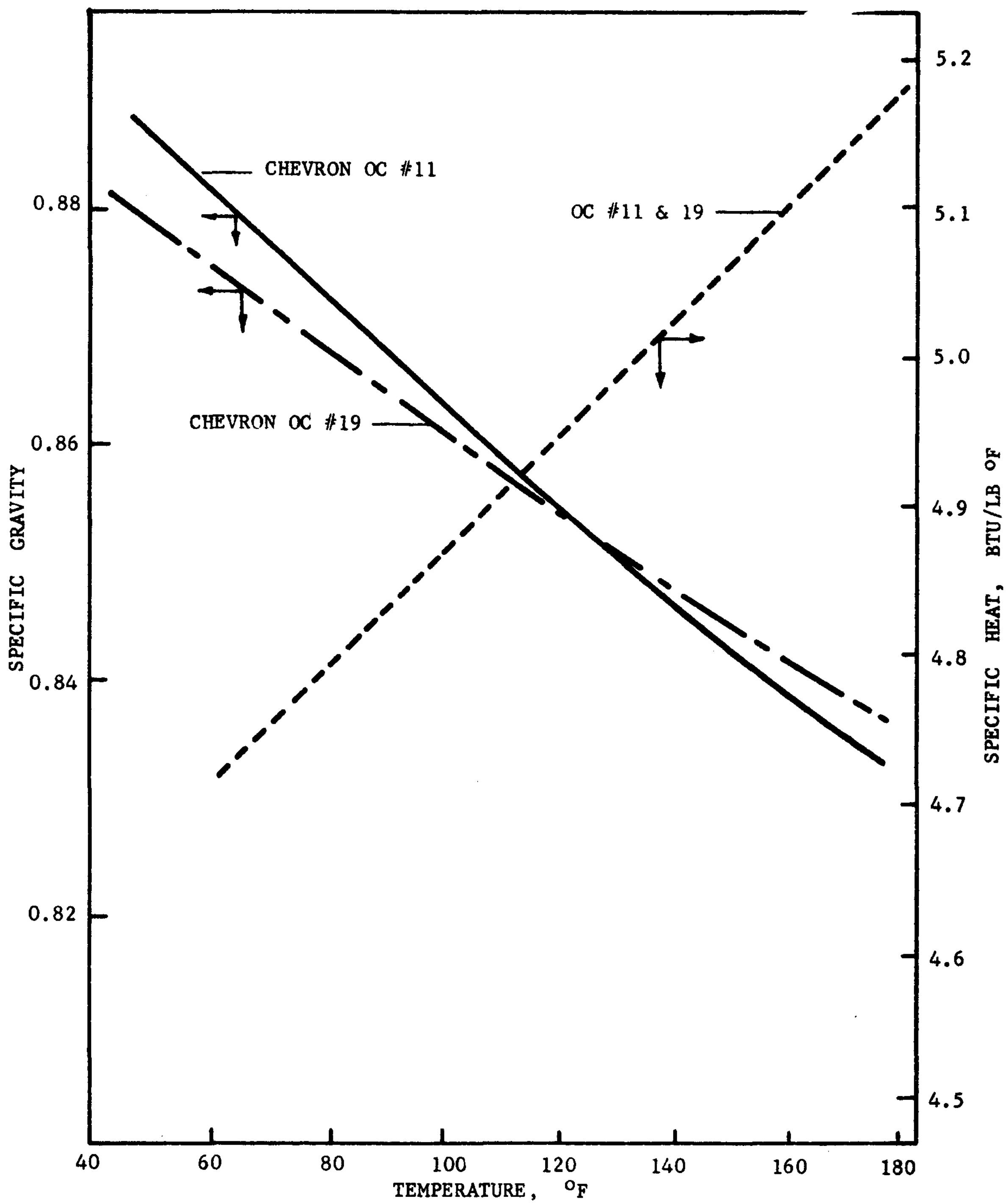
E. SUPPLEMENTAL INFORMATION

5. Reference Data

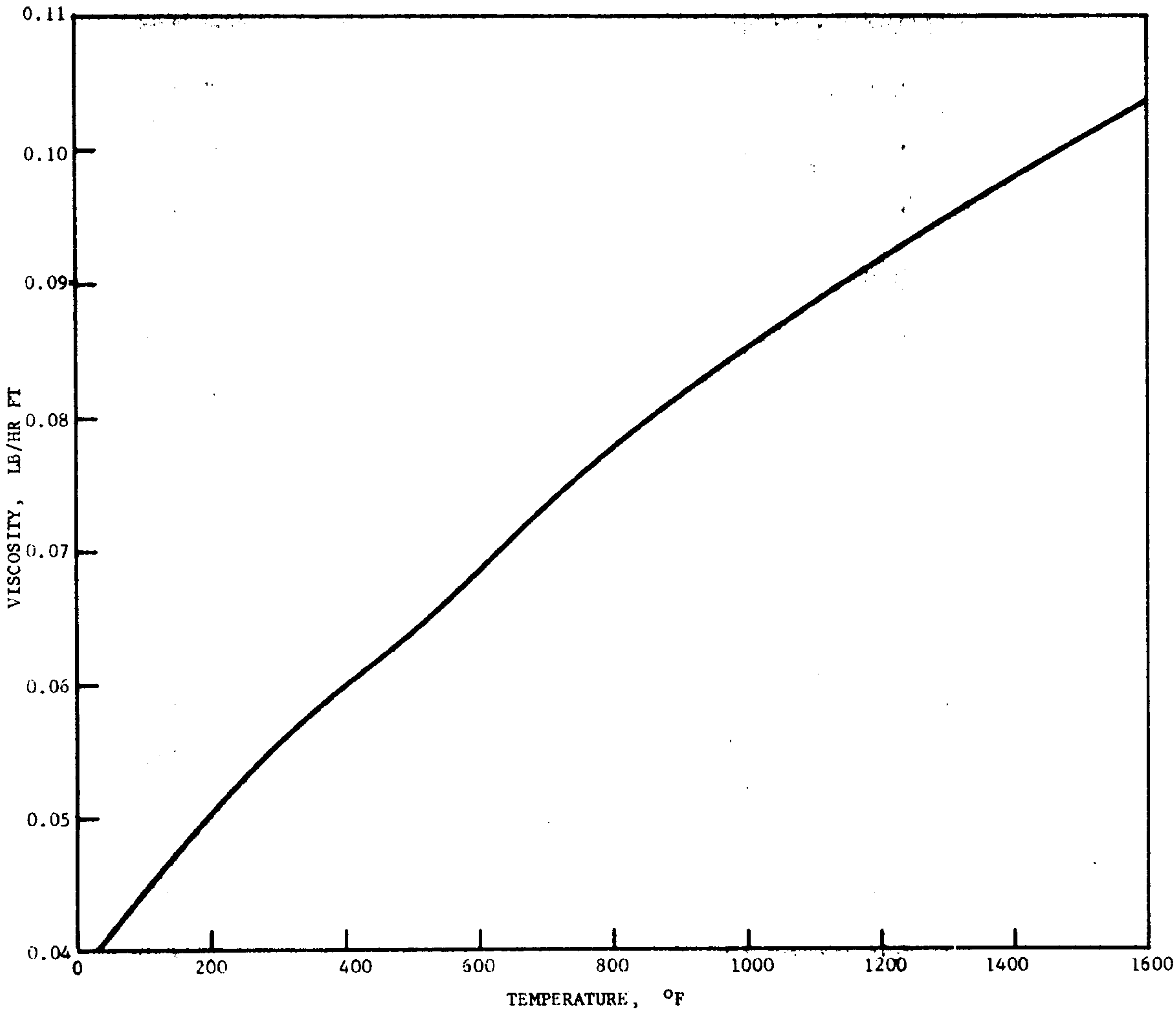
Lubricating Oil Specific Gravity and Specific Heat versus Temperature
Nitrogen Viscosity versus Temperature
Nitrogen Ratio of Specific Heat versus Temperature

LUBRICATING OIL

SPECIFIC GRAVITY AND SPECIFIC HEAT VERSUS TEMPERATURE

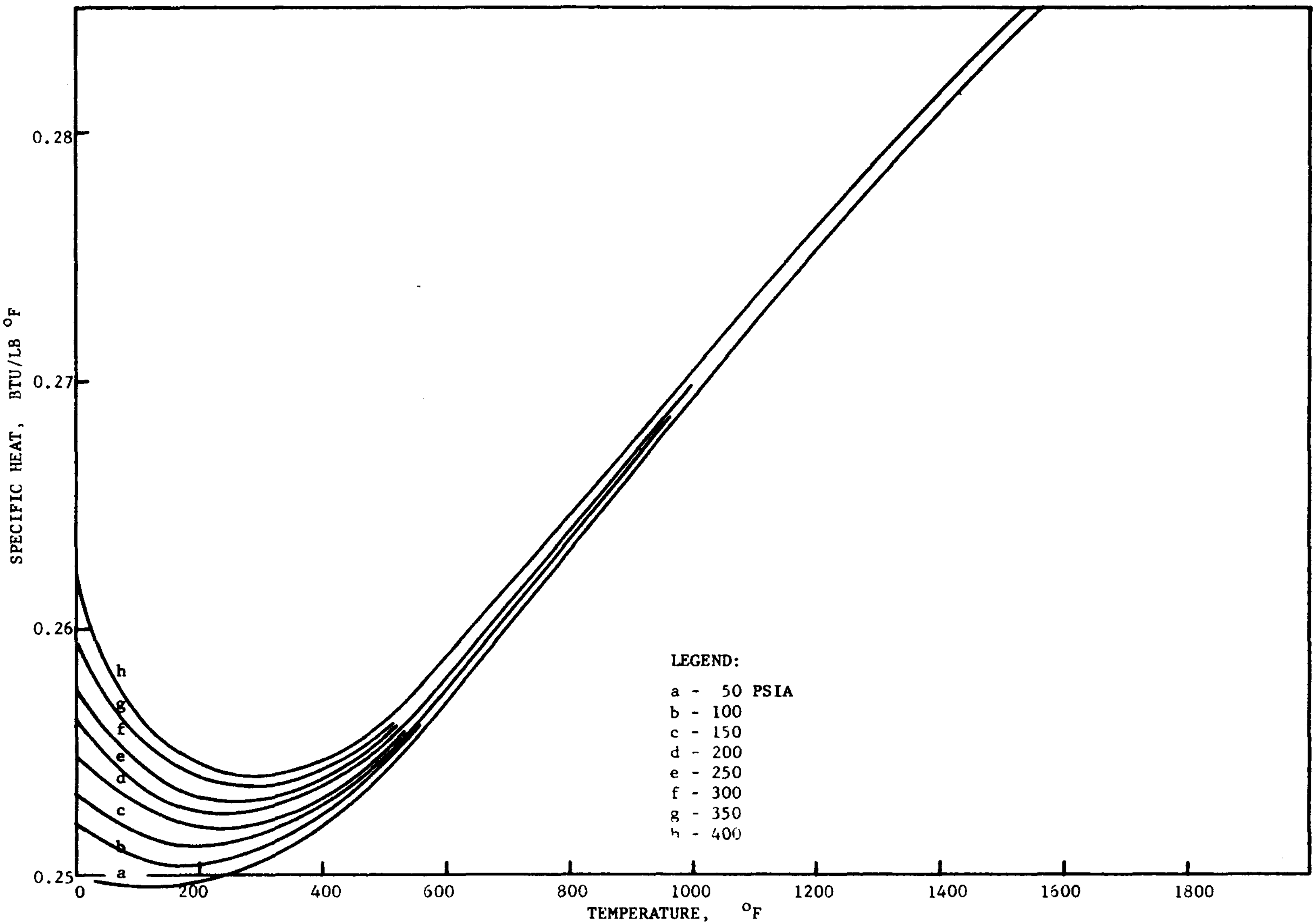


NITROGEN VISCOSITY, ± 1%



NITROGEN

SPECIFIC HEAT AT CONSTANT PRESSURE, ± 1/2 %



V. OPERATIONAL PROCEDURES

Presented on the following pages are preliminary writeups of the operational procedures for: 1) initial self-sustained operation of the ML-1 power plant, and 2) the full-power test of the plant.

The first procedure, designated ANSOP 16615, begins on page 194. The second, ANSOP 16625, begins on page 215.

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STANDARD OPERATING PROCEDURE
MOBILE LOW POWER REACTOR I

PROCEDURE SECTION 16 EXPERIMENTAL PROCEDURES

TITLE: INITIAL SELF SUSTAINED OPERATION

SCOPE:

This procedure provides for execution of the experiment, INITIAL SELF SUSTAINED OPERATION, which was described in Paragraph 2.a., page 64 of the ML-1 NUCLEAR POWER PLANT TEST PROGRAM.*

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

a. Bring the ML-1 Power Plant to self sustained condition.

b. Accelerate the machinery set to rated speed.

c. Transfer the reactor from manual to automatic gas temperature control.

d. Generate initial no load operating data.

e. Functionally check the alternator, its control center, and the load bank by applying and removing a token load.

f. Secure the power plant after several hours of operation.

This procedure covers the first of a series of initial power tests aimed at gross experimental evaluation of the power plant. This experiment will be followed by a full power test designed to determine the maximum load that can be applied to the power plant without exceeding specified operating limits. Succeeding experiments are described in the ML-1 NUCLEAR POWER PLANT TEST PROGRAM.

* The Test Program comprises Section IV of this supplement.

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SUPPLEMENTAL PROCEDURES

Supplemental procedures required for reference in implementing this procedure include:

TITLE	ANSOP NUMBER
Personnel Control Procedure	2302
Lock and Tag Procedure	3150
Power Plant Pre-Startup Check List	14000
Power Plant Post Shutdown Checks	14004
Power Plant Emergency Procedures	14005
Reactor Pre-Startup Check List	14020
Reactor Startup	14021
Low Power Reactor Operation	14022
Low Power Reactor Shutdown	14023
Nuclear Instrumentation Pre-Startup Check	14060
Non-Nuclear Scram Circuit Check	14070
Control Blade System Pre-Startup Check	14080
Reactor Temperature Control System Pre-Startup Check	14100
Lube System Startup	14131
Lube System Shutdown	14133
Precooler Assembly Startup	14171
Precooler Assembly Shutdown	14173
Speed Control System Pre-Startup Check	14210
Moderator System Startup	14251
Moderator System Shutdown	14253
Shield Water System Startup	14271
Shield Water System Shutdown	14273
Main Gas Loop Pressurization	14290
Gas Handling System Startup	14291
Gas Handling System Shutdown	14293
Battery Inverter System Operation	14300
Auxiliary Power Generator Startup	14321
Auxiliary Power Generator Shutdown	14323
Electrical Distribution System Pre-Startup Check	14340
Electrical Distribution System Operation	14342
SAM System Startup	14360
Gas Analysis Equipment Startup	14422

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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 task.

a.	Reactor Power	3.3 MW total
b.	Turbine Inlet Temperature	1225°F
c.	Compressor Inlet Pressure	120 psia
d.	Compressor Discharge Pressure	335 psia
e.	Precooler Inlet Temperature	500°F
f.	T-C Set Bearing Temperature	190°F
g.	Compressor Inlet Temperature	131°F
h.	Vibration	1.5 g
i.	Reactor Inlet Pressure	315 psia
j.	Alternator Stator Winding Temperature	275°F
k.	Start Motor Winding Temperature	400°F
l.	Start Motor Power (continuous)	37 kw
	(short time - less than 2 minutes)	67 kw
m.	Lube Oil Supply Temperature	150°F
n.	Start Motor Current per Phase (Continuous)	53 amps
	(Short time)	100 amps
o.	Positive Reactor Period	50 sec
p.	High Level Channels 5, 6, and 7	110% power
q.	Shorted Period Channels 1, 2, 3, and 4	10 sec period
r.	Reactor Outlet Temperature	1275°F
s.	Fast Pressure Loss $\frac{dp}{dt}$	$\frac{45 \text{ psi}}{10 \text{ sec}}$
t.	Moderator Water Flow Low	275 gpm
u.	T-C Set Speed	20,075 rpm
v.	Compressor Inlet Temperature	150°F

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w.	Reactor Outlet Temperature Error	$\pm$ 40°F
x.	Moderator Water Outlet Temperature from Reactor	195°F
y.	Moderator water Outlet Temperature from Heat Exchanger	185°F
z.	Moderator Water Level Low	-8 in.
aa.	Moderator Water Conductivity High	2 micromhos
bb.	Shield Water Level Low	-2 in.
cc.	Shield Water Conductivity Low	2 - 5% concentration boric acid
dd.	Shield Water Temperature Low	120°F
ee.	Lubrication Oil Sump Level Low	-6 in.
ff.	Lubrication Oil Filter Pressure Drop High	20 psi
gg.	Auxiliary Lubrication Oil Pump Startup	310 psia
hh.	Gas Storage Spheres A or B Pressure High	3000 psig
ii.	Transfer Compressor Oil Pressure Low	10 psig
jj.	Transfer Compressor Diaphragm Rupture	750 psig
kk.	Oxygen Make-up Pressure Low	200 psia
ll.	Control Cab Area Radiation High	1-5 mr/hr
mm.	Fuel Element Thermocouple High	1350°F
nn.	Reactor Skid Analysis Thermocouples	
	TX 211 (Inner Radial Shield)	300°F
	TX 212 (Upper End Cone)	250°F
	TX 213 (Shield Water)	200°F
	TX 214 (Shield Water Piping)	200°F
	TX 215 (Moderator Water Circulatory Pump)	200°F

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PROCEDURE:

NOTE: Execution of this procedure shall be closely monitored by:

1. ML-1 General Supervisor
2. Health and Safety Supervisor or his representative
3. Technical Support Head or his representative
4. Power Conversion Skid Engineer

Execution of this procedure will be at the direction of the ML-1 Shift Supervisor.

A. PREPARATION

1. Test Crew Briefing

The ML-1 General Supervisor will brief both operating test crews previous to the initiation of this procedure. He shall insure that all crew members are familiar with Power Plant Emergency Procedures (ANSOP 14005).

2. Execute Power Plant Pre-Startup Check List (ANSOP 14000).

a. Execute Reactor Pre-startup Check List (ANSOP 14020).

This check list includes coverage for:

1) Shield Water System Startup (ANSOP 14271)
2) Moderator Water System Startup (ANSOP 14251). After checkout, secure moderator/lube oil cooling fans.
3) Facility Pre-Reactor Operation Check List (ANSOP 12000)
4) SAM System Start-up (ANSOP 14361)
5) Nuclear Instrumentation Pre-Startup Check (ANSOP 14060)
6) Control Blade System Pre-Startup Check (ANSOP 14080)
7) Non-Nuclear Scram Circuits Check (ANSOP 14070)
8) Battery-Inverter System Pre-Startup Check (ANSOP 14300)
9) Personnel Control Procedure (ANSOP 2302)
10) General Inspection of the Test Areas and Equipment Involved

b. Reactor Temperature Control System Checkout

1) Checkout the reactor temperature control system in accordance with the Reactor Temperature Control System Pre-Startup Check Procedures (ANSOP 14100).

2) Leave the Reactor Temperature Control System in "Manual" position.

c. Speed Control System Check

1) Perform Speed Control System Pre-Startup Check (ANSOP 14210).

d. Electrical System Check

1) Perform Electrical Distribution System Pre-Startup Check (ANSOP 14340). This step provides for lineup of circuit breakers and switches necessary for power plant operation.

e. Gas Supply Unit Startup

1) Perform Gas Handling System Startup (ANSOP 14291).

f. Analysis Instrumentation Startup

1) Put all analysis parameter readout devices into operation (ANSOP 14522).

2) Check operation of oscillograph.

g. Lube System Pre-Start Check

Execute the pre-start section of the Lube Oil System Startup Procedure (ANSOP 14131).

This step is to provide for checking filters and oil levels prior to pressurizing the loop. The checks at this point include:

1) Insure that a clean filter element is installed in each of the three system filters (F601, F604, F621). Inspect applicable records to ascertain that filter elements were inspected following ANSOP 16415.

2) Insure that a fresh charge of Linde Co. Molecular Sieve Type 13X is in the desicant tank. Records should show that the unit was freshly charged pursuant to ANSOP 16415.

3) Insure that the oil level in the startup compressor is to "Hi" mark on dipstick (1½ pint level), and that the main oil sump is at the proper level. All these oil reservoirs contain OC#11 turbine oil.

4) Insure that emergency seal supply is connected to the fitting located in line 620-1-A7 between the gas filter (F621) and check valve (V621). Activate emergency seal supply system momentarily and record the TCS-670 seal pressure and flow data (Fg. 3 and F24).

h. Process Gas Analysis Equipment

1) Startup Process Gas Analysis Equipment in accordance with ANSOP 14422.

i. Pressurize loop to 40 psia in accordance with ANSOP 14290, Main Gas Loop Pressurization. Pressurizing the loop is accomplished by opening the motorized admission valve, V109, enough to slowly admit gas until the desired loop pressure level is reached. Then close V109.

NOTE: ANSOP 14290 calls for the startup compressor to be running on "slow" during pressurizing of the system under static conditions.

j. Lube Oil System Startup

Start up the lubricating oil system in accordance with ANSOP 14131 (Lube Oil System Startup Procedure). An observer, under the provisions of an SWP, will be stationed in the test building for this system startup.

The general sequence of operations involved in activating the lube oil system is as follows:

1) Line up valves and electrical switches in accordance with ANSOP 14131.

2) Apply buffer gas to the TCS 670 Turbine and Compressor Bearing Seals by starting the Startup Compressor on "Slow" speed. This insures that a pressure differential, in the proper direction, exists across the labyrinth seals involved.

Rotation of the startup compressor should produce a gas flow at Fg2 (Seal Gas Return to the Loop) and at Fg3 (Seal Gas Flow to Turbine Bearing Seals).

3) Establish a pressure differential between the sump and the separator by starting the sump equalizing compressor.

NOTE: The precooler fans may be operated as necessary to limit startup compressor discharge temperature to below 325°F and the sump equalizing compressor discharge temperature to below 250°F. Refer to step A15 for precooler fan operation.

4) After establishing a 15 psi minimum differential between the separator and the sump, start the auxiliary lube oil pump with V603 closed and the recirculating valve RV 641 open. This will provide for recirculating oil to the sump, while by-passing the rest of the oil system. During this recirculation period the oil will be heated to operating temperature (125 to 150°F) by energizing the sump heating elements and adjusting the rheostat (TIC 604) to the desired temperature level.

5) Open V603 and close RV 641. This allows circulation of oil through the entire oil system.

6) Check all oil system pressures, temperatures and flows indications.

7) Maintain oil temperature between 125 and 150°F. by using sump oil heaters, and oil cooler fans (moderator cooler fans) as necessary.

Refer to Step A15 for cooler fan startup procedure.

8) Visually check and mark level of oil on sump level sight glass.

k. TCS 670 Rotational Check

1) Station one or more observers near the PC Skid in the test building under provisions of an SWP. At least one of these observers shall be an engineer already familiar with the characteristics of the TCS 670. The function of the observer is to watch and listen for unusual occurrences during the rotational check.

2) Start the speed tracing oscillograph and momentarily energize the start motor in 4 pole mode. (Press the start motor "slow" button and after approximately 2 seconds press the start motor "stop" button.

Carefully observe and record peak start motor current. Secure the oscillograph after ascertaining that the machinery set has stopped.

The machinery set should, by this action, be accelerated to something less than 1000 RPM turbine speed and then decelerate to a stop. Determine deceleration rate from oscillograph trace and compare with

If deceleration rate is normal and if no unusual noises or other events occur, proceed to step 2k3 below. otherwise investigate and repeat 2k1 through 2k2 when considered safe to do so, and with specific permission of the shift supervisor.

3) Select Speed Control "Manual" -- Close Control "By-Pass Valve -- Insure that over speed trip valve is closed.

4) Alert observers on station, start the speed tracing oscillograph and energize the start motor in 4 pole mode by pressing the start motor "slow" button.

Allow the unit to accelerate to 4 pole motor speed (8000 RPM turbine speed). Stop oscillograph.

5) Observe start motor power. Do not allow the start motor power to exceed 50 hp (37 kw) continuously or a winding temperature of 400°F.

When the start motor is cold the start motor may be allowed to draw up to 90 hp (67 kw) for a duration not to exceed 2 minutes providing the motor winding temperature does not exceed 400°F.

6) If start motor power required is in excess of 50 hp (37 kw) reduce system mass until start motor power is at 50 hp or until the pressure differential between the lube oil separator and lube oil sump falls to 15 psia, whichever occurs first. Do not allow pressure differential between separator and sump to fall below 15 psi.

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7) Once the system is stabilized at 4 pole start motor speed, check instrumentation and record a complete set of power plant data. (Complete ANSOL 14001 and ANSOL 14002).

8) Set speed control set point at 10,000 RPM and select "Automatic" speed control.

9) Slowly reduce speed set point setting until speed control valve (SCV 102) barely cracks open. Observe and record speed control set point and the speed error value when this occurs.

   This value should be equivalent to the current speed of the turbine.

10) Slowly reduce set point setting until SCV 102 is full open or until 60 kw on start motor is reached. Record the set point value.

    CAUTION: Do not overload start motor (37 kw) for a period longer than two minutes. Do not exceed 67 kw or 400°F. on start motor.

11) Return speed set point to 10,000 rpm, and observe that the speed control valve fully closes. Move speed control selector to "Manual."

12) Ascertain that overspeed trip is set to trip at 20,075 rpm (TCS 670).

13) Manually trip the overspeed trip valve (SAV-101), determine that it has opened, and immediately reset.

    CAUTION: Do not overload start motor for more than two minutes. Do not allow start motor power to exceed 90 hp (67 kw).

    If the overspeed trip valve cannot be immediately reset to close the overspeed trip valve and thereby reduce start motor load, press the start motor "stop" button and allow unit to decelerate to a stop. Time deceleration.

14) Visually check and record oil level in oil sump sight glass.

15) Record, just before proceeding on to next step, the following:

    a) Oil temperatures (TI-601, TX-612, TX-613, TX-614).

    b) Compressor inlet pressure (PI-101a)

    c) Compressor Flow (FX-110-1)

    d) Turbine speed (SX-102)

    e) Turbine inlet temperature (TX-101-a)

    f) Start motor power

    g) Seal gas flow (FX-601)

    h) Balance chamber flow (Fg 6)

    i) Speed control valve position (VPnI-102). (Insure that SCV 102 is closed.)

    j) Compressor inlet temperature

    k) Bearing temperatures (TI-602. abcdefghjk)

16) Start speed tracing oscillograph.

17) Press start motor "stop" button. Using a stop watch time deceleration from the instant the "stop" button is pressed until unit reaches 1000 rpm turbine speed.

18) Compare start motor power requirements, bearing temperatures, deceleration rates, and other data, with previous test data. If significant variation from prior machinery set performance is noted the cause of the difference will be resolved and appropriate action taken before proceeding.

    Specific permission from the ML-1 General Supervisor or his representative shall be obtained before proceeding with this experiment under any circumstances.

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1. Precooler

   1) Start Precooler and Moderator Cooler Fans and check out associated systems (LOUVERS) in accordance with ANSOP 14000 and ANSOP 14001.

B. EXPERIMENT

NOTE: If more than four hours have elapsed since completion of the Nuclear Instrumentation Pre-Startup Check (ANSOP 14060), repeat step 7 and step 9 of ANSOP 14020. (Ref. step A2a5 of this procedure).

1. Execute ANSOP 14021, Reactor Startup. Rod withdrawal pattern shall be Rod Pattern No. 1 (all shims equally withdrawn).

2. Continue to operate reactor at low power in accordance with ANSOP 14022.

   NOTE: The reactor is now operating at low power (100 watts). All power plant auxiliary systems are operating. Lubricating oil is being circulated through the bearings and supply oil temperature is being maintained between 125 and 150^{o}F.

   System pressure level is approximately 40 psia. The startup compressor, on slow speed, is supplying seal gas to the turbine and compressor seals at approximately 65 psia. The mechanical integrity of the machinery set has been checked during steps 2k.1) through 18) above. The 480 volt Auxiliary Bus is being energized by commercial power and the 100 kw Emergency Diesel unit operating in parallel. The speed control set point is at 10,000 rpm, and the speed control system selector is in "Manual" position. Reactor Outlet (turbine inlet) temperature control selector is in "Manual" position. A final check of instruments will indicate that the power plant is ready for startup. Continuous monitoring of all power plant readout devices shall be in effect.

3. Turn on speed tracing oscillograph.

4. Press "slow" start button to energize start motor.

5. Allow machinery set to stabilize at 4 pole start motor speed (≈8000 rpm).

   CAUTION: Observe start motor power and/or current. Do not allow motor to draw more than 50 hp (37 kw) continuously.

   Maximum allowable start motor winding temperature is 400°F.

6. Manually open and close speed control valve (SCV 102) as follows:

   a. Open 10% - observe valve position (VPnI-102) and close.

   b. Open 20% - observe valve position (VPnI-102) and close valve.

   c. Open to 100%, briefly - observe (VPnI-102), and close.

7. Turn off speed tracing oscillograph.

8. Select "Automatic" position with speed control selector switch.

9. Slowly lower speed control set point from 10,000 rpm until speed control by-pass valve (SCV-102) cracks open.

   Observe and record turbine speed at the point SCV-102 cracks open. The set point should approximate actual turbine speed.

11. <u>Data Point No. 1.</u> Record a complete set of power plant data. Complete ANSOL 14001 and ANSOL 14002 and ANSOL 14520.

12. Withdraw shim rod number 2 to establish a positive period of 60 seconds. Hold this desired rate of power rise (period) until a reactor power level of one (1) kw is attained. (10^6 NV on Log N Power Meter).

13. Adjust shim rod number 2 to maintain a power level of one (1) kw.

    Log the time when 1 kw is attained.

14. Data Point No. 2. Record a complete set of power plant data . Complete ANSOL 14001, ANSOL 14002 and ANSOL 14520.

NOTE: Although reactor control adjustments up to now have been made using the neutron flux level indicators as power indicating devices, cross referencing with the reactor outlet (turbine inlet) temperature shall be made continuously.

The above change in reactor power from 100 watts to 1kw is roughly equivalent to an increase of 1°F in the turbine inlet temperature (TX 101a) under the existing power plant conditions. If an increase of greater than 1° is observed, determine the cause of increase before continuing with the next step.

15. Withdraw shim rod #2 and establish a positive period of 60 seconds, increasing the reactor power to 10 kw.

16. Adjust shim rod number 2 to hold the desired power level (~10 kw) and log time that 10 kw is obtained.

17. Data Point No. 3. Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002 and ANSOL 14520.

a. Start a plot of start motor power against turbine inlet temperature.

b. Cross plot nuclear channels 3 and 7 and the SAM chambers for linearity.

c. Pull a carbon trap sample and count the sample.

18. Withdraw shim rod #2 and establish a positive period of 60 seconds, increasing the reactor power to 100 kw.

19. Adjust shim rod #2 to hold the desired power level (approximately 100 kw) and log time that 100 kw is attained.

NOTE: At this point a reading of about 3% should appear on the linear power meter (5, 6 and 7). The ΔT across the reactor should be about 75°F. It is estimated that the turbine inlet temperature should be approximately 210°F.

20. Data Point #4. Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002 and ANSOL 14520.

    a. Plot start motor power against turbine inlet temperature.

    b. Cross plot nuclear channels 3 and 7 and SAM channels for linearity.

    c. Pull a carbon trap sample and count the sample.

21. Withdraw shim rod #2 and establish a positive period of 60 seconds, increasing the reactor power to 250 kw.

22. Adjust shim rod number 2 to hold the desired power level (250 kw) and log time that 250 kw is obtained.

23. Data Point No. 5. Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002 and ANSOL 14520.

    a. Plot start motor power against turbine inlet temperature.

    b. Cross plot nuclear channels 3 and 7 and the SAM channels for linearity.

    c. Pull a carbon trap sample and count the sample.

NOTE #1:

Reactor power of 250 kw is expected to yield the following:

a. A reading of approximately 2.5×10^8 nv on the Log N Power Meter (channels 3 and 4).

b. A reading of approximately 7.5% total power on the linear power meter (channels 5, 6 and 7).

c. A ΔT across the reactor of approximately 180°F (assuming a mass flow of 4.5 lb/sec).

d. A turbine inlet temperature of 725°F.

<u>NOTE # 2:</u>

A plot is being maintained of start motor power vs turbine inlet temperature to determine prediction for the self-run temperature at the current system pressure level (40 psia at compressor inlet).

24. Using regulating rod, increase turbine inlet temperature at a rate of less than 50°F per minute until one of the following occurs:

    a. Self-run is attained. (Start motor power drops to near zero).

    b. Turbine inlet temperature reaches 1200°F.

    c. Reactor power reaches 500 kw (t) $\approx$ 15% on linear power scale.

    d. Precooler inlet temperature reaches 500°F.

    e. First indication of compressor surge.

25. <u>Data Point No. 6.</u> Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002 and ANSOL 14520.

    a. Plot the start motor power against turbine inlet temperature.

    b. Cross plot nuclear channels 3 and 7 and the SAM channels for linearity.

    c. Pull a carbon trap sample and count the sample.

26. In the event self-run cannot be attained by increasing turbine inlet temperature up to 1200°F, execute step B27. Otherwise proceed to step B28.

27. Raise system pressure (compressor inlet) in 5 psi increments. Allow plant to stabilize at each pressure level. Plot start motor power against compressor inlet pressure at constant temperature to predict self-run pressure.

    Maintain 1200°F turbine inlet temperature by adjusting regulating rod. It will be necessary to increase reactor power roughly in proportion to increase in system pressure.

NOTE: a. Do not exceed 120 psi at compressor inlet.

b. Do not increase system pressure at this point beyond that required to attain self-run.

28. When self-run is attained, allow the unit to accelerate to set point speed (10,000 rpm).

29. Secure start motor.

30. Data Point No. 7. Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002, and ANSOL 14520.

31. If the speed control by-pass valve (SCV-102) is open more than 10% (VPnI-102) slowly advance speed control set point and allow turbine to accelerate to rated speed, pausing at each 1000 rpm long enough to insure that the power plant is under complete control. Adjust regulating rod to maintain 1200°F turbine inlet temperature.

If SCV-102 is not 10% open, slowly increase compressor inlet pressure (not to exceed 120 psia) until SCV-102 is at least 10% open but not more than 60% open. Then advance speed control set point and allow unit to accelerate to rated speed, pausing at each 1000 rpm to insure that the power plant is under complete control. Use regulating rod to maintain a turbine inlet temperature of 1200°F.

NOTE: a. The machinery set shall not be held in a speed region of vibration resonance as determined either by previous tests or by vibration readings.

b. If at any time during the startup period the speed control by-pass valve (SCV-102) is more than 60% open to hold desired speed, either turbine inlet temperature or system pressure shall be reduced until the by-pass valve is less than 60% open.

c. Auxiliary oil pump should shut off automatically at about 60% rated speed.

d. Startup compressor should shut off at about 90% rated speed.

32. Stabilize power plant at rated speed. Adjust cooler louvers as necessary to maintain desired moderator water and oil temperature.

33. Maintain 1200°F at Reactor Outlet (turbine inlet). Reactor power will now be at 50 to 90% power depending upon system pressure required to attain rated speed.

34. Set alternator voltage regulator to produce an alternator output voltage of 4160 volts (phase to phase).

35. <u>Data Point No. 8.</u> Complete ANSOL 14001, ANSOL 14002, and ANSOL 14520. Record a complete set of power plant data.

36. Slowly adjust system pressure until speed control valve is 40% open (if obtainable) at 1200°F turbine inlet temperature.

CAUTION: Do not exceed 120 psia at compressor inlet under any circumstances.

37. <u>Data Point No. 9.</u> Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002, and ANSOL 14520.

38. Ascertain that the electrical distribution system, including the load bank, is lined up, in accordance with ANSOP 14340, to load alternator with load bank only.

39. Using load bank control console, apply up to 50 kw balanced resistive load to the alternator in 5 kw increments (1.67 kw per phase). Reference ANSOP 14342, Electrical Distribution System Operation.

40. <u>Data Point No. 10.</u> Record a complete set of power plant data. Complete ANSOL 14001, ANSOL 14002, and ANSOL 14520.

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41. Ascertain that reactor temperature control system has been prepared for operation in accordance with ANSOP 14100.

    a. Adjust reactor temperature control set point to 1200°F. (Zero error.)

    b. Ascertain that regulating rod is positioned at 30°, and that temperature error is zero. Adjust shim rod number 2 as necessary to "position" regulating rod.

    c. Switch temperature control selector from manual to automatic control.

    CAUTION: Be prepared to override automatic temperature control system in the event of malfunction of large "overshoot."

    If automatic temperature control is not satisfactory, return to manual control of regulating load.

42. Slowly reduce turbine inlet temperature by adjusting temperature control set point until speed control by-pass valve is not more than 2% open.

43. Data Point No. 11. Record a complete set of power plant data.

44. Operate the power plant under these conditions for at least 2 hours. Do not exceed any limit set forth under POWER PLANT OPERATING LIMITS FOR THIS TEST above.

    A complete set of power plant data will be recorded every 30 minutes:

    Data Point No. 12

    Data Point No. 13

    Data Point No. 14 - - - -

45. Reduce alternator load in 5 kw increments until all electrical load is removed. Closely monitor automatic temperature and speed control responses and bypass valve positions (reactor outlet temperature).

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46. Slowly reduce system pressure until unit begins to decelerate. Reduce system pressure by venting through V-109 to the low pressure storage tank.

    CAUTION: Do not allow compressor inlet pressure to fall below 40 psia.

    If it is necessary to reduce compressor inlet pressure to 40 psia during the deceleration process, hold system pressure and reduce turbine inlet temperature to effect continued deceleration to 4 pole start motor speed. Reduce temperature by slowly adjusting temperature control set point.

    As unit decelerates, follow turbine speed with speed control set point.

47. Once the turbine is on the start motor (at least 5 kw indicated on start motor power meter):

    a. With turbine inlet temperature stabilized at zero error, move temperature control selector to "manual" position.

    b. Using shim rods manually reduce power level at a rate to effect a decrease in turbine inlet temperature of about 100°F per minute.

    c. Insure that the startup compressor and auxiliary oil pump are both operating.

        CAUTION: Do not overload start motor. Bleed system pressure to 40 psia (compressor inlet) after unit is on start motor.

48. When the reactor power level drops to less than 100 watts execute a reactor shutdown in accordance with ANSOP 14023.

49. Continue to rotate machinery set until turbine inlet temperature is stable at a temperature below 175°F. Continue to monitor and log fuel element temperatures radiation levels, and other power plant parameters.

50. In preparation for machinery set deceleration check, log:

    a. Compressor Inlet Pressure and Temperature

    b. Compressor, Turbine, By-Pass, and Seal Gas Flow data.

    c. Oil Supply Temperature

    d. Bearing Temperature

    e. Turbine Inlet Temperature

    f. By-Pass Control Valve Position

    g. Start Motor Power.

    Start speed tracing oscillograph.

51. Press start motor stop button. Using a stop-watch, measure time required for turbine to decelerate to 1000 rpm.

52. Stop speed tracing oscillograph. Record seal gas flow data, oil flow data, oil system pressure and temperature after unit has stopped.

53. Continue to monitor and record shutdown radiation levels and reactor fuel element temperatures. Log data at least once each hour.

54. Secure precooler fans in accordance with ANSOP 14173.

55. Secure lube oil system in accordance with ANSOP 14133.

56. Secure Battery-Inverter System in accordance with ANSOP 14300.

57. Secure auxiliary power unit in accordance with ANSOP 14323.

58. Secure Gas Supply Unit in accordance with ANSOP 14293.

59. Secure Gas Analysis Equipment

60. Secure instrumentation readout equipment except as required for special data (shutdown radiation level).

61. Execute Power Plant Post Shutdown Checks as radiation levels permit.

62. Obtain at least a 100 ml sample of oil from the oil sump at earliest opportunity.

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STANDARD OPERATING PROCEDURE
MOBILE LOW POWER REACTOR-I

PROCEDURE SECTION 16 EXPERIMENTAL PROCEDURES

TITLE: FULL POWER TEST

SCOPE:

This procedure provides for execution of the experiment, FULL POWER TEST, which was described in Paragraph 2.b, page 67, of the ML-1 NUCLEAR POWER PLANT TEST PROGRAM.*

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

a. Bring the ML-1 Power Plant to rated speed.

b. Apply balanced load in small increments to determine the maximum permissible gross electrical load that can be applied without exceeding the power plant limits established for this test.

c. Secure the power plant after several hours of operation under load.

The procedure covers the second of a series of initial power tests aimed at gross experimental evaluation of the power plant. This experiment 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 ML-1 NUCLEAR POWER PLANT TEST PROGRAM.

* The Test Program comprises Section IV of this supplement.

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SUPPLEMENTAL PROCEDURES

Supplemental procedures required for reference in implementing this procedure include:

TITLE	ANSOP NUMBER
Personnel Control Procedure	2302
Lock and Tag Procedure	3150
Power Plant Pre-Startup Check List	14000
Power Plant Post Shutdown Checks	14004
Power Plant Emergency Procedures	14005
Reactor Pre-Startup Check List	14020
Reactor Startup	14021
Low Power Reactor Operation	14022
Low Power Reactor Shutdown	14023
Nuclear Instrumentation Pre-Startup Check	14060
Non-Nuclear Scram Circuit Check	14070
Control Blade System Pre-Startup Check	14080
Reactor Temperature Control System Pre-Startup Check	14100
Lube System Startup	14131
Lube System Shutdown	14133
Precooler Assembly Startup	14171
Precooler Assembly Shutdown	14173
Speed Control System Pre-Startup Check	14210
Moderator System Startup	14251
Moderator System Shutdown	14253
Shield Water System Startup	14271
Shield Water System Shutdown	14273
Main Gas Loop Pressurization	14290
Gas Handling System Startup	14291
Gas Handling System Shutdown	14293
Battery Inverter System Operation	14300
Auxiliary Power Generator Startup	14321
Auxiliary Power Generator Shutdown	14323
Electrical Distribution System Pre-Startup Check	14340
Electrical Distribution System Operation	14342
SAM System Startup	14360
Gas Analysis Equipment Startup	14422

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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 test:

a.	Reactor Power	3.3 MW total
b.	Turbine Inlet Temperature	1225°F
c.	Compressor Inlet Pressure	120 psia
d.	Compressor Discharge Pressure	335 psia
e.	Precooler Inlet Temperature	500°F
f.	T-C Set Bearing Temperature	190°F
g.	Compressor Inlet Temperature	131°F
h.	Vibration	1.5 g
i.	Reactor Inlet Pressure	315 psia
j.	Alternator Stator Winding Temperature	275°F
k.	Start Motor Winding Temperature	400°F
l.	Start Motor Power (continuous)	37 kw
	(short time - less than 2 minutes)	67 kw
m.	Lube Oil Supply Temperature	150°F
n.	Start Motor Current per Phase (Continuous)	53 amps
	(Short time)	100 amps
o.	Positive Reactor Period	50 sec
p.	High Level Channels 5, 6, and 7	110% power
q.	Shorted Period Channels 1, 2, 3, and 4	10 sec period
r.	Reactor Outlet Temperature	1275°F
s.	Fast Pressure Loss $\frac{dp}{dt}$	$\frac{45\ \text{psi}}{10\ \text{sec}}$
t.	Moderator Water Flow Low	275 gpm
u.	T-C Set Speed	20,075 rpm
v.	Compressor Inlet Temperature	150°F

w.	Reactor Outlet Temperature Error	$\pm$ 40°F
x.	Moderator Water Outlet Temperature from Reactor	195°F
y.	Moderator Water Outlet Temperature from Heat Exchanger	185°F
z.	Moderator Water Level Low	-8 in.
aa.	Moderator Water Conductivity High	2 micro/mhos
bb.	Shield Water Level Low	-2 in.
cc.	Shield Water Conductivity Low	2 - 5% concentration boric acid
dd.	Shield Water Temperature Low	120°F
ee.	Lubrication Oil Sump Level Low	-6 in.
ff.	Lubrication Oil Filter Pressure Drop High	20 psi
gg.	Auxiliary Lubrication Oil Pump Startup	310 psia
hh.	Gas Storage Spheres A or B Pressure High	3000 psig
ii.	Transfer Compressor Oil Pressure Low	10 psig
jj.	Transfer Compressor Diaphragm Rupture	750 psig
kk.	Oxygen Make-up Pressure Low	200 psia
ll.	Control Cab Area Radiation High	1-5 mr/hr
mm.	Fuel Element Thermocouple High	1350°F
nn.	Reactor Skid Analysis Thermocouples	
	TX 211 (Inner Radial Shield)	300°F
	TX 212 (Upper End Cone)	250°F
	TX 213 (Shield Water)	200°F
	TX 214 (Shield Water Piping)	200°F
	TX 215 (Moderator Water Circulatory Pump)	200°F

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PROCEDURE

NOTE: Execution of this procedure shall be closely monitored by:

1. ML-1 General Supervisor or his representative.

2. Health and Safety Supervisor or his representative.

3. Power Conversion Skid Engineer.

Execution of this procedure shall be at the direction of the ML-1 Shift Supervisor.

A. PREPARATION

1. Execute Steps A1 through A15 of ANSOP 16615.

B. EXPERIMENT

NOTE: If more than four hours have elapsed since completion of the Nuclear Instrumentation Pre-Startup Check (ANSOP 14060) repeat step 7 of ANSOP 14020 and ANSOP 14070.

1. Execute steps B1 through B37 of ANSOP 16615.

   This leaves the power plant at the following conditions:

   a. Rated Speed.

   b. 1200°F Turbine Inlet Temperature.

   c. 50 KW of balanced resistive load applied.

   d. Operating on AUTOMATIC temperature and speed control.

2. Slowly reduce turbine inlet temperature to 1100°F by adjusting temperature set point in 10° increments.

3. Slowly increase system mass by admitting gas through V109.

   a. Admit gas to increase compressor inlet pressure in 5 psi increments.

b. Increase compressor inlet pressure to 100 - 110 psia depending upon ambient temperature.

c. Hold compressor inlet pressure constant.

d. Maintain 1100°F at turbine inlet.

e. Watch position of SCV-102. Log position of valve after each 5 psi change in system pressure. Maintain turbine inlet temperature constant.

f. If SCV-102 should reach 80% open position in order to hold turbine speed, stop adding gas to system until enough load is applied to close SCV-102 under the 80% open position.

g. Log complete set of power plant data following each 10 psi rise in compressor inlet pressure.

DATA POINTS 9, 10, 11, 12, 13, and 14.

4. Apply a balanced load with load bank to alternator in 10 KW increments until 100 KW is reached or until speed control by-pass valve closes to 2% open, whichever occurs first. Watch winding and bearing temperatures.

5. DATA POINT

Record a complete set of power plant data. Ascertain that power plant conditions are satisfactory before proceeding.

If SCV-102 is 2% open with 100 KW or less applied proceed to step B 14. Otherwise, proceed to step B 6.

6. Apply balanced load (with load bank) in 10 KW increments until 150 KW is applied to alternator or until SCV-102 is 2% open, whichever occurs first.

7. DATA POINT

Record a complete set of power plant data.

Ascertain that power plant is operating satisfactorily within established limits for this test before proceeding. T_7 = 1100°F.

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If SCV-102 is only 2% open with 150 KW or less load applied, proceed to step B 14. Otherwise, proceed to next step (B 8).

8. Apply balanced load in 10 KW increments until 200 KW is reached or until SCV-102 is 2% open.

9. DATA POINT

Record a complete set of power plant data.

Ascertain that power plant is operating satisfactorily before proceeding.

If SCV-102 is only 2% open with 200 KW or less applied proceed to step B 14. Otherwise proceed to step B 10.

10. Apply balanced load in 10 KW increments until 250 KW is applied or until SCV-102 is 2% open.

11. DATA POINT

Record a complete set of power plant data.

Ascertain that power plant is operating satisfactorily before proceeding.

If SCV-102 is only 2% open with 250 KW or less load applied proceed to step B 14. Otherwise, proceed to step B 12.

12. Apply balanced load in 10 KW increments until control by-pass valve (SCV-102) is 2% open.

13. DATA POINT

Record a complete set of power plant data.

14. If compressor inlet pressure is less than 110 psia, slowly admit gas to system through V109 until a compressor inlet pressure of 110 psia is reached.

If compressor inlet pressure is 110 psia and the by-pass valve SCV-102 is 2% or less open, proceed to step B 16. Otherwise, proceed to next succeeding step B 15.

15. Apply balanced load to alternator in 10 KW increments until control by-pass valve (SCV-102) is 2% open.

    Turbine inlet temperature should be 1100° F.

16. DATA POINT

    Record a complete set of power plant data. Complete ANSOL 14001 and ANSOL 14002.

17. Operate power plant at this condition (T_7 = 1100° F.) for at least two hours. Log a complete set of data every 30 minutes. (DATA POINT).

18. Slowly advance reactor outlet (turbine inlet) temperature controller set point to 1200°F in 10°F increments. Monitor automatic temperature controller closely and be prepared to "over ride" regulating rod automatic control.

    Watch turbine speed and position of by-pass valve (SCV-102) closely. By-pass valve shall not be permitted to open more than 80%.

19. DATA POINT

    Record a complete set of power plant data.

20. Using the load bank control console apply load to alternator in 10 KW steps until speed control by-pass valve (SCV-102) is 1 to 2% open.

    NOTE: Do not exceed any power plant limit established for this test.

21. DATA POINT

    Record complete set of power plant data at this full power condition.

22. Continue to operate power plant for at least one hour at this full power condition. Record data (DATA POINT) every 30 minutes.

23. To initiate power plant shutdown, remove alternator load in 10 KW steps until the speed control by-pass valve (SCV-102) is at least 10% open.

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24. Slowly move gas temperature controller set point to 1100°F or until SCV-102 is 2% open, whichever occurs first.

25. Remove load in 10 KW steps until all electrical load is removed from alternator.

26. Execute steps B 46 through B 62 of ANSOP 16615.

APPENDIX A

RECOMMENDATIONS BY U.S. AEC DIVISION OF LICENSING AND REGULATION

RECOMMENDATIONS BY U.S. AEC DIVISION OF LICENSING AND REGULATION

Recommendation 1: It is recommended that an inspection method be developed for the purpose of detecting defects or incipient failures (such as pits, cracks or distortion) in the system and there be periodic inspection to verify the integrity of the system.

This recommendation is particularly apropos in light of the recent failure at the GCRE. Inspection of the interior surface of the GCRE pressure tube, including the roll and weld areas, is being done with a boroscope. This method also will be utilized on the ML-1 on a periodic basis whenever core activation precludes direct visual inspection. While an inspection of the exterior (moderator side) surface would be desirable, no practical method is known for accomplishing this in the existing plant. The importance of this recommendation is fully recognized, and further investigation of new inspection methods is in progress.

Recommendation 2-a: Consideration should be given to a quick acting back-up or emergency shutdown system.

During the preliminary design phase of the ML-1, a great deal of consideration was given to a quick-acting emergency shutdown system. The results of this investigation are summarized in AGN TM-342, Reactor Fuse Applications to AGCRSP, 15 January 1959.

An emergency shutdown system is being incorporated into the ML-1: The borated shield water will be introduced into the inlet side of the moderator circulating pump by means of a bypass line from the shield water circulating pump discharge line. A solenoid valve in the bypass line will be manually energized from the control cab. Opening of the solenoid valve will introduce borated water into the moderator circuit.

Recommendation 2-b: A method should be devised to indicate separation or failure of control blade linkage.

It was recognized early in the design phase that the control blade position indicators should be placed as close as possible to the blades. However, high radiation levels preclude electrical transducers in the core region, and a less direct method (measuring shaft rotation) was necessarily adopted. A direct indication of blade motion is available, however: when any blade pair is withdrawn, a significant change occurs in the neutron level, even in the far subcritical condition. If the control blade linkage has failed, this change will not occur, thus giving an unequivocal indication of the failure to the reactor operator. This detection method has been incorporated into the ML-1 operating procedures.

Recommendation 2-c: Means should be provided for mechanically locking the blades in the core during maintenance, refueling, and transport operations.

There are two mechanisms for locking the control blades in the reactor core:

The first mechanism consists of a spring-loaded pin that locks the limit switch arm of the actuator in position with the limit switch support. By forcing the clutch to slip, the mechanism will override any attempts to operate the actuator electrically.

The second mechanism is used when an actuator is removed. Immediately after removal, the driveshaft locking fixture is placed over the tang of the driveshaft and flat on the actuator support structure. The spring pin chained to the fixture is inserted through holes in the fixture and in the support structure.

The existing clock-type holding spring exerts a torque of approximately 30 in.-lb to hold the blades in the scrammed position. This torque is sufficient to require a wrench on the tang of the driveshaft to override the spring intentionally and cause the blades to open.

The blades are unbalanced; the upper blade is heavier than the lower blade. The blades weigh 6.2 and 5.4 lb, respectively. The center of gravity of each blade is approximately 5.8 in. from the axis of the driveshaft. Consequently, shock loads in a downward direction will tend to close the blades. Shock loads in an upward direction produce approximately: (6.2 - 5.4) lb x 5.8 in., or 3.5 in.-lb/g. Therefore, a shock load equivalent to 30 in.-lb / 3.5 in.-lb-g, or 8-1/2 g is required to equalize the closing torque.

In the case of horizontal shock loads, one set of control blades will be subjected to a maximum opening force; two other sets will receive lesser opening forces; and three sets will receive closing forces. The center of gravity of the blades is approximately on a line passing through the axis of the drive gears at 5° from horizontal. Shock loads produce approximately: $(6.2 + 5.4) \times 5.8 \sin 5^\circ$, or 5.9 in.-lb/g. Thus, a horizontal shock load of 30 in.-lb / 5.9 in.-lb/g, or 5.1 g is required to equalize the closing torque.

When the reactor is being transported, either the actuators or the driveshaft locking fixtures will be in place, to augment the action of the holding spring in maintaining the blades in the scrammed position.

During maintenance, it is possible to remove the dashpot assembly in addition to the actuator mechanism, although this will be done only infrequently. With the dashpot removed, the blades are held in the core by gravity (due to the weight inbalance between the upper and lower blades) and friction. In this condition, it is relatively easy to actuate the blades out of the core. However, maintenance will be performed on only one blade at a time; and the actuator housings are locked to prevent inadvertent manipulation. The reactor will remain subcritical under all conditions even if any two pairs of blades are withdrawn. Therefore, no credible hazardous situation will result from the unlocked blades. The blades will be positively locked during all transport.

Recommendation 2-d: Consideration should be given to removal of moderator water or to neutron poisoning of the water during maintenance, refueling and transport operations.

It has been experimentally verified that the ML-1 will remain subcritical with any two pairs of control blades withdrawn with the core in any possible condition (hot or cold, flooded or unflooded). In addition, the control blades will be locked in position during any refueling or transport operation. The ML-1 may be transported with the moderator passages empty or filled with either borated or unborated water, depending on existing radiation and afterheat problems. The safest method of transport would be with the core completely flooded with unborated water as no nuclear accident could then result from submerging the reactor in water and subsequently filling the voids in the core or replacing borated water with unborated water. Nevertheless, with the control blades locked in place, no credible nuclear accident can result during transport.

Recommendation 2-e: All reactor maintenance activities should be performed under direct supervision and in accordance with detailed procedures in order to minimize the possibility of uncontrolled reactivity increases as a result of inadvertent movement of the control blades.

Existing operating philosophy specifies that all activities be performed under the direct supervision of AGC employees and in accordance with previously approved detailed procedures.

Recommendation 3-a: We recommend that only the regulating blades be used for "automatic" control and that the automatic shimming feature be removed.

The control circuitry has been modified to delete the provision for automatic positioning of the shim blades. Only the regulating blade will be on automatic control.

Recommendation 3-b: It is recommended that an interlock be installed to prevent the use of "automatic" control during "startup" or at low power levels. This interlock would decrease the probability of a "startup" accident or a power excursion.

Additional circuity is being added to provide an interlock to prevent use of "automatic" control during startup or at low power levels. The interlock will permit switching to automatic control only after a predetermined power level has been reached in the intermediate power level channels.

Recommendation 4: It is recommended that a recorder be provided for startup and for maintaining permanent records during future operation at other sites.

ML-1 has such a recorder for operation at NRTS. Provisions are also being made to incorporate a recorder in the ML-1A design.

Recommendation 5: It is recommended that detailed procedures and allowable activity limits be established before these <open-cycle air> operations are performed.

Existing operations policies cover this item; detailed procedures have been developed for such operations (refer to ANSOP 2100 included at the end of Appendix A). An air monitor adjacent to the reactor is set to provide an alarm above the predetermined level.

Recommendation 6: Inasmuch as the procedures are incomplete and have not received final approval, it is recommended that no facility operations, including maintenance, be performed until appropriate procedures applicable to particular operations are available.

The existing procedural system and philosophy of operation is in accordance with this recommendation.

Recommendation 7: Prior to operation of the reactor, there should be assurance that the staff is adequately trained and qualified to operate this facility.

The approach taken on qualification for reactor operation, beginning in September 1960, was to present a series of formal lectures to the reactor operators. The lectures covered a wide range of topics, including basic reactor design, operational theory, safety considerations, health physics, plant chemistry, and operation of reactor auxiliaries. Each lecture was presented by a specialist and examinations were administered at the conclusion of most of the lectures. The lectures were followed by on-the-job training at San Ramon and Azusa, in which the reactor operators participated in and observed the assembly and testing of reactor and control cab components. Following the training period, operators were assigned to the GCRE for on-the-job training in gas-cooled reactor technology. At the conclusion of this training, the operators were given a written and oral examination concerning GCRE.

As the next step, a familiarization program was conducted with the reactor skid and control cab during final installation and pre-critical testing at NRTS. Prior to taking the reactor to criticality, a written examination was administered to all ML-1 operators.

Reactor power plant qualification and training will consist primarily of familiarization with the power-conversion skid and operation of the skid at Azusa prior to shipment to NRTS.

In the cases of both the reactor skid and the entire power plant, periodic re-examinations will be conducted on a six-month basis. The re-examination will consist of an oral test to insure that the operator is familiar with all sensitive aspects of equipment operation and with potential hazards. The oral test will be supplemented by a written examination.

In addition to the periodic re-examinations, a continuing program has been established to present lectures in the areas of health physics, safety, and nuclear instrumentation. To supplement the overall program, brief lectures are presented prior to conducting each ANSOP, in order to discuss the purpose, method of performance, and potential hazards of the procedures.

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STANDARD OPERATING PROCEDURE
GAS-COOLED REACTOR EXPERIMENT-I

PROCEDURE SECTION: 2 RADIOLOGICAL SAFETY

TITLE: RADIOLOGICAL HAZARDS CONTROL

SCOPE

This procedure sets forth the basic control criteria which will be used to minimize the radiological exposure hazard of personnel associated with the GCRE-I. The radiation exposure and contamination limits are generally more conservative than those specified in AEC Manual, Chapter 0524. Adequate records and controls have been established (see ANSOP's 2000 and 2900) to assure that the procedures herein described have been satisfied.

PROCEDURE

A. MAXIMUM PERMISSIBLE EXPOSURES FROM EXTERNAL SOURCES OF RADIATION

1. Whole Body Exposure

   No more than 50 mrem/day or 300 mrem/week or 15 rem/year provided that the accumulated lifetime exposure of an employee with age = N does not exceed 5(N-18)rem.

2. Body Extremities Exposure

   No more than 300 mrem/day or 1.5 rem/week provided that the accumulated lifetime exposure of an employee with age = N does not exceed 10 (N-18) rem.

3. Special Notes

   a. Up to 900 mrem body exposure and up to 4.5 rem extremities exposure may be accumulated in one week with prior approval of the Health & Safety Supervisor and Operating Superintendent. This may occur only once in any calendar quarterly period.

   b. The entire weekly dose may be accumulated in one day with prior approval of the Health & Safety Supervisor and Operating Superintendent.

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c. Up to 100 mrem body exposure and up to 600 mrem extremities exposure may be accumulated in one day with prior approval of the Shift Supervisor. This may occur only once in any week. Notice must be given to the Health & Safety Supervisor of such action within 24 hours.

d. In all of above cases, the Shift Supervisor must contact the individual involved and review with the individual his exposure history, being sure he understands how to control his activities for the balance of the week or quarter.

e. In no case, will an individual be permitted to accumulate more than 300 mrem body exposure or 1.5 rem extremity exposure in a single exposure.

f. The film badge and wrist badge records will be the prime source of information pertaining to radiation exposures.

4. The table given below may be used to correleate indicated radiation levels with the MPE established under #1.

Radiation	Rate to give 50 mrem in 8 hrs	Rate to give 300 mrem in 40 hrs
X, γ or β	6.25 mr/hr	7.5 mr/hr
Slow Neutrons	1250 $n/cm^2/sec$	1500 $n/cm^2/sec$
Fast Neutrons	42 $n/cm^2/sec$	50 $n/cm^2/sec$

B. MAXIMUM PERMISSIBLE CONCENTRATION OF RADIOACTIVITY IN AIR AND WATER

1. In accordance with AEC Manual, Chapter 0524-02-2 C,the concentration of airborne or waterborne radioactive contaminats (where inhalation or ingestion are possible) will be kept within the limits established in BNS Handbook #52. The added instruction that ingested radiation having the whole body or the gonads as the critical organ will be kept to one-third the MPC listed in BNS #52 will also be met. For unidentified mixtures of contaminants in air or water, the following MPC's will apply:

Medium in Which Contained	β or γ Emitter	α Emitter
Air	10^{-9}	5×10^{-12}
Water	10^{-7}	10^{-7}

2. Frequent checks will be made of the GCRE-I environment to establish the airborne and waterborne radio-contaminant concentration level. The presence of contamination levels greater than those listed in 1 above will require corrective and personnel protection measures until such time as allowable levels have been re-established.

C. SURFACE CONTAMINATION

1. Any area known to be contaminated will be isolated and established as an RCZ. The hazard will be evaluated and decontamination will be initiated in accordance with ANSOP 2600.

D. PERSONNEL RADIOLOGICAL HYGIENE

1. As part of the employee pre-employment physical examination, a complete blood analysis and vital capacity measurement will be taken.

2. After employment, the "lab work" and vital capacity measurement will be repeated no less frequently than every nine (9) months.

3. A follow-up physical examination will be conducted no less frequently than each eighteen (18) months after employment.

4. In the event of a serious incident, or where otherwise indicated, bio-assays will be made of biological specimens supplied by GCRE employees to determine the presence or absence of radioactive material.

5. All data accumulated under Items #1 - 4 above will be reviewed and evaluated by Aerojet's Radiological Medicine personnel who will advise GCRE management of corrective actions when necessary.

6. The complete blood analysis and vital capacity measurement will be repeated as a part of the termination of employment physical examination.

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STANDARD OPERATING PROCEDURE
AGN-IDAHO OPERATIONS

PROCEDURE SECTION 0 ADMINISTRATIVE PROCEDURES

TITLE: PREPARATION AND APPROVAL OF ANSOP AND ANTS

SCOPE

This procedure outlines the responsibilities and authorities involved in the preparation and approval of ANTS and ANSOP.

PROCEDURE

A. PREPARATION AND APPROVAL

1. ANTS and ANSOP will be drafted by the NRTS Operations Group.

2. All ANTS and all ANSOP related to reactor operation, reactor safety or experimental procedures will be submitted for approval to the Procedure Review Board at San Ramon. (See ANSOP 0103 for the charter of the PRB).

3. ANSOP relating to reactor safety, as designated by the Manager, Operations Department or by the Supervising Representative,will be reviewed by the AGN Reactor Safety Committee.

4. All ANTS and ANSOP will be submitted to the Supervising Representative for approval per Section B of this procedure. Steps 2 and 3 above will be completed prior to this submittal where required.

5. All ANTS and ANSOP, after approval by the Supervising Representative, will be submitted to the Contracting Officer, USAEC-IDO, for approval per Section B of this procedure.

6. When all of the above approvals have been received, the final procedure will be published by the NRTS Operations Department as outlined in Section B of this procedure.

B. TRANSMITTAL AND APPROVAL FORM

1. ANTS and ANSOP submitted for approval to the Supervising Representative or Contracting Officer will be transmitted under three copies of ANSOL 0001.

2. Approval signatures will be affixed in ink on all copies of ANSOL 0001 at the time of approval.

3. The Supervising Representative or the Contracting Officer may retain a copy of ANSOL 0001 for his files after his approval signature is affixed. The Supervising Representative's copy will become official file copy at San Ramon.

4. The original copy of ANSOL 0001 with both approval signatures will be transmitted to the NRTS Operations Group.

5. Upon receipt of completed ANSOL 0001, the originating group will complete the reproducible copy of the procedure in the "approved" block (top left) and reproduce the procedure for distribution and use.

C. REVISIONS

1. Revisions will be prepared by the NRTS Operations Group.

2. a. Revisions to procedures specified in A-2 and A-3 above will be submitted for approval to the Procedure Review Board at San Ramon.

   b. A revision approved by the PRB will be published on yellow paper and incorporated in the manuals for temporary use over the authorizing signature of the NRTS Operations Department Head, provided the revision is within Technical Standards.

3. ANSOP revisions which are outside Technical Standards and all revisions to ANTS will be submitted for approval per Sections A and B of this procedure before use.

4. All revisions to procedures not covered by C-2 or C-3 above will be issued on yellow paper and incorporated in the manuals for temporary use over the authorizing signature of the NRTS Operations Department Head.

5. All temporary revisions will be submitted for approval per Sections A and B of this procedure. Upon receipt of approval, the yellow issue will be replaced with a white issue.

D. TEMPORARY AUTHORIZATIONS

1. ANSOP, except those relating to reactor safety, reactor operation or experimental procedure, may be approved for use under a temporary authorization by the NRTS Operations Department Head pending receipt of formal approval.

2. The NRTS Operations Department Head shall indicate such temporary authorization by so marking two copies of the procedure and affixing his signature and the date. Such authorization will be given only after the Operations Department Head has satisfied himself by consultation and investigation of the correctness of the procedure.

E. SPECIAL EXPERIMENTAL PROCEDURES

1. Reactor or power plant experimental operations, which constitute a combination of normal operations (as differing from experimental procedures) specified in approved ANSOP, may (at the discretion of the NRTS Operations Department Head) be conducted under the authorization of a special experimental procedure. Such procedures will be assigned ANSOP numbers, will be in ANSOP format, and must be approved by the NRTS Department Head prior to performance. Special experimental procedures will be reviewed by the NRTS Procedures Review Board at the direction of the NRTS Department Head. In no case may approval be granted for a special experimental procedure which violates ANTS.

F. DEVIATIONS FROM PROCEDURE - LEVELS OF AUTHORIZATION

1. It is recognized that although ANSOP are screened at several technical levels, inadequacies in procedures may become apparent during performance of the procedure. This fact, coupled with the unanticipated failure of equipment during a test run, may necessitate field modifications or deviations from written procedures during test operation. The levels of authorization for such deviation are presented below:

   a. Shift Supervisor - No authority to deviate from written procedure.

   b. General Supervisor - Authority to make field changes from written procedures which DO NOT violate ANTS, the safety intent of the ANSOP or good operating practice.

c. NRTS Operations Department Head - Authority to make field changes which do not violate ANTS or jeopardize the safety of personnel.

2. All field changes shall be processed as ANSOP revisions as soon as practical.