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UC-81:"Reactors-Power"
TID-4500 (15th Edition)
CONTRACT AT(10-1)-880

ARMY GAS—COOLED REACTOR SYSTEMS PROGRAM

THE ML-1 DESIGN REPORT

16 MAY 1960

THE MILITARY PROJECTS DIVISION

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

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Published
16 May 1960
by

The Military Projects Division
Aerojet-General Nucleonics
San Ramon, California
A Subsidiary of Aerojet-General Corporation

Approved by:

G. A. Linenberger
Supervising Representative
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ML-1 DESIGN REPORT

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THE ARMY GAS-COOLED REACTOR SYSTEM PROGRAM

THE ML-1 DESIGN REPORT

ABSTRACT

This report describes the design of the mobile nuclear power plant being developed for the United States Atomic Energy Commission and the United States Army Corps of Engineers by Aerojet-General Corporation under Contract AT(10-1)-880 and Contract DA-44-009-ENG-3252. The ML-1 is to be the prototype of a mobile, low-powered nuclear power plant intended to furnish electrical power in remote locations. It is to be transportable by several types of aircraft, ship or barge, railroad flatcar, and on standard Army trailers.

The ML-1 is a high temperature, gas-cooled, water-moderated reactor coupled to compact power conversion equipment. This closed-cycle gas-turbine power plant will have an electrical power generating capacity of 300 to 500 kw. The design is reported in detail. The ML-1 will be installed at the National Reactor Testing Station early in 1961, and initial criticality is scheduled for April of that year.

1 INTRODUCTION

THE ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

THE ML-1 DESIGN REPORT

I. INTRODUCTION

This design report describes the mobile nuclear power plant being developed by the United States Atomic Energy Commission, the U. S. Army Corps of Engineers, and the Aerojet-General Corporation under Contract AT(10-1)-880 and Contract DA-44-009-ENG-3252.

The ML-1 nuclear power plant (see Figure 1, following page) is a merger of a high-temperature, gas-cooled, water-moderated reactor with compact power conversion equipment. This closed-cycle, gas-turbine power plant will have an electrical power generating capacity of 300 to 500 kw. The ML-1 will serve as an operating prototype for plants to furnish electrical power at remote military installations. Facilities that support the design and development of this plant include the Gas-Cooled Reactor Experiment I (GCRE-I) at the National Reactor Testing Station (NRTS) and the Gas Turbine Test Facility (GTTF) at Fort Belvoir, Virginia.

The four major parts of the plant are the nuclear reactor skid, the power conversion skid, the control cab for instrumentation and control, and the auxiliary sub-systems used in start-up and shutdown. The plant incorporates the military characteristics of Army field electrical generating plants and is transportable on the C-124, the C-130, or the C-133 military cargo transport aircraft; by ship or barge, by railroad flatcar; and on standard Army trailers.

The ML-1 will be installed at NRTS (Idaho Falls, Idaho) early in 1961. Reactor criticality is scheduled for April of that year, and full power operation is scheduled for several months later.

The report is divided into sections corresponding to the major parts into which the power plant is separated for transport. These sections are followed by a section on plant transport, assembly and operation. Included as an appendix are the military characteristics required of the ML-1 power plant.

THE ML-1 POWER PLANT

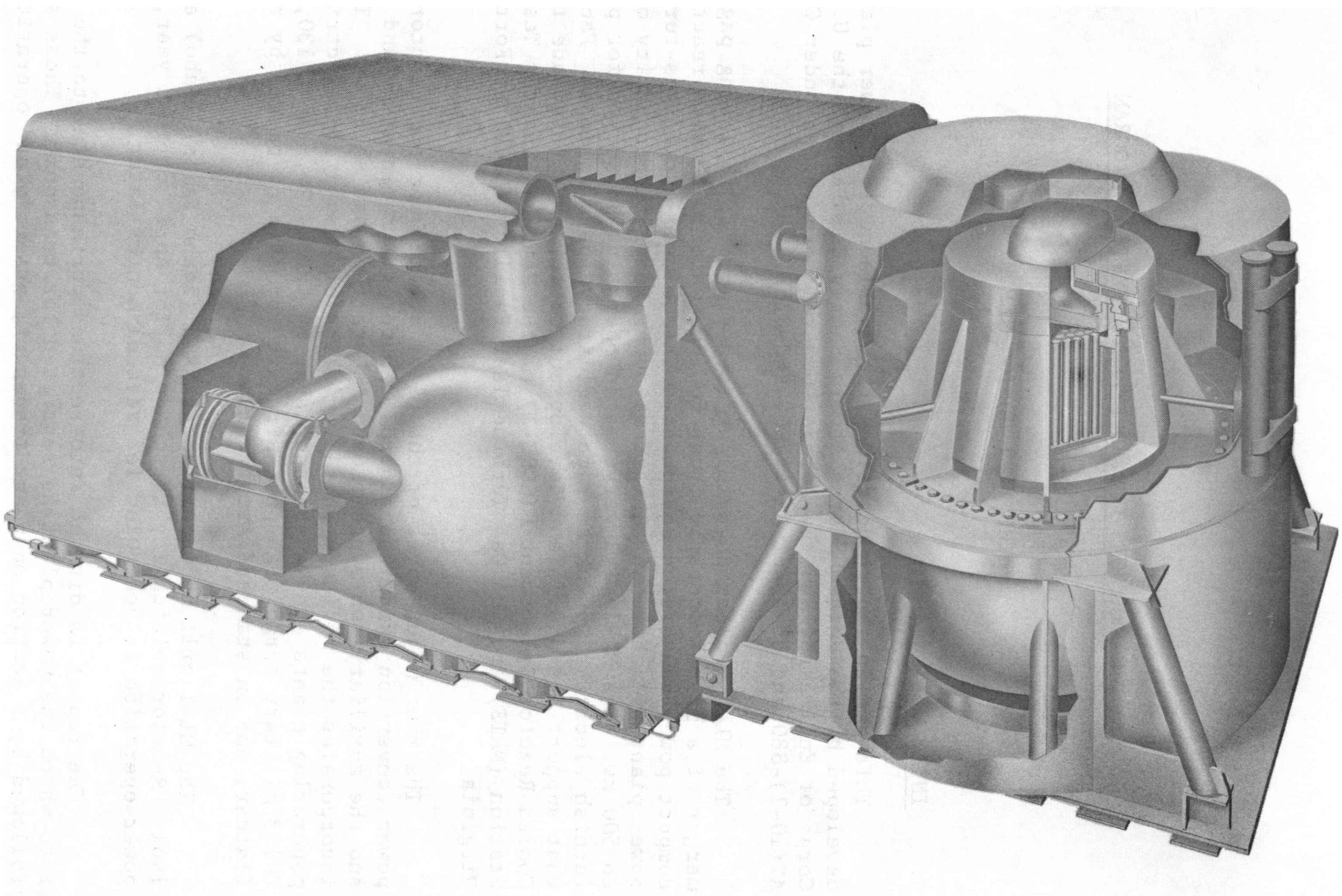


FIGURE 1

II GENERAL PLANT DESCRIPTION

II. GENERAL PLANT DESCRIPTION

A. GENERAL REQUIREMENTS

Following is a list of the principal military requirements for the ML-1 mobile power plant as set forth in detail in Military Characteristics (Appendix A).

1.	Electrical output	300-500 kw, 2400/4160 v, 3 phase, 50-60 cycle, at ambient temperatures ranging from -65° to + 100°F
2.	Weight	Approx. 40 ton total: 15 ton max. pkg
3.	Design Lifetime	10,000 hr between fuel changes 50,000 hr overall plant
4.	Radiation	15 mr/hr at 25 ft forward direction 24 hr after shutdown
5.	Transport	
	As integral package	M-172, M-172A trailer; rail, barge
	Split packages	C-130, C-124, and C-133 aircraft, sled
6.	Size	As dictated by transport
7.	Environment	Conformance with military shock, vibration, temperature, and atmosphere specifications
8.	Field Procedure Requirements	
	Installation time	12 hr
	Preparation for relocation from aircraft	6 hr

B. SYSTEM DESCRIPTION

The ML-1 is a compact readily transportable, nuclear power plant, designed to meet the military characteristics listed in Appendix A. The power plant operates as a conventional Brayton closed-cycle gas turbine plant utilizing a nuclear reactor as the heat source and oxygenated nitrogen (0.5 vol % O_2 + 99.5 vol % N_2) as the power plant working fluid. The power plant is capable of producing electrical power within the range of 300 to 500 kw in ambient air temperatures ranging from -65 to + 100°F. The power plant equipment is rated to produce a net 330 kw(e) at 100°F.

The power plant consists of two major skid-mounted power plant packages and a control cab skid as follows:

(1) The reactor skid: this includes the reactor core, shielding, and reactor auxiliaries.

(2) The power conversion skid: this includes the turbine compressor set, recuperator, pre-cooler, alternator, and electrical switchgear.

(3) The control cab skid: this includes the instrument and control console for remote plant start-up and operation.

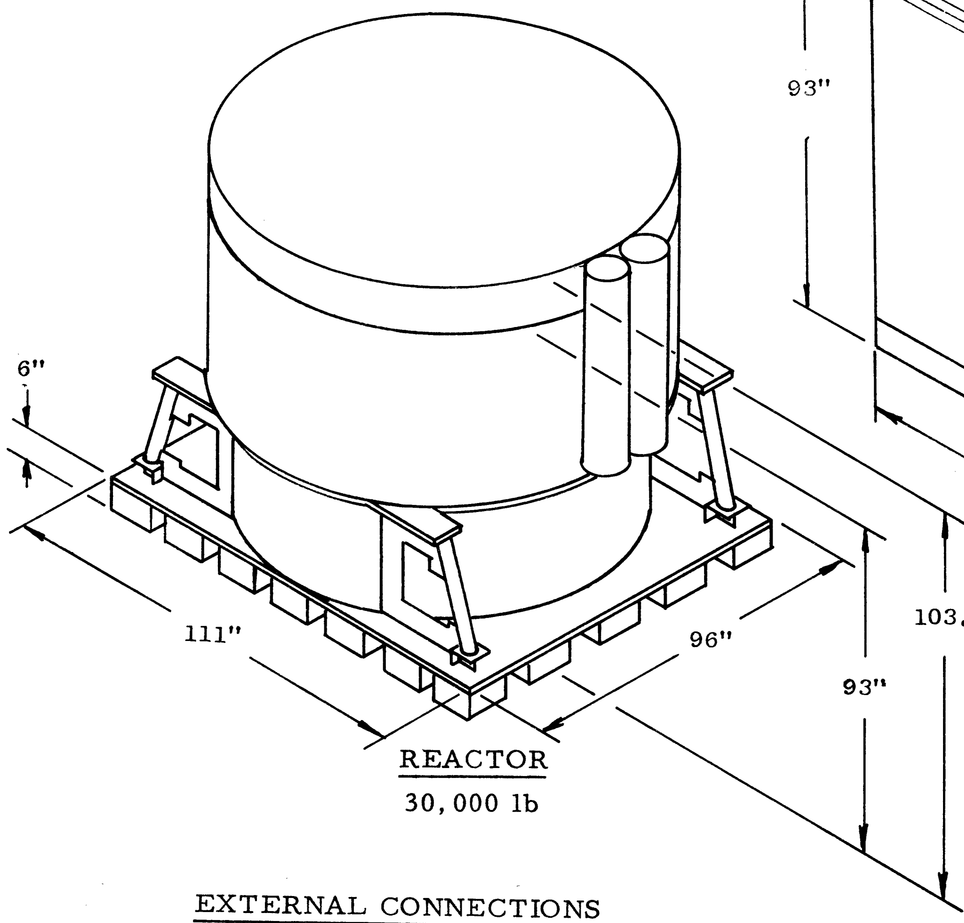
Auxiliary equipment(consisting of a cable reel for the power plant controls and instrumentation, make-up water treatment equipment, gas processing and make-up equipment, and drums containing bulk chemical equipment) is skid mounted for ease of transport. (Figure 2 shows package weights and dimensions for the ML-1 plant.)

The reactor and power conversion packages are both mounted on skids equipped with shock mounts. Both packages are rigidly coupled during operation to form a complete power plant except for the instrumentation and control provisions located remotely in the control cab. Each of the packages may be transported separately on their individual skids or the reactor and power conversion packages may be shipped as a single unit with the two skid structures bolted together. Figure 1 shows a representation of the reactor and power conversion packages coupled into a single unit for transport.

The control cab can be located up to 500 feet from the power plant during operation. The control cab is electrically connected to the power plant skids by four armored control cables. The control cab is an enclosed, compact central plant control station equipped with shock mounts and skid runners.

The reactor is a heterogeneous, water-moderated type fueled by enriched uranium dioxide (UO_2). The core consists of 61 fuel-bearing pressure tubes connecting the inlet (upper) and outlet (lower) plenum chambers. The reactor heat is transferred to the

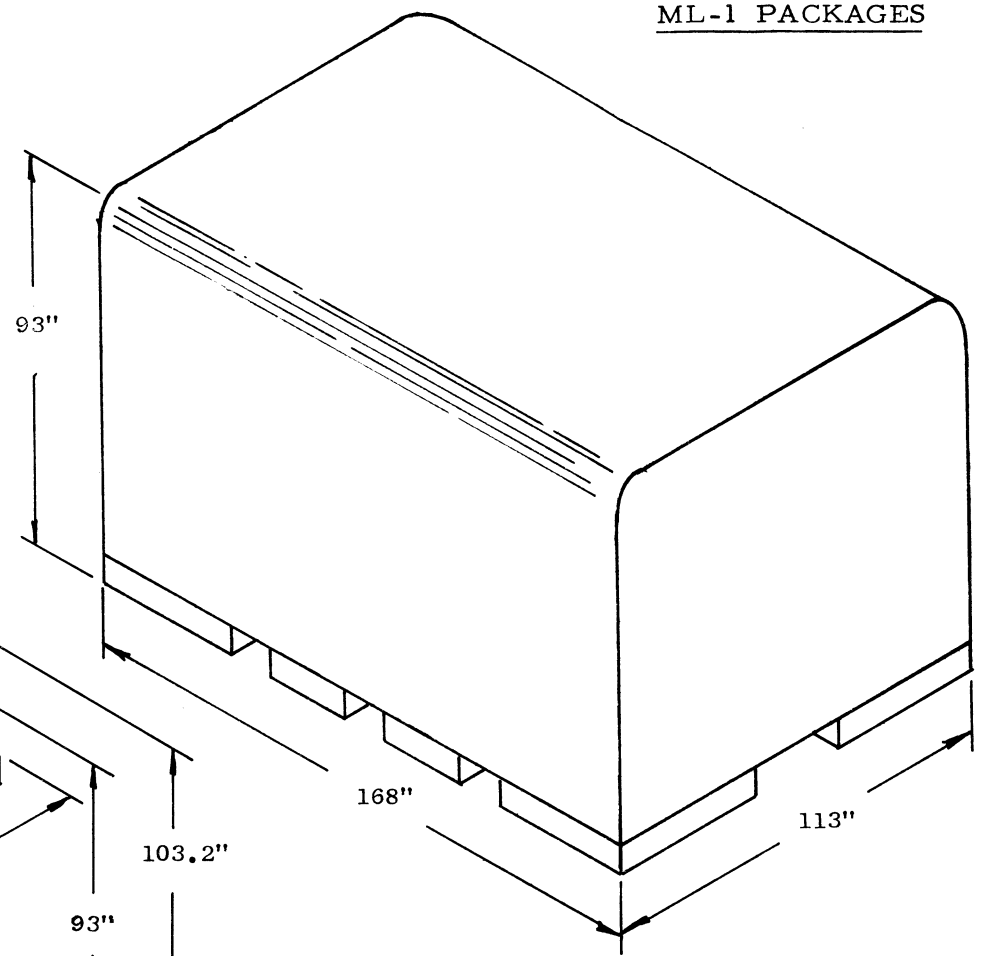
WEIGHTS AND DIMENSIONS OF ML-1 PACKAGES



REACTOR
30,000 lb

EXTERNAL CONNECTIONS

2 - 10 in. gas ducts to power conversion
2 - 4 in. moderator pipes to power conversion
4 - electrical cables to power conversion
2 - water supply pipes during startup

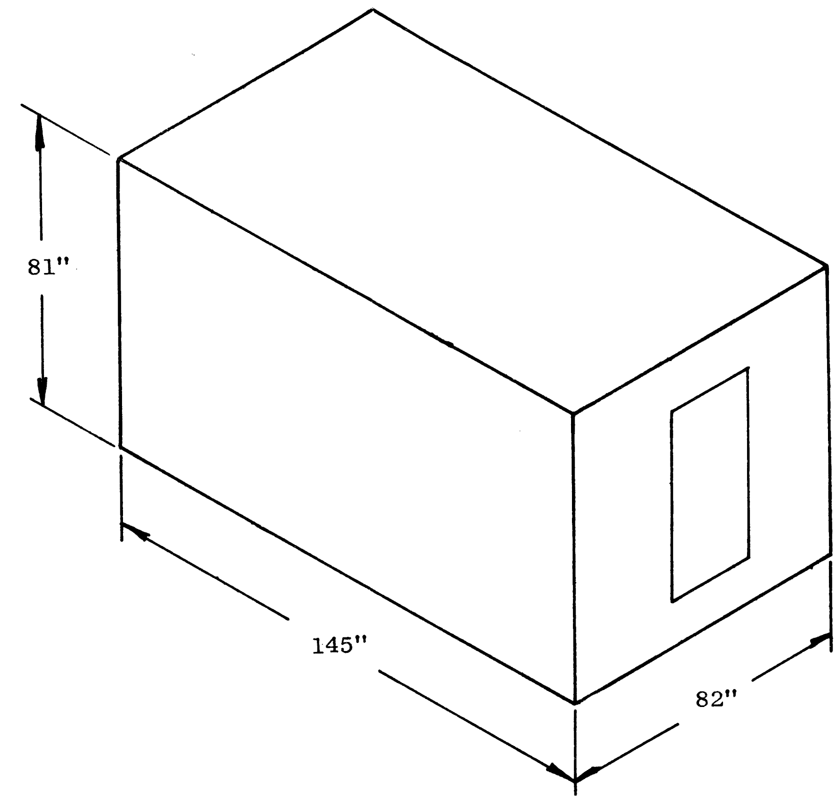


POWER CONVERSION EQUIPMENT

30,000 lb

EXTERNAL CONNECTIONS

2 - 10 in. gas ducts to reactor
2 - 4 in. moderator pipes to reactor
4 - electrical cables to reactor
4 - electrical cables to control cab
1 - electrical cable to auxiliary power source for startup
1 - electrical cable to load
4 - 1/2 in. gas lines to gas systems



CONTROL CAB
5,000 lb
EXTERNAL CONNECTIONS

4 - electrical cables to power conversion

AUXILIARIES	EXTERNAL CONNECTIONS
CABLE REEL 6000 lb	NONE
WATER MAKEUP 900 lb	2 - PIPES TO REACTOR DURING STARTUP
WASTE GAS SYSTEM 2000 lb	3 - 1/2 IN. LINES TO POWER CONVERSION
GAS SUPPLY 2000 lb	1 - 1/2 IN. LINE TO POWER CONVERSION
BORON COMPOUND 1200 lb	NONE

FIGURE 2

SIMPLIFIED FLOW DIAGRAM FOR THE ML-1

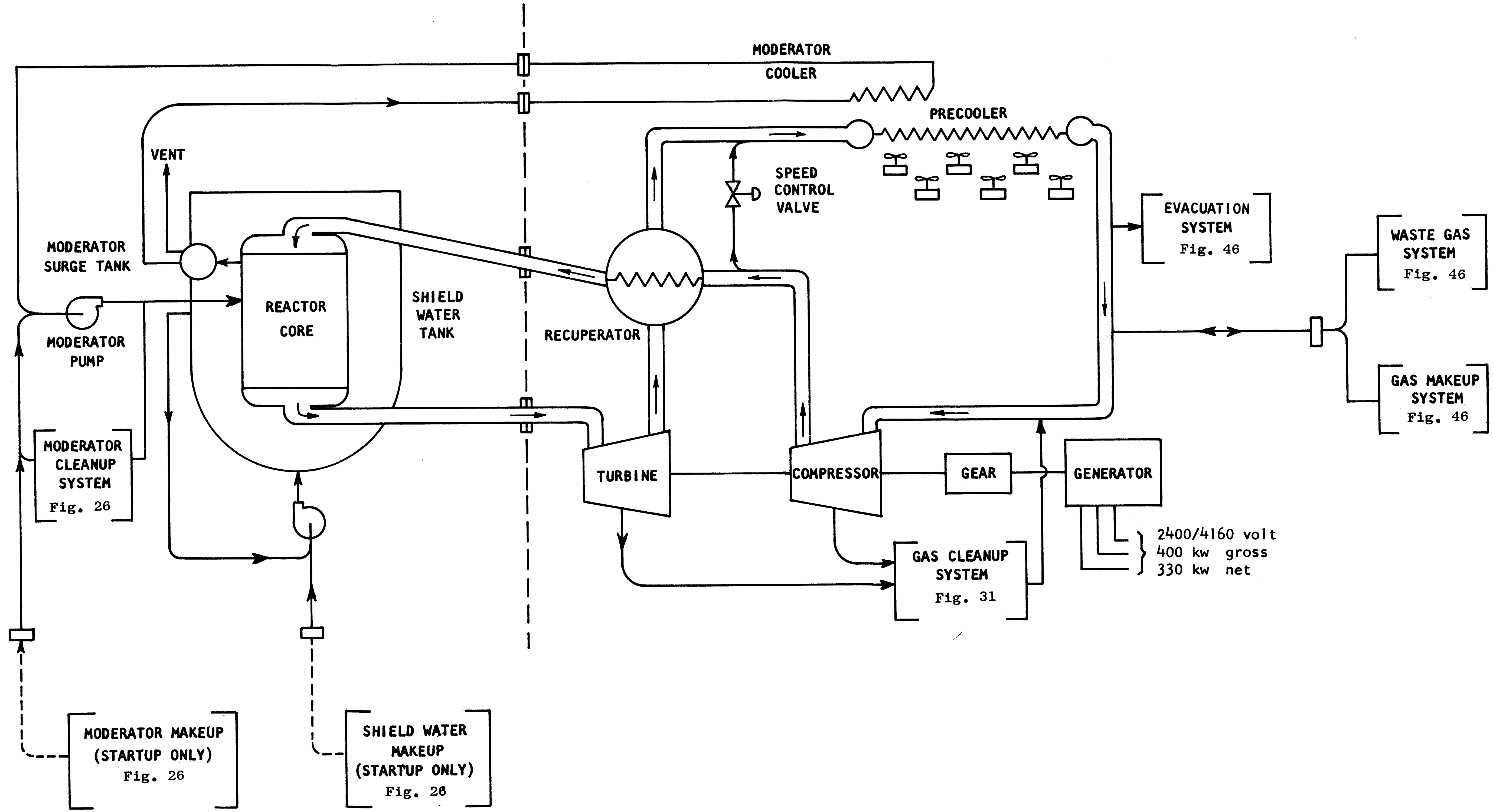


FIGURE 3

reference working fluid as it flows past the pin-type elements. At the design condition of 100°F, the coolant enters the reactor at a nominal 800°F, and leaves at 1200°F. The de-mineralized water moderator surrounds the pressure tubes and flows under forced convection counter-current to the gas flow. An integral radiation shield surrounds the reactor to protect personnel during reactor shutdown. The core, shielding, and pressure vessel assembly are enclosed in a tank of borated water during operation to provide additional neutron shielding.

Reactor control is effected by six pairs of semaphore-type control blades placed near the circumference of the core. The control blades are actuated by electro-mechanical devices in accessible cavities in the periphery of the shield water tank. Five blades provide shim-scram service, and one is a control unit to regulate reactor outlet temperature. All blades are fully inserted to scram the reactor.

Major components of the power conversion system are a turbine-compressor set and reduction gear; alternator and starting motor; pre-cooler with fans; recuperator; switch gear and connecting piping and valving. The hot gas leaves the reactor at 1200°F (Figure 3); expands in the turbine; passes through the low pressure side of a regenerative heat exchanger (recuperator) and through an air-cooled pre-cooler where the waste heat is rejected to the atmosphere. After being compressed in the compressor, the gas is pre-heated to about 800°F as it passes through the high pressure side of the recuperator; thence through the reactor to the turbine inlet, completing the cycle. The turbine work drives the direct-coupled compressor and the alternator through a gear box. The net useful output from the turbine shaft drives the rotor of a brushless alternator operating at 3600 rpm. The equipment is mounted on a lightweight, shock isolated skid. The doors of the structure are opened during operations to permit flow of air through the pre-cooler.

For a reactor outlet temperature of 1200°F, the lifetime of the first ML-1 core loading is estimated to be about 3000 hr, and is limited by corrosion. At ambient temperatures less than 100°F, it is possible to achieve rated power output with lower reactor temperatures (Figure 4). At an ambient temperature of 50°F, it is possible to reduce the fuel temperature and corrosion, thus about doubling fuel lifetime.

The state points of the cycle are shown in Figure 5 for ambient air temperatures of 125°, 100°, 0°, and -65°F.

The ML-1 plant will operate initially at NRTS. A test building will be provided for maintenance and experimental operation. A concrete pad will be provided outside the test building for normal operation. An auxiliary control building will also be provided for the analytical equipment required for initial ML-1 operation.

In addition to the ML-1, a typical power generating station for military field use would require support equipment. This equipment, to be supplied by the Army, will include: a 600 gph water purification unit for initial startup, transport and handling vehicles, and auxiliary electrical power (not to exceed 45 kw) for startup and shutdown.

PLOT OF PERFORMANCE VS. AMBIENT TEMPERATURE
FOR THE ML-1

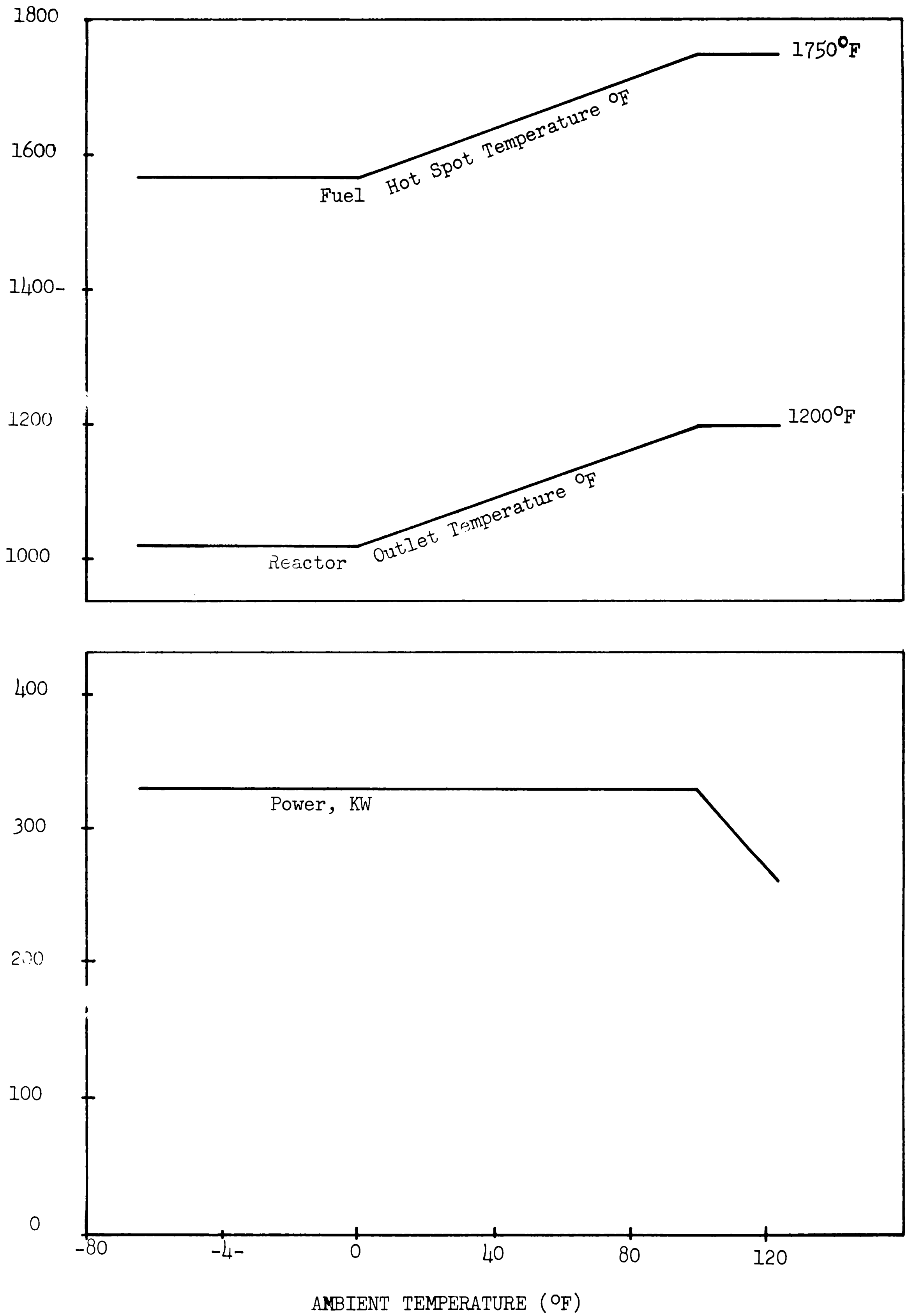
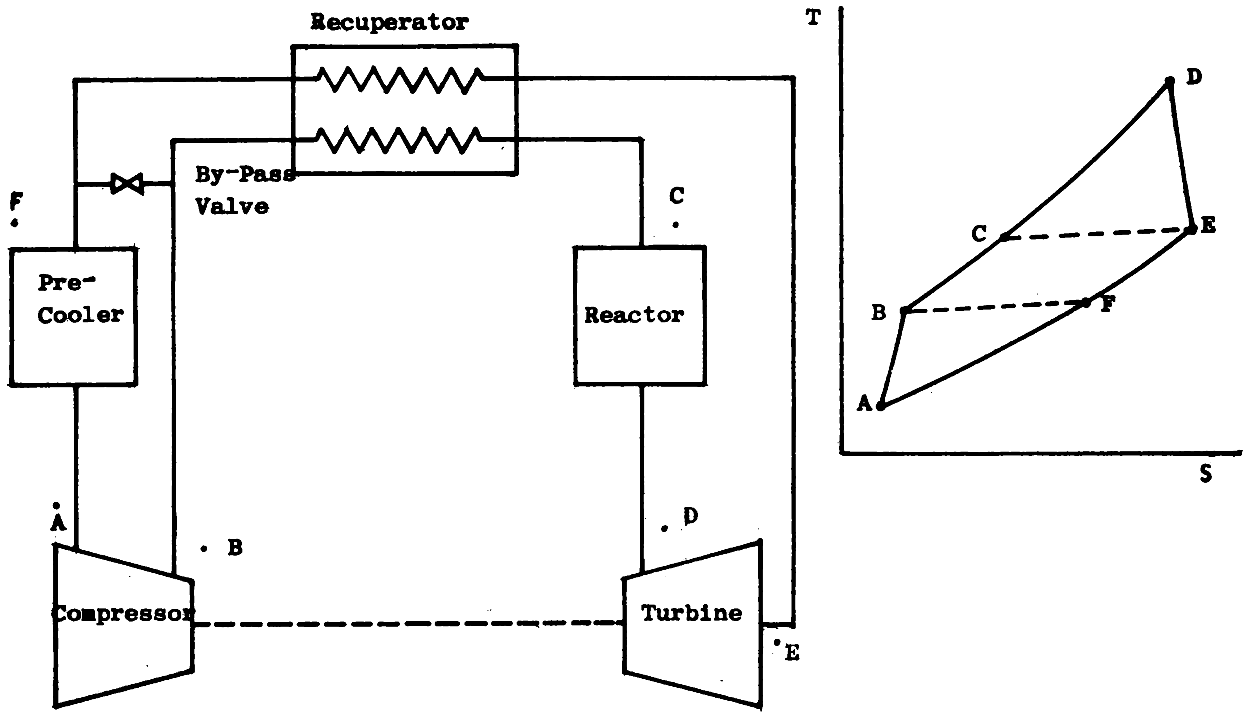


FIGURE 4

ML-1 CYCLE CHARACTERISTICS



Ambient Temperature		125°F	100°F	0°F	-65°F
kw		276	330	330	330
mass, lb		52	52	52	52
by-pass %		1	1	1	1
A	P, psia T, °F	123 156	117 132	97 25	97 25
B	P T	321 388	320 366	307 270	307 270
C	P T	312 819	313 791	299 636	299 636
D	P T	292 1200	289 1200	280 1023	280 1023
E	P T	128 922	120 901	102 720	102 720
F	P T	125 495	118 479	100 362	100 360

FIGURE 5

C. PLANT CHARACTERISTICS

1. General

Design performance at 100°F

Gross electrical output	400 kw
Net electrical output	330 kw
Reactor thermal power	3.0 Mw to gas; total - 3.4 Mw
Cycle efficiency	13.3%
Plant thermal efficiency	9.7%
Coolant flow	95,000 lb/hr

Dose rate at control cab at 500-ft during full power operation	5 mr/hr (with expedient shielding as needed)
Dose rate at 25-ft, 24 hr after shutdown (direction of transport vehicle cab with P-C skid in place)	15 mr/hr
Overall plant dimensions	279- x 113- x 93-in. high

Overall plant weight and dimensions	Weight (lb)	Dimensions (in.)
Reactor package	30,000	111 x 110 x 93 high (plus ion exchange column on end)
Power conversion package	30,000	168 x 113 x 93 high
Control cab	5,000	145 x 82 x 81 high
Auxiliary equipment	11.600	- - -

Operating supplies (startup and 90 day operation):	
Demineralized water	2900 gal
Nitrogen (with 0.5 vol% Oxygen)	1800 scf
Oxygen	200 scf
Anhydrous boric acid (B_2O_3)	1200 lb
Mixed bed ion exchange resin	900 lb max.
Lubricating oil	180 gal
Filter elements	6
Plant startup time	12 hr
Auxiliary power requirements	
Pre-startup	30 kw max
Normal startup	45 kw max
Normal shutdown	45 kw max, 3 kw ave
Emergency shutdown	none
Reactor drying	45 kw max

2. <u>Reactor Thermal Characteristics</u>

Power density	700 kw/ft^3
Maximum heat flux	130,000 Btu/hr/ft^2
Average heat flux	77,000 Btu/hr/ft^2
Heat transfer surface	133.5 ft^2
Maximum-to-average heat flux ratio	1.7
Maximum fuel center temperature	2150^oF
Maximum moderator temperature	200^oF
Maximum surface temperature of fuel cladding (nominal, average)	1420^oF
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1750^oF

3. <u>Reactor Nuclear Characteristics</u>

Average thermal neutron flux (fuel)	$1.9x10^{12}$ neut/cm^2-sec
Average fast neutron flux (fuel)	$1.7x10^{13}$ neut/cm^2-sec
Maximum to average thermal flux ratio (fuel)	3.9

Hydrogen to U-235 atom ratio	36
Core buckling	0.0053 cm^{-2}
Fermi age	92 cm^2
Square of thermal diffusion length, L^2	2.56 cm^2
Thermal utilization, f	0.82
Infinite multiplication factor, k	1.70
Neutron lifetime	3.0 x 10^5 sec
K_{eff}, cold, clean core; no shims or burnable poison	1.102
K_{eff}, cold, clean core, with shims, no burnable poison	1.043
K_{eff}, cold, clean core, with shims and burnable poison	1.021
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.6% in 10,000 hr
Prompt temperature coefficient, $\Delta k/k/^{o}C$	$(-0.8\pm1)\times10^{-6}$ @ $0^{o}C$ $(-1.7\pm1)\times10^{-6}$ @ $90^{o}C$

4. <u>Reactor Vessel</u>

Materials

Tube sheets	Stainless steel, type 304, 3 inches thick
Pressure tubes	Stainless steel, type 321
Gas ducts, plenums and baffle supports	Stainless steels, Types 304-L, 321 and 347
Outside diameter	30.968 in. max. exclusive of upper flanged connection)
Overall height	79.5 in.
Pressure tube length	24 in. between inside surfaces of tube sheets
Design pressure	345 psia
Design temperature	$400^{o}F$
Wall thicknesses	Tubes .020 in.; plenum 1.25 in. min

5. Reflector

Composition, top	2 in. H_2O; 3 in. stainless steel; 3 in. W
bottom	3 in. stainless steel; 3 in. W
radial	1.8 in. Pb; 2 in. W; 180^o segment 4 in. Pb; 180^o segment
Total heat generation	6 x 10^5 Btu/hr
Maximum power density	360 Btu/hr-in^3

6. Biological Shielding

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

7. Core (excluding reflector)

Diameter	22 in. equivalent
Height	22 in.
Number of fuel elements	61
Number of coolant passages	61
Number of coolant passes	1
Type and geometry of fuel elements	cluster of 19 pins
Cold, clean critical mass, U-235, no shims, no burnable poison	25 kg
U-235 loading	49 kg
Enrichment, inner 7 pins	93% U-235 as UO_2
outer 12 pins	31 vol% UO_2, 93% U-235, 69 vol% BeO

Core composition

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

8. Fuel Element

Dimensions	1.72 in. OD x 32 in.
Fuel material	UO_2
Number of pins per element	19
Pin outside diameter	0.241 in.
Pin cladding material	Hastelloy-X
Pin cladding wall thickness	0.030 in.
Pin spacer	0.040 in. OD Hastelloy wire
Heat transfer material	He
Pellet diameter	0.174 in. and 0.177 in.
Type burnable poison	Cadmium
Reactivity worth of burnable poison	2.2% at startup

9. Control Element

Type	Flat blades
Location	Moderator
Number:	
Shim-scram blades	5 pairs
Control blades	1 pair
Absorber material	
Shim-scram blades	Cadmium-indium-silver
Control blades	Stainless steel
Cladding material	None
Dimensions	3.37 x 9.65 in. each blade
Reactivity worth of control elements	
Shim-scram blades	0.050 $\Delta k/k$
Regulating blades	0.005 $\Delta k/k$
Total	0.055 $\Delta k/k$

10. Moderator

Type	Water
Reactor inlet temperature	180°F
Reactor outlet temperature	190°F
Pressure	32.5 psi max
Flow rate	300 gpm

Type of flow circulation	Forced
Purity:	
Total solids	1 ppm
Resistivity	10^5 to 10^6 ohm-cm
Total heat removal rate	1.5×10^6 Btu/hr

11. Reactor working fluid flow

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

12. Power cycle

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

Cycle characteristics

Ambient temperature	100°F	0°F	-65°F
Net power, kw	330	330	330
Reactor inlet, °F	791	636	636
Turbine inlet, °F	1200	1026	1026
Compressor inlet, °F	132	25	25
Compressor inlet, psia	117	97	97
Compressor outlet, psia	320	307	307
Reactor inlet, psia	313	299	299

13. Turbine-compressor set

	Radial Flow Compressor	Axial Flow Compressor
Speed	18,000 rpm	22,000 rpm
Turbine stages	2	2
Turbine rotor material	Incoloy 901	Incoloy 901
Turbine blade material	Inco 713	N 155

Turbine stator blade material	Inconel	N 155 or 19-9DL
Expansion ratio	2.38	2.29
Compressor stages	2	11
Compressor material	AL 355 T71 (wheel)	403 Stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compression ratio	2.72	2.59
Case material	304 Stainless steel	Low carbon steel
Seals		
at journals	Buffered labyrinth	Buffered labyrinth
interstage	Plain labyrinth	Plain labyrinth
shaft	Buffered labyrinth	Double "L" ring seal oil buffered
Bearings		
journal	Tilting pad	Plain babbitt
thrust	Kingsbury type (in low-press. area)	Kingsbury type (in low-press. area)
Support	Overhung turbine	Turbine and compressor supported between bearings

14. <u>Alternator</u>

	60 Cycle Operation	50 Cycle Operation
Output		
Rating	500 KVA	417 KVA
Voltage	2400/4160 V	2000/3467 V
Rotor shaft speed	3600 rpm	3000 rpm
Case		
Diameter	38 inches	
Length	34 inches	
Weight	3600 lb	
Temperature, operating	250°F internal max (hot spot)	

15. <u>Recuperator</u>

Length	81 in. (with external insulation)
Outside diameter	45 in. (with external insulation)
Headers	
High pressure inlet	8 in.
High pressure outlet	8 in.
Low pressure inlet	20 in.
Low pressure outlet	14 in.
Effectiveness	80.75%
Pressure loss	
High pressure $\Delta p/p$	1.61 %
Low pressure $\Delta p/p$	1.06 %
Type	Shell and tube regenerator
Tubes	4 passes x 840 tubes
Shell	1 pass
Surface	External fins
Materials	300 series stainless steel

16. <u>Pre-cooler and Moderator cooler</u>

Dimensions:	
Length, overall	168 in.
Pre-cooler	128 in.
Moderator cooler	27½ in.
Oil cooler	12½ in.
Width	113 in.
Thickness, overall	32 in.
Core	15 in.
Fans and plenums	17 in.
Materials	
Tubes and fins	Series 1100 aluminum
Headers	Series 2219 aluminum
Weight	6500 lb
Pre-cooler:	
Header, inlet	One, 14 in.
Header, outlet	One, 10 in.

Effectiveness	93%
Total Δ p/p	1.55 %
Air flow	289,000 lb/hr
Type	Fin fan air-to-gas exchanger
Tubes	1131 tubes,single pass
Surface	Internal and external fins
Moderator cooler:	
Headers, inlet and outlet	4 in.
Total Δ p	6.0 psi
Water temperature:	
In	190°F
Out	180°F
Airflow	78,600 lb/hr
Type	Fin fan air-to-water exchanger
Tubes	84 tubes, three passes
Surface	External fins
Oil cooler:	
Headers, inlet and outlet	1½ in.
Total Δ p	11.1 psi
Oil temperature	
In	180°F
Out	150°F
Oil flow	19,380 lb/hr
Air flow	29,400 lb/hr
Type	Fin fan air-to-oil exchanger
Tubes	42 tubes, 2 passes
Surface	Internal and external fins

III THE NUCLEAR REACTOR

III. NUCLEAR REACTOR DESIGN

A. GENERAL

The ML-1 reactor uses a heterogeneous, water-moderated core of 61 fuel-bearing pressure tubes. The stainless steel pressure tubes are arranged in a bundle and are fastened to a tube sheet at either end. This tube bundle, together with the inlet (upper) and outlet (lower) plenum chamers, forms the reactor pressure vessel. The reactor package is shown in Figure 6. The gas coolant, under a nominal 300 psi pressure, enters the reactor at 800^{o}F and leaves at 1200^{o}F.

A lead shield around the pressure tube bundle is a fast-neutron reflector. Six pairs of semaphore-type control blades are placed near the circumference of the core. Aluminum-encased lead encloses the reactor vessel to provide shielding from residual radiation during shutdown and transport. The lead shield incorporates an annulus to contain borated water during operation.

The reactor and its shield are supported within a tank 9-ft in diameter. This tank is filled with borated water to provide the main operational neutron shielding. It is drained before shipment to reduce weight. Equipment mounted outside the reactor tank circulates demineralized moderator water in a system separate from the shield water. The tank is covered to prevent contamination. When fuel elements are to be installed, or other maintenance is to be done on a "hot" core, an extension is added to the tank and filled with water to provide radiation shielding for personnel working above the reactor core.

The shipping skid is a structural part of the reactor tank bottom. Inner and outer continuous skirts separately transmit the main reactor and tank loads to the shock mounts underneath. The reactor is suspended in a canned lead shield with twelve aluminum ribs. Each rib assembly is bolted to the inner and outer radial shields and to the outer aluminum support ring. The aluminum support ring is, in turn, wedge-bolted to the reactor tank inner support.

B. CORE

1. General

The size of the ML-1 reactor core is governed by requirements for shutdown dose rate and reactor weight. The shutdown dose rate at 25-ft from the reactor, 24 hr after reactor shutdown, must not exceed 15 mr/hr in order to comply with military requirements for mobility and maintenance. The maximum package weight must not exceed 15 tons in order to meet the weight limitations of the C-130 aircraft. Within these limits, the maximum core size for the ML-1 is about five cubic feet.

The ML-1 core is hexagonal. Each face is 11.9-in. wide and has an active length of 22-in. This hexagon is approximated for neutronic calculations by a cylinder having an 11.0-in. radius. The shielding weight requirements with this size core were met by surrounding the core with material of high density to attenuate the gamma rays produced by fission product decay. Therefore, the ML-1 radial reflector is composed of lead and tungsten, where the latter material is not precluded by its high neutron absorption. The axial reflectors consist of the steel tube sheets backed up by tungsten. Water is used to provide some additional axial reflection to reduce the leakage, and thereby lowers the critical loading.

The choice of reactor types, within these core sizes and reflector requirements and making allowance for cooling passages, was limited to hydrogen-moderated or fast reactors. In a thermal reactor of this size, a minimum of 50% of the total core volume must be filled with water or with a material of equivalent hydrogen density. In addition to designing a fuel element within these space limitations, it was considered desirable to:

1) Minimize coolant pressure drop. (A pressure drop of 1 psi results in a loss of 7 kw in plant output.)

2) Minimize the surface temperature of the fuel element. (The lifetime of the ML-1 fuel element is limited by surface corrosion, rather than burn-out, and hence is highly sensitive to temperature.)

3) Minimize uranium inventory. (This was accomplished by using highly enriched uranium and by having a water volume-fraction of over 50% to reduce neutron leakage and allow a reduction in required neutron utilization.)

4) Minimize the conduction of heat from the hot fuel into the relatively cold water. (This heat must be dissipated as waste heat and decreases overall plant efficiency.)

The design of the ML-1 core represents a compromise between these conflicting requirements. The design uses about 49 kg of highly enriched uranium in the form of UO_2 and $BeO-UO_2$ pellets. The UO_2 is diluted with BeO, where required, to optimize power distribution within the fuel element. These pellets are sealed into helium-containing cylinders to prevent the escape of fission products from the fuel into the gas stream. The fuel cylinders (or pins) are grouped in 19-pin clusters to form individual fuel elements.

THE ML-1 REACTOR PACKAGE

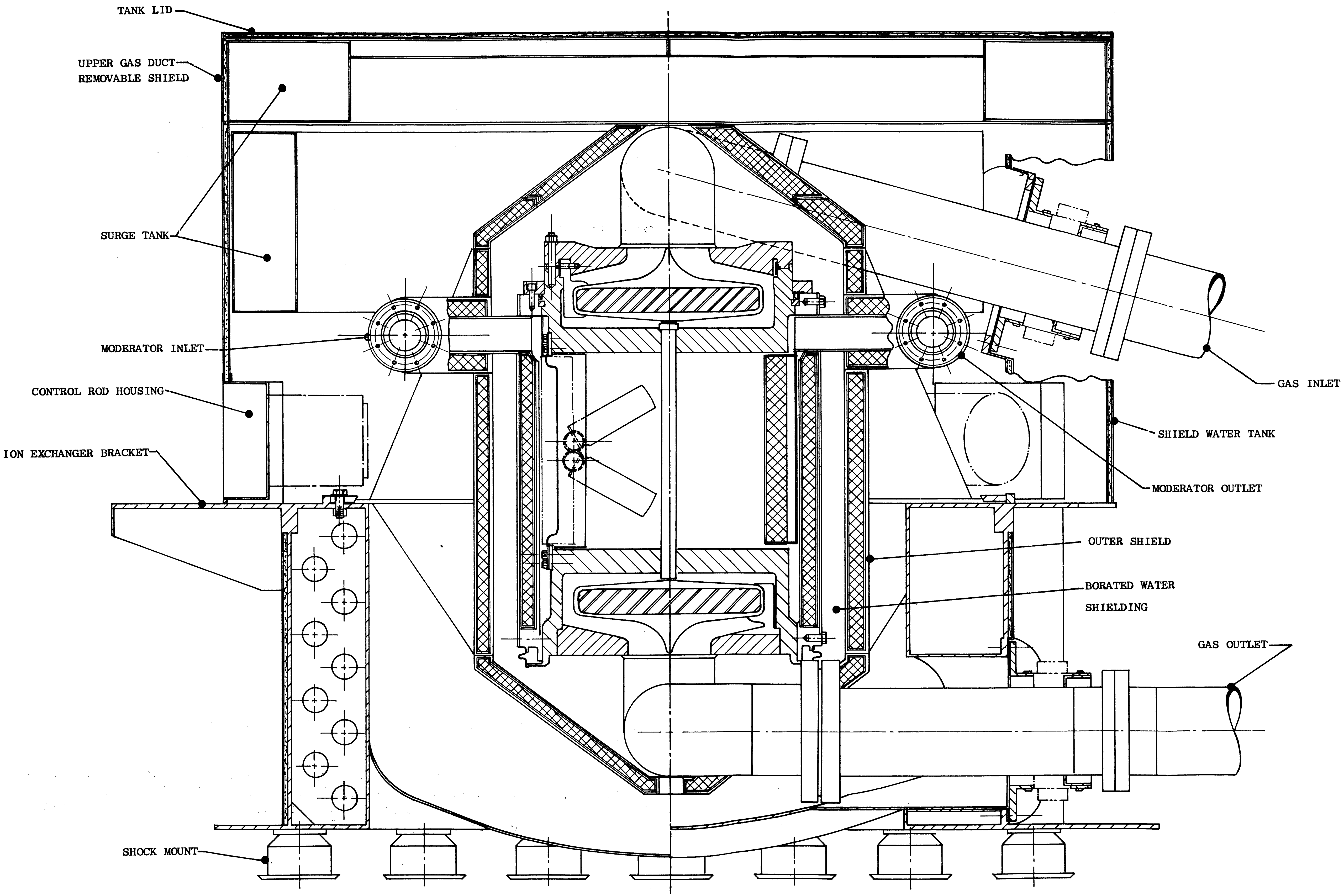


FIGURE 6

2. Reactor Physics

A hydrogen (water) moderated type of reactor was chosen for the ML-1 reactor in order to reduce operating hazards and lower the uranium inventory. The geometric buckling of the small core with metal reflection is large. To achieve criticality, it was necessary to minimize the neutron migration area during slowing down.

The reactor contains 61 fuel elements arranged in a lattice. Fuel element spacing in this lattice is varied to flatten radial power distribution in the core (see Figure 7). The power distribution obtained in this way eliminates the need for extensively orificing the outlet gas. This in turn reduces pressure drop in the system and improves the overall system efficiency. Calculated radial and axial flux distributions using four neutron energy groups, are shown in Figures 8 and 9, respectively.

A burnable poison is employed to compensate for the reactivity loss due to fuel depletion and fission product build-up. This poison will burn out, increasing the system reactivity at approximately the same rate as fuel depletion and fission products decrease the system reactivity. Thus the excess reactivity required for operation is maintained within 0.5% of the initial value during core life.

Extensive use was made of computer codes for the IBM-704 in calculating criticality and power distribution. Intracell flux distributions were calculated using the P_3 approximation to transport theory. Two-dimensional diffusion theory calculations, with four energy groups, were utilized in the determination of criticality. All neutron cross sections were appropriately weighted to compensate for variations in spectrum and flux distribution in the various regions of the core. Where possible, these calculations were normalized to critical experiments performed at Battelle Memorial Institute. Estimated reactivity requirements for the ML-1 reactor are listed in Table 1.

It is essential, to minimize coolant pressure drop, to operate the ML-1 with the full loading of 61 fuel elements. In addition, the desired reactivity must be assured. The design calls for overloading the core to insure the desired reactivity. The predicted k_{eff} is 1.102 for a loading of 49 kg compared to the desired initial k_{eff} of 1.043. The core, therefore, will be overloaded by about 6% in reactivity. This excess reactivity will be poisoned by shim liners placed around the outer liner of the fuel elements. The shim liners make it possible to obtain the exact excess reactivity desired, and can be installed in the field. The liners may also aid slightly in flattening the radial power distribution.

Different fuel loadings are used in the pins to equalize the surface temperatures of the seven inner pins and the 12 outer pins. The amount of U-235 placed in each inner pin is 74.2 g, and the 12 outer pins will each contain 23.0 g of U-235.

The predicted k_{eff} is shown in Figure 10 as a function of total fuel loading for the 61 element core to show the parametric

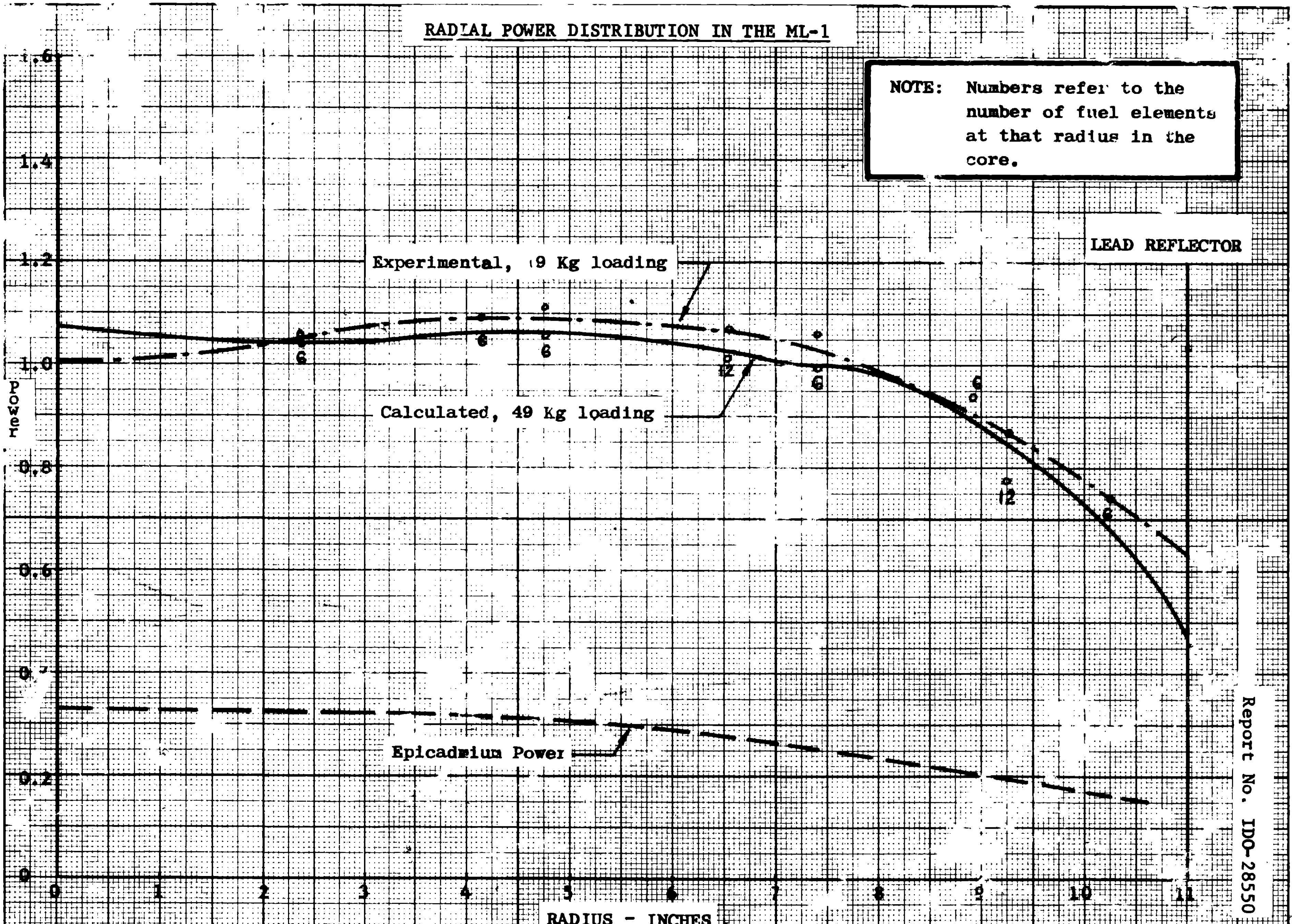

RADIAL POWER DISTRIBUTION IN THE ML-1
NOTE: Numbers refer to the number of fuel elements at that radius in the core.
LEAD REFLECTOR
Experimental, ‹9 Kg loading
Calculated, 49 Kg loading
Epicadmium Power
Power
RADIUS - INCHES
0
1
2
3
4
5
6
7
8
9
10
11
0.2
0.6
0.8
1.0
1.2
1.4

FIGURE 7

RADIAL FLUX DISTRIBUTION
IN THE ML-1

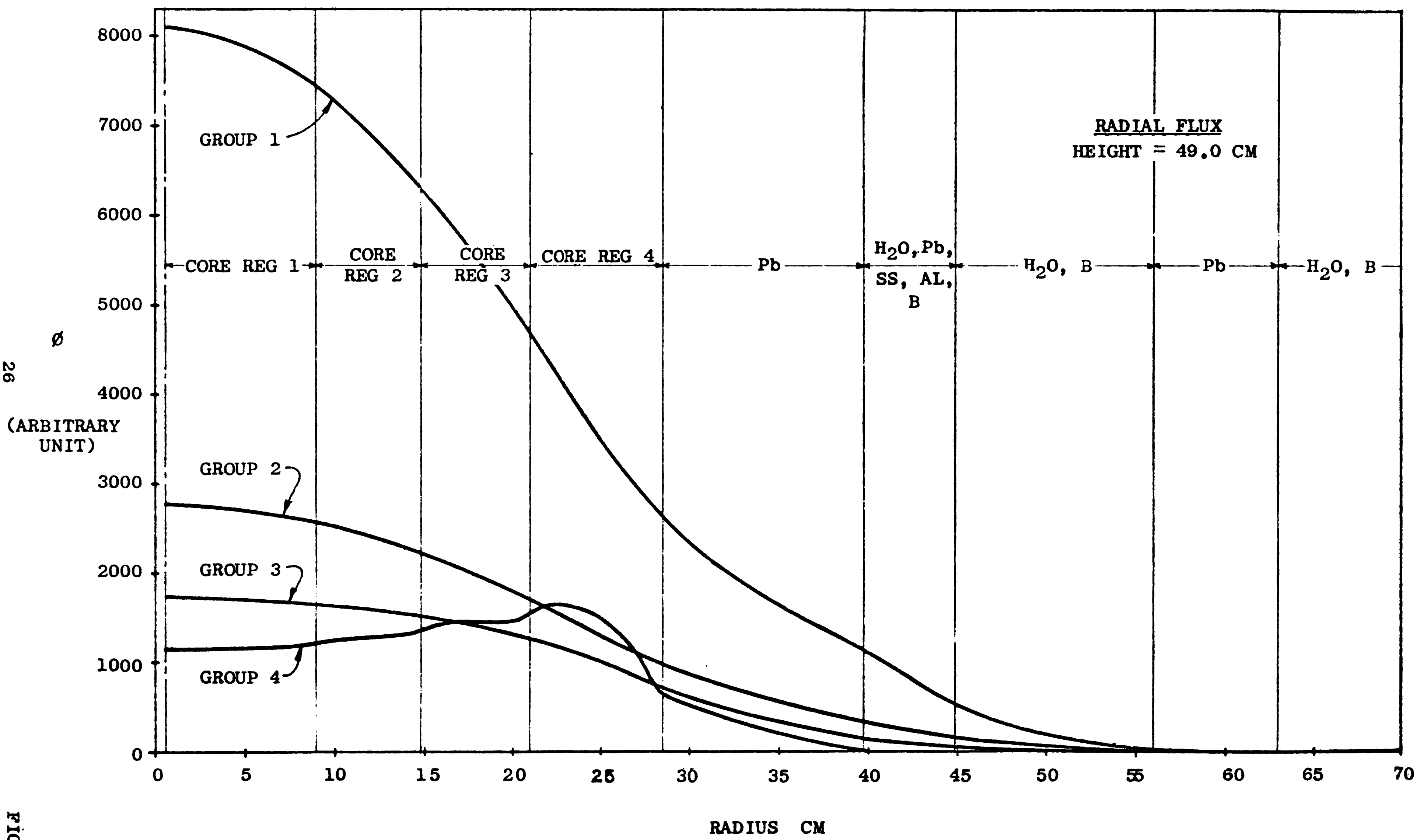
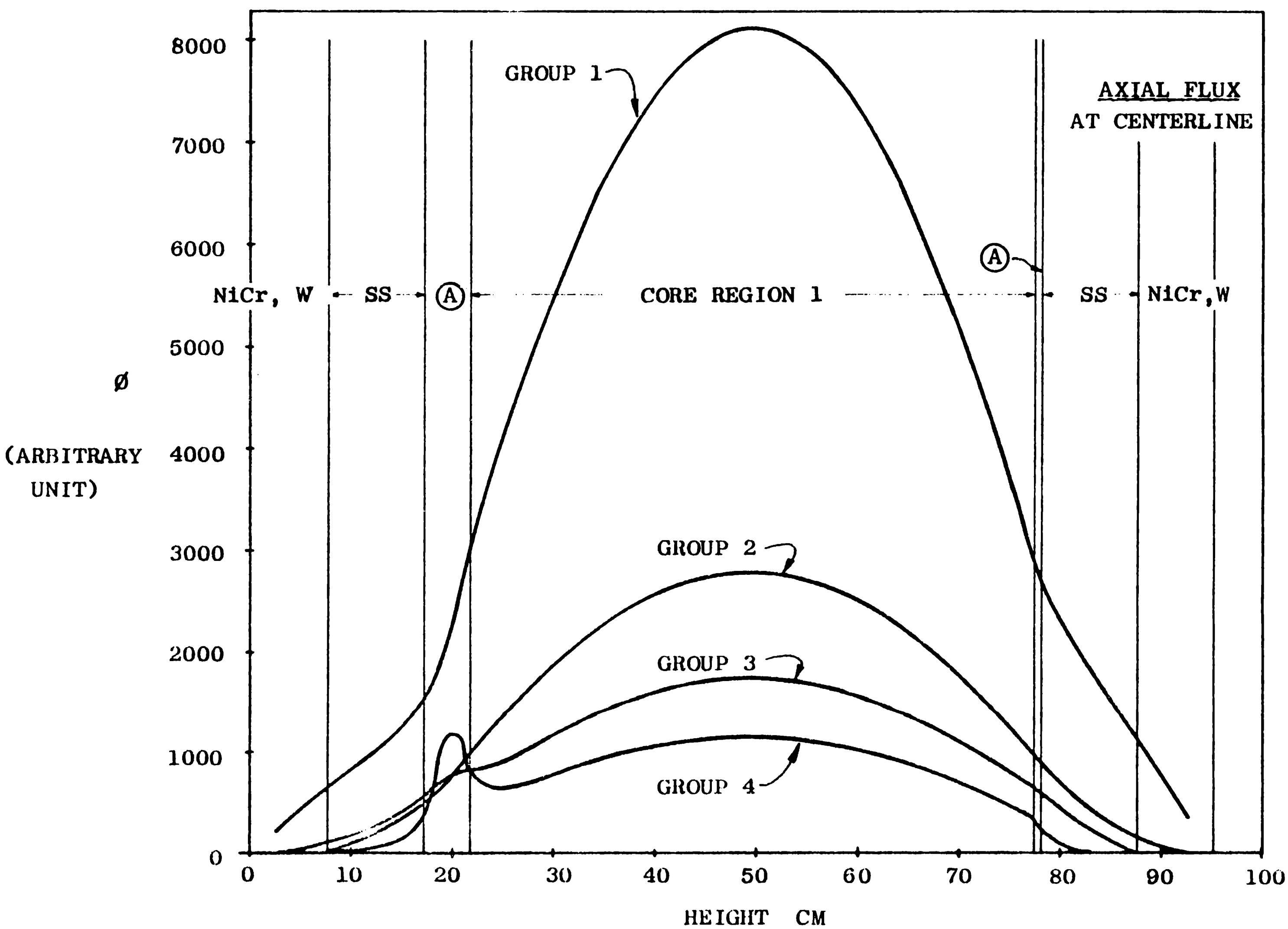


FIGURE 8

AXIAL FLUX DISTRIBUTION
AT CENTERLINE IN THE ML-1



A = H_2O, BeO, S.S., HAST X

FIGURE 9

TABLE 1

ESTIMATED REACTIVITY REQUIREMENTS FOR ML-1

Initial Operating Conditions	
k_{eff}, cold and clean, without burnable poison	1.043
k_{eff}, cold and clean, with burnable poison	1.021
Δk, xenon	-.010
Δk, xenon overide	-.001
Δk, moderator temperature	-.004
Δk, nitrogen pressure	-.001
Δk, control margin	-.005
10,000 Hour Operating Conditions	
Δk, fission products	-.014
Δk, fuel depletion	-.008
Δk, burnable poison	+.021

K_{eff} vs. FUEL LOADING

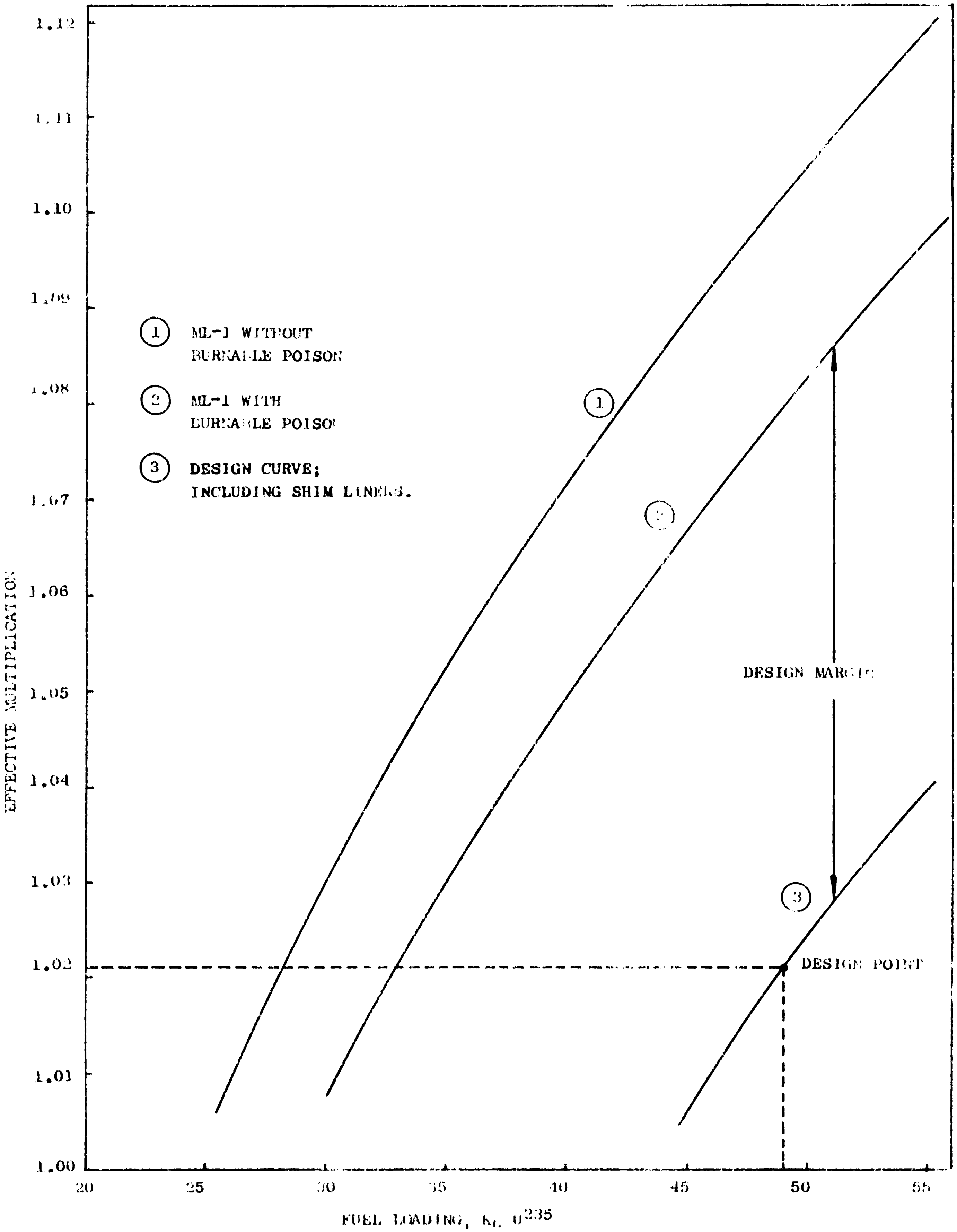


FIGURE 10

dependence of these quantities. Pin to pin power distribution was kept constant in performing these calculations. (The estimated reactivity requirements for full power operation of the ML-1 are shown in Table 1.)

A radium-beryllium source with a strength of about 3×10^7 n/sec is permanently mounted in a thimble near the center of the core. The strength and lifetime of this source is sufficient to provide start-up neutrons for the life of the reactor.

3. Thermal Design

a. Operating Core Temperatures

At the design operating point, ML-1 fuel element temperatures are calculated to be:

1) Pin metal wall temperature next to coolant:

Nominal maximum	1420°F
Hot spot maximum, reference	1750°F

2) Maximum fuel temperature

Hot spot maximum, UO_2	2500°F
Hot spot maximum, UO_2-BeO	2200°F

For ML-1 conditions, the highest nominal pin wall temperature occurs at X/L = 0.678. At this position, the coolant temperature is 1100°F and the film drop is 320°F.

Hot spot factors are used in order to define the upper limits of temperature. Hot spot factors are established by considering all conditions tending to increase the core temperature. These conditions include restriction of coolant due to orificing error or pin size variation, error in the determination of the heat transfer coefficient, errors between calculated power and true power, effect of control blades and other similar items.

The factors are evaluated separately and combined to give what is termed "a reasonable combined effect". These factors are then applied to the nominal case to arrive at a prediction of hot spot temperatures by a two-step calculation: First, the hot spot factors are applied to calculate new higher gas and wall temperatures with a coolant inlet temperature that is somewhat different from the nominal 800°F.

$$T_w = T_{inlet} + C_B \,\Delta T \text{ (bulk nominal)} + C_f \,\Delta T \text{ (film nominal)}$$

$$= 792 + 1.28\ (308) + 1.54\ (320)$$

$$= 792 + 394 + 494$$

$$= 1680^\circ F$$

Finally a correction is made for the reduction in the heat transfer coefficient arising from the temperature difference between the gas and the wall.

$$\Delta T_f \text{ (hot spot)} = \Delta T_{film} \left(\frac{T_w}{T_g}\right)^{0.575}$$

$$= 494 \, [1.16]$$
$$= 573^{o}F$$

This results in a hot spot temperature of:

$$T_w \text{ (hot spot)} = 792 + 394 + 573 = 1759^{o}F$$

This is nearly the same as the reference $1750^{o}F$ hot spot wall temperature.

Calculations of the preceding type are used to define upper and lower limits of temperature. However, in order to more fully evaluate the effects of detailed power generation and coolant flow distribution, a heat transfer code called HECTIC was used. This code permits a detailed evaluation of temperatures both along and around individual pins and includes the effects of pin wall conduction, thermal radiation, detailed power distribution, variation in channel size, and interchannel mixing of the coolant.

The code makes it possible to divide the pin bundle into many subchannels of flow and associated heat transfer surfaces.

The code then divides the coolant among the various channels such that pressure drops end to end are equal.

The code then proceeds in an axial stepwise calculation of temperatures using conventional heat transfer correlations, including the exchange of heat transfer between channels (mixing effect). The code has provision for utilizing modified correlations as determined by heat transfer tests. For instance, the heat transfer coefficient is determined by using the Colburn equation. This coefficient is multiplied by a constant to take care of differences between the predicted value and the value determined by test. The code does not have provisions to make T_w/T_g ratio corrections so these are applied to the results after the calculation. Interchannel mixing was varied (normalized) to correspond to test results. The code serves as a good calculational aid and permits a much better evaluation of temperatures and the effects of varying parameters than could be done by hand computation. Comparisons between temperature prediction and test measurements are made wherever possible and reasonably good agreement has been found ($\pm$ $50^{o}F$ for the IB-1αT in-pile test).

Fuel temperatures in ML-1 have been calculated to be less than $2500^{o}F$. Capsule tests at accelerated burnup rates (3 times ML-1) to the equivalent of 3000 hr ML-1 operation have shown that there is no problem with the ML-1 fuels and the associated pin material (Hastelloy-X). The capsules were run at hot spot metal temperatures in prototype geometry.

b. Non-operating Core Temperatures

There are two shutdown conditions of interest:

1) Normal Scram: In this case pin wall temperatures peak at 1632°F, 590 seconds after scram.

2) Coolant Loss Accident: In this case pin wall temperatures peak at 2210°F, 150 seconds after scram.

The difference arises due to cooling from the turbine-compressor set coast-down. Accidents such as shaft seizure in the T-C set would give intermediate temperatures. The core might be seriously damaged by a coolant loss accident.

4. Mechanical Design of Fuel Elements

The ML-1 fuel element assembly (Figure 11) basically is a cylindrical tube 32-in. long with an outside diameter of 1.720-in., and weighs about ten pounds. The active fuel length is 22-in. Each fuel element consists of seven central fuel pins, loaded with fully enriched UO_2 pellets; and 12 pins in the outer ring, loaded with BeO-UO_2 pellets. The pins hang from an upper spider and are free to expand into a lower spider. Spiral wires running the length of the pin serve as spacers. The pins are surrounded by an inner liner, a layer of insulation, and an outer liner. The fuel pins, made of Hastelloy-X tubes, are 0.241-in. O.D. with 0.030-in. walls.

The fuel element is supported at its top by the upper tube sheet of the reactor, and it is restrained from moving upward by the fuel element retainer plate. A seal is formed (similar to a valve seat) between the tube sheet and the fuel element to prevent coolant gases from by-passing the element. The coolant gas flows downward past the fuel pins so that the forces of gravity and coolant pressure tend to place the element structure and fuel pins in tension. A spider supports the pins at the top of the element. The spider has two levels to reduce pressure drop.

Spiral wires wrapped four turns around the full length of all except the center pin prevent lateral shift of the fuel pins. The wire spacer is made of 0.040-in. dia Hastelloy-X and is attached to the upper and lower pin plugs. The wire passes through a hole perpendicular to the axis of the plug and is crimped over and spot welded to the upper and lower pin plugs. The end plugs are pressed into the fuel tube ends and Heli-arc welded to complete the enclosure of the fuel pins. The lower spider spaces the lower ends of the pins and would keep the pins from dropping into the lower plenum if the primary support of the pins failed. The pins are not attached to the lower spider, but each lower pin plug has a cylindrical section that slides freely through its respective aperture in the lower spider so that differential thermal expansion from pin to pin will not cause the pins to buckle. The lower spider is offset to reduce pressure drop.

THE ML-1 FUEL ELEMENT

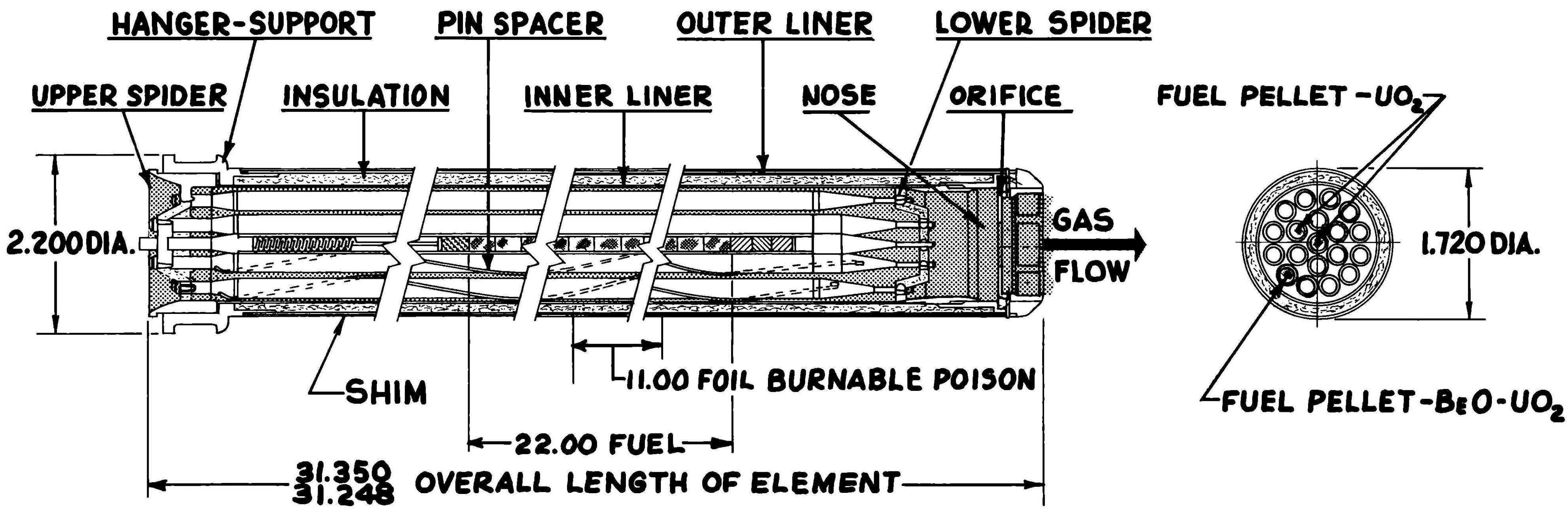


FIGURE 11

It is desirable, for heat transfer reasons, to adjust the power between pins to equalize the maximum metal temperature. Equal wall temperature is maintained among the pins by placing more uranium in the central pins than in the outer 12, since the thermal neutron flux is lower in the center of the element. Thus the seven inner pins are filled with fully enriched UO_2 pellets (nominally 0.177-in.-dia by 0.325-in.-long) and the outer 12 pins are filled with BeO-UO_2 so that these pellets (nominally 0.176-in.-dia by 0.22-in.-long) are only 31 vol% highly enriched UO_2. All pellets are cold pressed and sintered to about 96% theoretical density.

The insulation (Thermoflex) is cut from bulk sheets as washers and stacked between the inner and outer liners. The inner liner is Hastelloy-X 1.426-in. ID with 0.010-in.-wall. The outer liner is a stainless steel tube (with 0.12-in. wall) welded to the upper and lower fuel element closures. It supports the fuel element nose (bottom end closure). The nose of the element may be orificed to allow minor adjustments in the coolant flow to control fuel element temperatures in accordance with minor variations in power distribution across the core. Thus all elements will run, ideally, at the same temperature. The burnable poison, formed of a cadmium alloy canned in stainless steel foil, is attached to the inside of the outer liner opposite the lower half of the fuel. The poison is used in this location to reduce the peak temperature of the fuel pin during the first several thousand hours.

The fuel pins are assembled as follows: a lower plug is pressed into the fuel pin and Heli-arc welded. Then 3/4-in. of MgO pellets are placed into the fuel pin, and 22-in. of either BeO-UO_2 pellets or UO_2 pellets are placed into the fuel pin. A BeO pellet is added, and a spring spacer inserted on top of the pellet stack (to prevent pellets from moving into the gas expansion chamber and to keep the gaps between the pellet ends to a minimum during the reactor operation). The pin is then evacuated and back filled with helium. The top end plug is pressed into the pin and Heli-arc welded to the pin. The MgO pellets are used to reduce the temperature of the weld that joins the lower plug to the tube. The BeO pellet at the top of the fuel stack disperses the heat from the top fuel pellet thus reducing the peak temperature gradient in the fuel pin at this point of the fuel stack. The fuel envelope is made of Hastelloy-X.

Hastelloy-X was selected as a reference material for the fuel pins since it displayed the best physical characteristics when screened with other materials in gas corrosion tests (0.0035 in. corrosion per first 5000 hours under ideal conditions in reference atmosphere) and in creep tests in the range of 1750°F in the ML-1 atmosphere (nitrogen plus 0.5 vol % of oxygen). The Hastelloy-X for the fuel pins has a cobalt content of less than 0.1%. The low cobalt content minimizes loop contamination from possible erosion of the cobalt 60 from the fuel pins and reduces parasitic neutron absorption.

There is a large body of knowledge on the fabrication of both UO_2 and BeO-UO_2 pellets. In addition, the irradiation stability is well-known to burn-ups of interest to the design of the ML-1 reactor. There are several reasons for selecting BeO as a diluent for the 12 outer pins; a lower fuel inventory is required; the BeO gives better thermal conductivity and hence lower fuel temperature; and the BeO-UO_2 pellets may have better fission gas retention than UO_2 pellets.

The fuel tubes are inspected with a Radac eddy current testing machine. The end welds of the fuel pins are made on a semi-automatic tungsten inert gas welder without filler rod. The welds are inspected with a helium leak spectrometer and by X-rays. Each fuel pin assembly is checked with a gamma ray scintillation spectrometer to insure that the UO_2 pellets are not mixed with BeO-UO_2 pellets.

5. Effect of Fission Product Release

The possibility of pin holes occurring in fuel pins is recognized. The extent of the resulting contamination problem depends upon many factors. The cases below are presented in order of increasing severity. The calculations for these cases were based on WAPD data[1], but limited testing of ML-1 pin specimen capsules indicates that the release of fission gases from UO_2 may be significantly less than predicted if there is no oxidation of the UO_2.

Case A: Consider first that the leak occurs in an average pin, that is, one which runs at near nominal temperatures and has average pellet properties. Furthermore, consider that the leak is small, such that fission products leak but without the entrance of appreciable quantities of cxygen. In this case, the calculations show:

Single Average Pin

Release of gaseous fission products	1.9 curies
Dose at truck cab after 24 hr shutdown	1.7 mr/hr

Case B: Conditions as in Case "A" except for a hot spot pin (peak wall near 1750°F). Calculations show:

Single Hot Spot Pin

Release of gaseous fission products	5.5 curies
Dose at truck cab after 24 hr shutdown	5.6 mr/hr

Case C: This case considers a hot spot pin and a leak big enough (for example, 0.01-in. diameter) so that the reference gas causes pellet oxidation and that operation has continued for 400 hr. In this case:

Single Hot Spot Pin after 400 hr in Air

Release of gaseous fission products	10 to 50 curies
Dose at truck cab after 24 hr shutdown	8 to 50 mr/hr

(1) Lustman, B. "Release of Fission Gases from UO_2" WAPD-173, 1957

Case D: Identical to Case "C" except the coolant is air:

<u>Single Hot Spot Pin after 400 hr in Air</u>

Release of gaseous fission products	100 to 500 curies
Dose at truck cab after 24 hr shutdown	80 to 500 mr/hr

Tests of failed pins will provide better information on the magnitude of the effects of fission product release.

If fission product leaks occur in service, it may be possible to switch to pure nitrogen as a coolant. The elimination of the 0.5 vol% oxygen would thus eliminate the oxidation of UO_2 and the high releases associated with Cases "C" and "D". Experiments are underway to determine the effect of high purity nitrogen on fuel element materials. It is important to retain fission products within the sealed fuel pins because the ML-1 has a single loop and the power conversion equipment is unshielded. For these reasons, special attention has been given to the integrity of fuel pins to minimize the release of fission products.

C. PRESSURE VESSEL

1. <u>General</u>

The pressure vessel assembly is designed to operate at stress levels within the material limits allowed by the ASME Pressure Vessel Code. The basic relationships between various components of the pressure vessel are shown in Figures 12 and 13.

The shear ring (Figure 12) transfers the weight of the pressure vessel assembly to a continuous stainless steel ring on the upper portion of the inner lead shield assembly. Gussets in the shield configuration transfer the load to the reactor shield tank structure. Torsional loads created by the thermal expansion of the gas duct are transmitted to the shield structure by shear keys at the top and bottom. This device prevents the undesirable application of torsional loads on the pressure tubes.

2. <u>Tube Bundle</u>

The core shell is a bundle of 61 pressure tubes arranged in a lattice (Figure 13) and held in position by tube sheets, 3-in. thick, at each end. The pressure tubes separate the primary coolant gas from the water moderator, and provide precise positioning of the fuel elements.

The tubes are made of AISI Type 321 stainless steel (titanium stabilized to prevent carbide precipitation). They have a minimum inside diameter of 1.756-in. and an 0.020-in. nominal wall thickness. The tube sheets are forged integral with the plenum cavity sidewalls, thereby eliminating a joint. These forgings are of AISI Type 304 stainless steel. The carbon content of the forging is low enough to preclude carbon precipitation when welding the tube-to-tube sheet seal.

ELEVATION OF THE ML-1 REACTOR

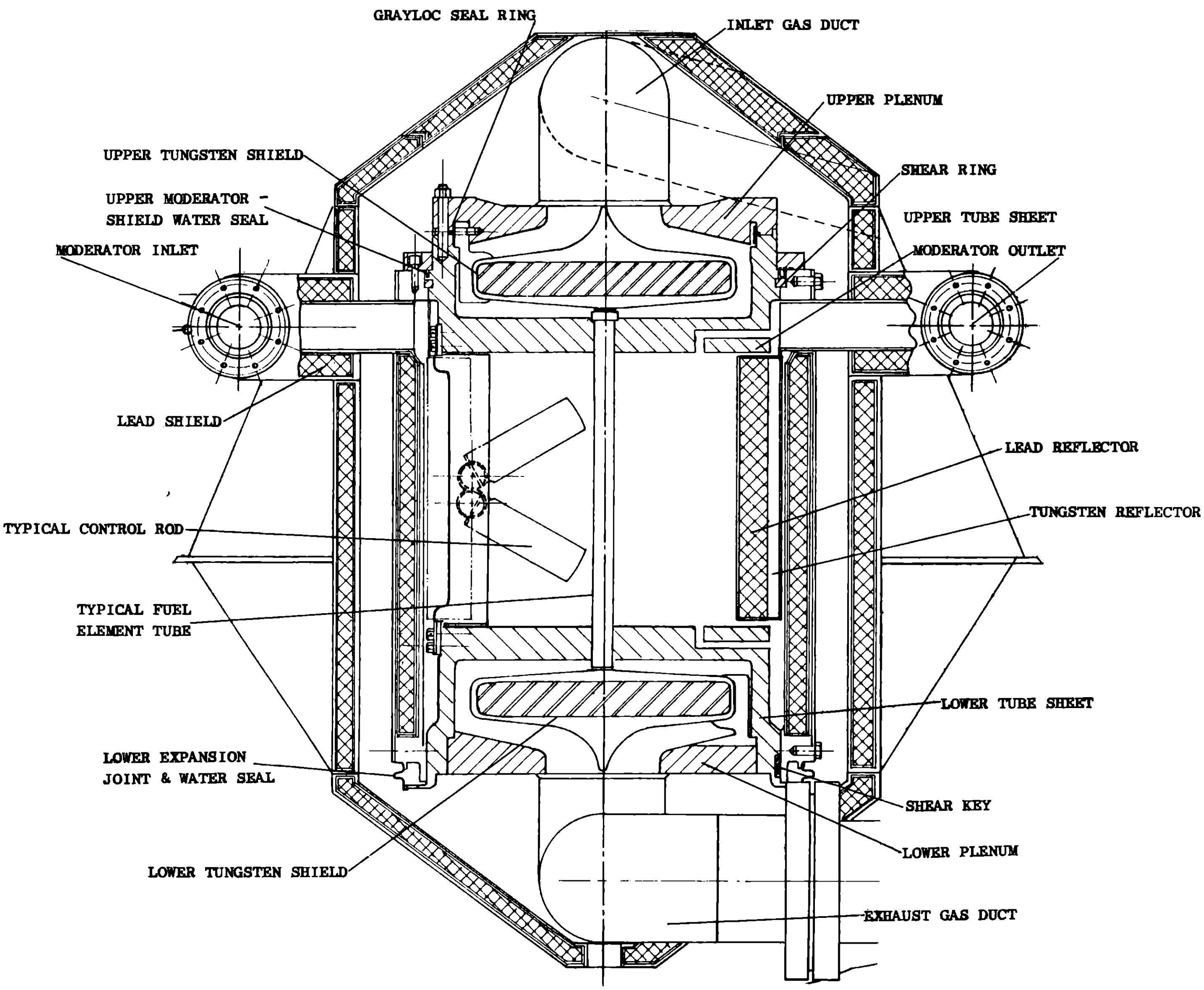


FIGURE 12

CROSS SECTION OF THE ML-1 REACTOR

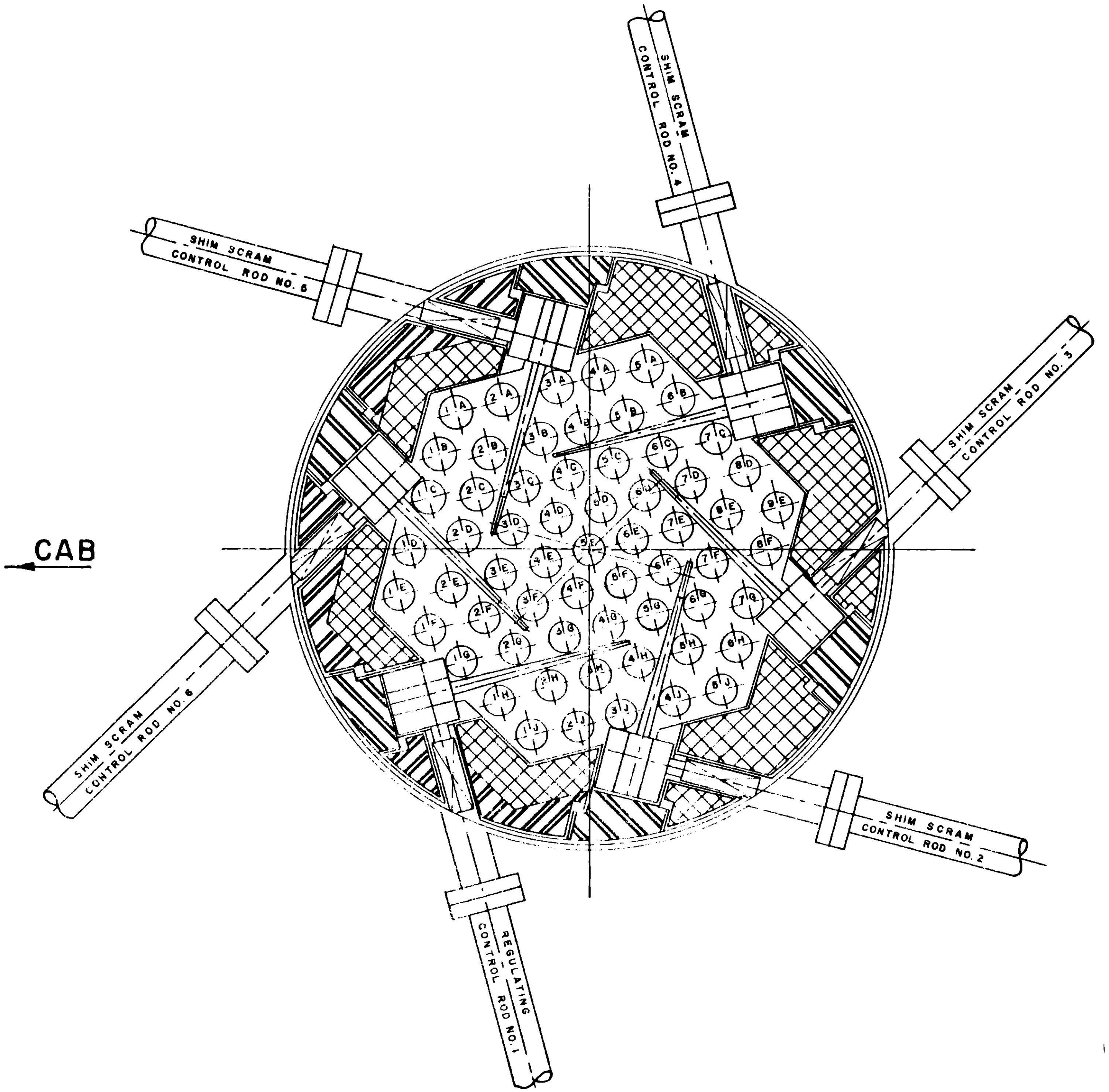


FIGURE 13

The internal cooling passages (Figure 14) are counter-bored with overlap between adjacent holes to provide adequate flow of moderator water. These internal cooling surfaces are needed to minimize thermal stresses in the ML-1 tube sheets. In joining the pressure tubes to the tube sheet, each tube is expanded into the bored hole by rolling the tube to a pre-determined amount of plastic deformation. The rolling is done in two steps: the back joint first, and then the front joint.

After tube expansion, the joint is machined flush to the surface of the tube sheet and machine welded to insure a positive seal. Exhaustive tests have been performed to insure the mechanical integrity and seal capability of the reference joint design. These tests included pull tests, thermal cycle tests, and thermal shock (Δt of 400°F) tests.

3. Plenums

The cylindrical portions of the plenum cavities, as explained in the previous section, are forged integral with the tube sheets. The lower plenum cap is lightly pressed into the lower plenum. In addition, a series of press-fitted radial shear pins join the plenum wall and cap. The entire cap is then welded to form a gas-tight assembly.

The upper plenum cap is removable to permit access to the fuel element array. Therefore, it is joined to the upper plenum (Figure 12) by a bolted flange and a Grayloc seal (manufactured by the Gray Tool Co., Houston, Texas). The Grayloc design was selected because, among other reasons, the seal ring is re-usable indefinitely and the joint is unaffected by pressure variations. The pre-acceptance tests included pressure and temperature leak tests as well as helium mass spectrometer tests.

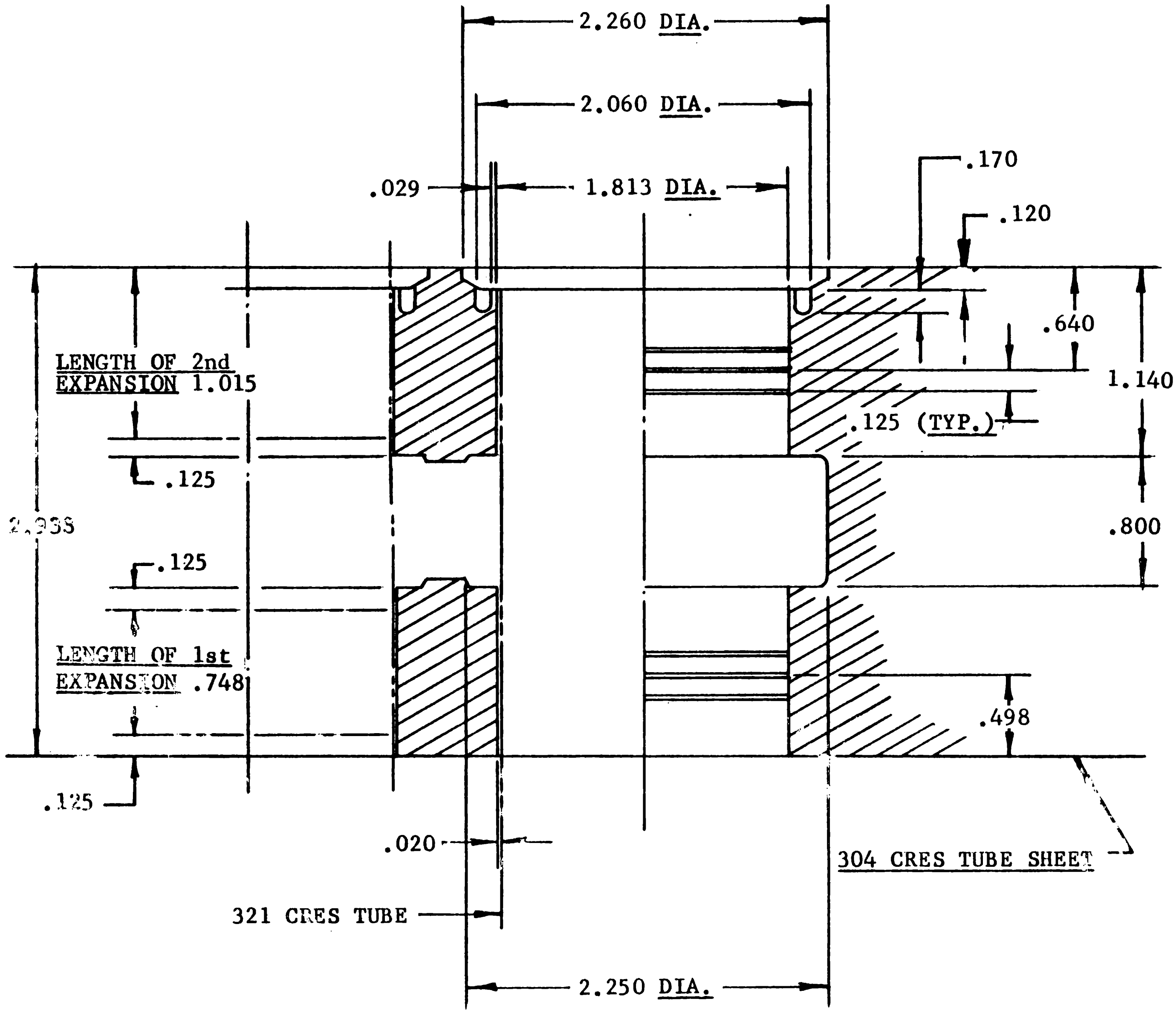
Internal heat-shielding is used to keep the metal at low operating temperatures to reduce stresses in all plenum components. The design (Figure 15) consists of an inner liner separated from the plenum by three concentric, uniformly spaced, thin walled (0.015-in.) radiation baffles. Analytical studies, supported by test samples of various proposed configurations, were used to determine the number and spacing of baffles. The tube sheet is insulated with a "Refrasil" blanket (manufactured by the H. I. Thompson Co., Los Angeles, Calif.) similar to that used in GCRE-I.

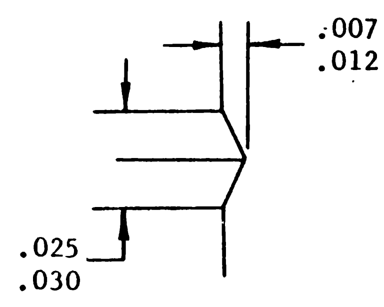
4. Gas Ducts

The upper and lower gas ducts (which direct the coolant gas into and out of the fuel element array) are forged and welded stainless steel pipe manufactured to rigid specifications. The pipe is hydrostatically tested and all welds are dye checked and X-rayed.

Internal insulation, similar to that in the plenums, is used to maintain low pipe operating temperatures. The over-lapping scarf joint (Figure 16) allows for axial expansion. The over-lap design of the radiation baffles permits circumferential expansion.

TUBE TO TUBE SHEET JOINT
(SHOWING INTERNAL COOLING PASSAGES)





TYPICAL GROOVE DETAIL

UPPER PLENUM ASSEMBLY

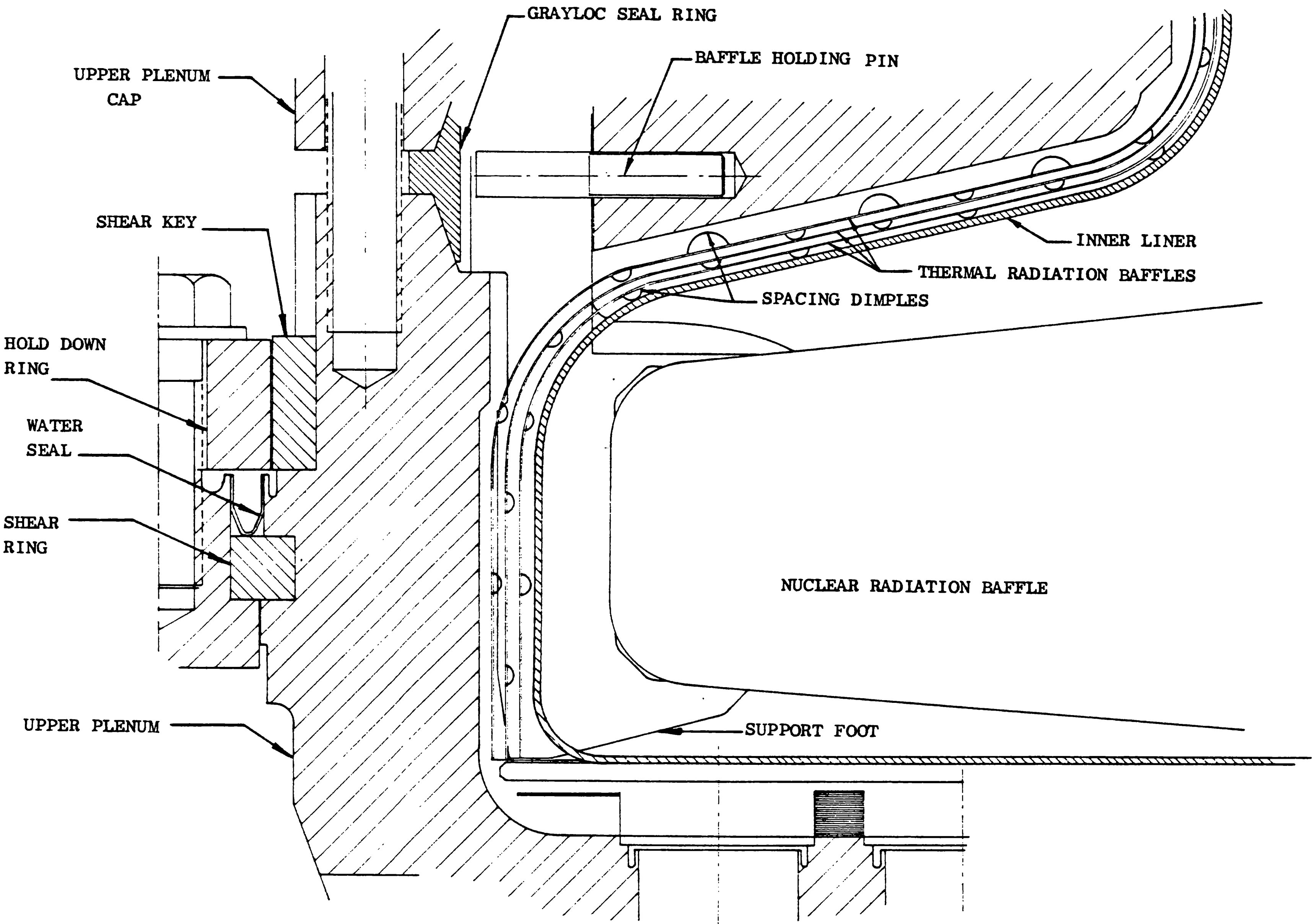


FIGURE 15

GAS DUCT INSULATION JOINT

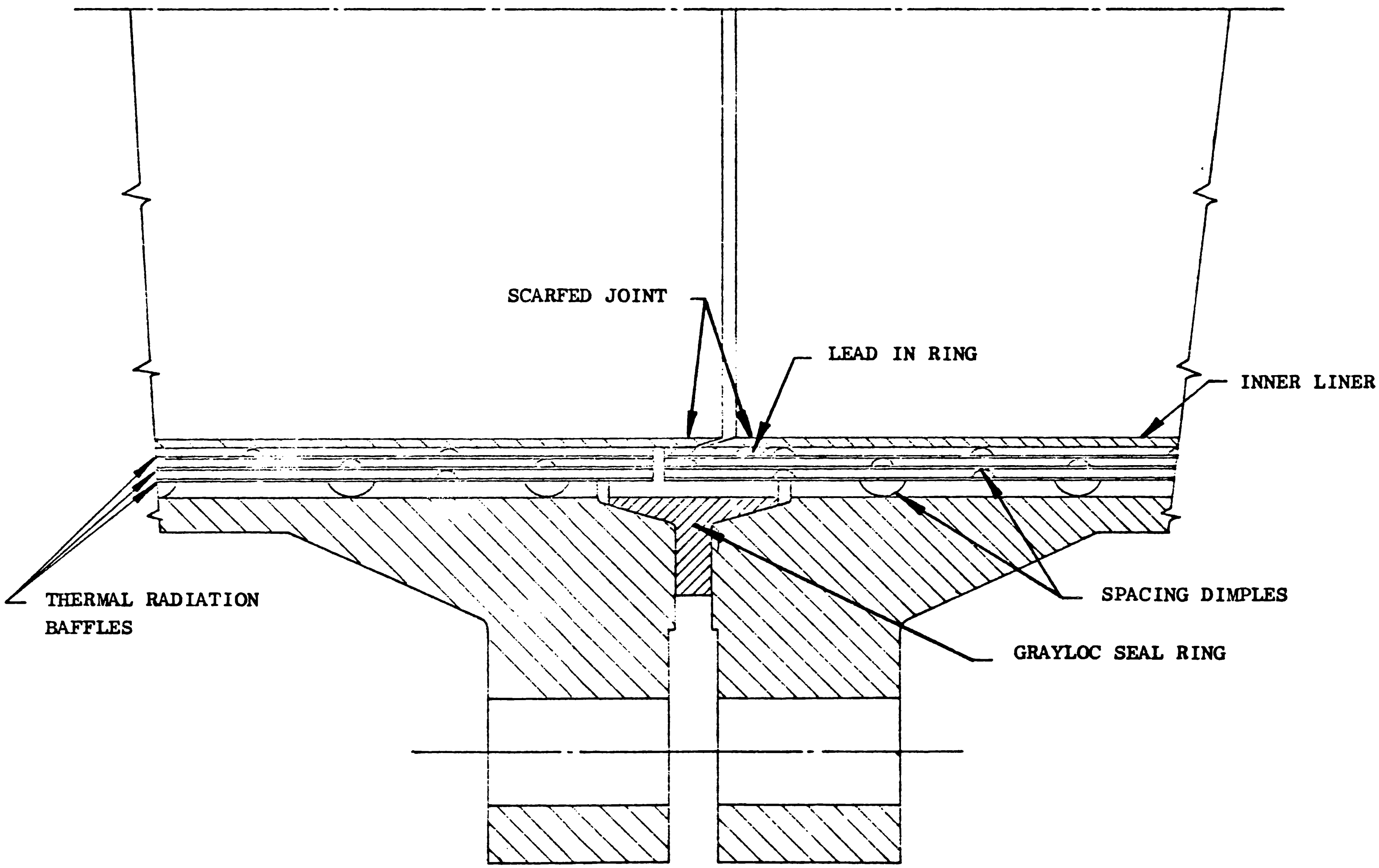


Figure 16

The inlet gas duct is designed with a Grayloc joint accessible from the field servicing scaffold, since the duct must be removable with the upper plenum cap. The lower gas duct also incorporates a Grayloc flange to permit assembly of the reactor into the shield tank. The gas ducts penetrate the shield tank through flexible bellows (Figure 17).

D. SHIELDING

1. General

The shield design is based on the following criteria:

1) The maximum radiation level, with the water removed from the shield tank, shall be 15 mr/hr 24 hr after shutdown at 25-ft horizontally from the reactor centerline in the direction of the cab of the transport vehicle.

2) The maximum radiation level vertically shall not exceed 1500 mr/hr 24 hr after shutdown at 25 feet.

3) The maximum radiation level in any other direction shall not exceed 150 mr/hr 24 hr after shutdown at 25 feet.

4) The operational dose level shall be minimized consistent with the shutdown dose level imposed by 1) above and the 15-ton reactor package weight limitation.

These criteria impose rigid conditions on the tolerable shutdown dose levels around the reactor package. As a result of these criteria, the shield is primarily designed as a shield against core gamma activity and the radiation from activation of shield components and support structure. The operational dose level has been minimized only after adhering to the shutdown dose requirements and after providing a reactor package within the 15-ton weight limitation.

The requirements are met by:

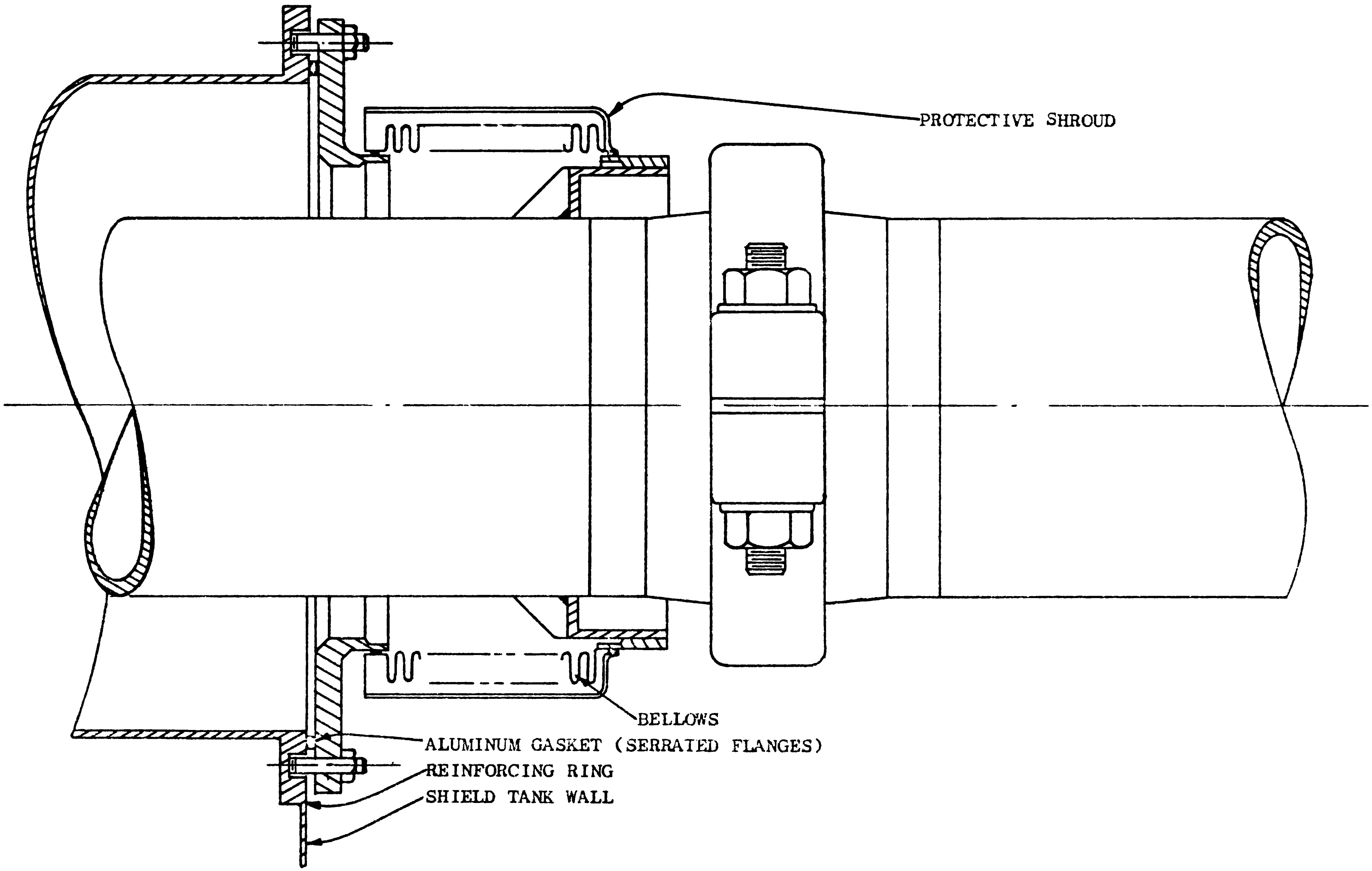
1) Minimizing the size of the active core, and thus minimizing the volume to be shielded;

2) Surrounding the core and end ducts with high density/high atomic number materials to shield the gamma rays produced by fission product decay and by activation within the core, plenum and shield regions;

3) Providing an expendable borated-water neutron and gamma shield. This shield affords operational shielding with minimum transportable shutdown shielding weight; and,

4) Providing a small thickness of permanent neutron shielding to attenuate the beryllium photoneutrons produced after shutdown.

BELLOWS FOR GAS DUCT TO SHIELD TANK PENETRATIONS



2. Shutdown Shielding

The reactor shielding for the ML-1 has a twofold function: it must meet the basic nuclear shielding requirements for the reactor, and it must structurally support the reactor package and control components. The present shield design incorporates an optimum shield and structure compatible with the 15-ton weight limitation for the ML-1.

The ML-1 shield (Figure 6) consists of a lead fast neutron reflector, 2-in. thick, surrounding the core in the radial direction. Outside the lead reflector (in the forward direction) is about 2-in. of tungsten. Both the lead and tungsten are integrally canned in stainless steel (AISI Types 321 and 304-L) to prevent corrosion and to provide structural integrity. Next to the reflector is about 2-in. of lead and a 3-in. annulus. The annulus is filled with borated neutron shield water during operation. A second lead region surrounds the radial shield and end ducting outside the water annulus.

The shutdown shielding in the axial direction consists primarily of tungsten end plugs, each about 3-in. thick. The plugs are streamlined and positioned within the plenums so the gas flows through the reactor core with minimum pressure drop. An end shield of 2½-in. of lead is used to enclose the upper and lower stainless steel plenums and end ducting.

The calculations of the shutdown dose levels assume one year of operation at a reactor power level of 3×10^6 watts (thermal). An isodose plot giving the shutdown dose levels as a function of distance from the reactor centerline is shown in Figure 18. The values quoted are the estimated dose levels at 24 hr after shutdown with the shield tank drained. These levels are based on results of recent ORNL Lid Tank experiments in which the shield was mocked up in slab geometry; and foil activation and operational neutron and gamma measurements were made. The attenuation of the dose rate with time (broken down by source) is shown in Figures 19, 20 and 21.

Power conversion equipment and all reactor equipment outside the shield tank can be maintained with water in the shielding tank. The dose levels with the tank filled is lower by a factor of 20 than the values shown in Figure 18.

The shutdown dose in the direction of the cab of the tractor at 25 ft is a result of contributions from various sources as shown in Table 2, on page 50.

3. Operational Shielding

The operational shield within the limitations of package size and weight reduces the neutron and gamma dose outside the shield region to a minimum. It prevents radiation damage or activation of components outside the reactor. (The 15-ton weight limitation refers only to the transportable weight. It does not preclude the use of expendable or expedient operational shielding.)

SHUTDOWN DOSE LEVELS FOR THE ML-1

ONE YEAR OPERATION, 24 HOURS AFTER SHUT DOWN, SHIELD & MODERATOR WATER DRAINED

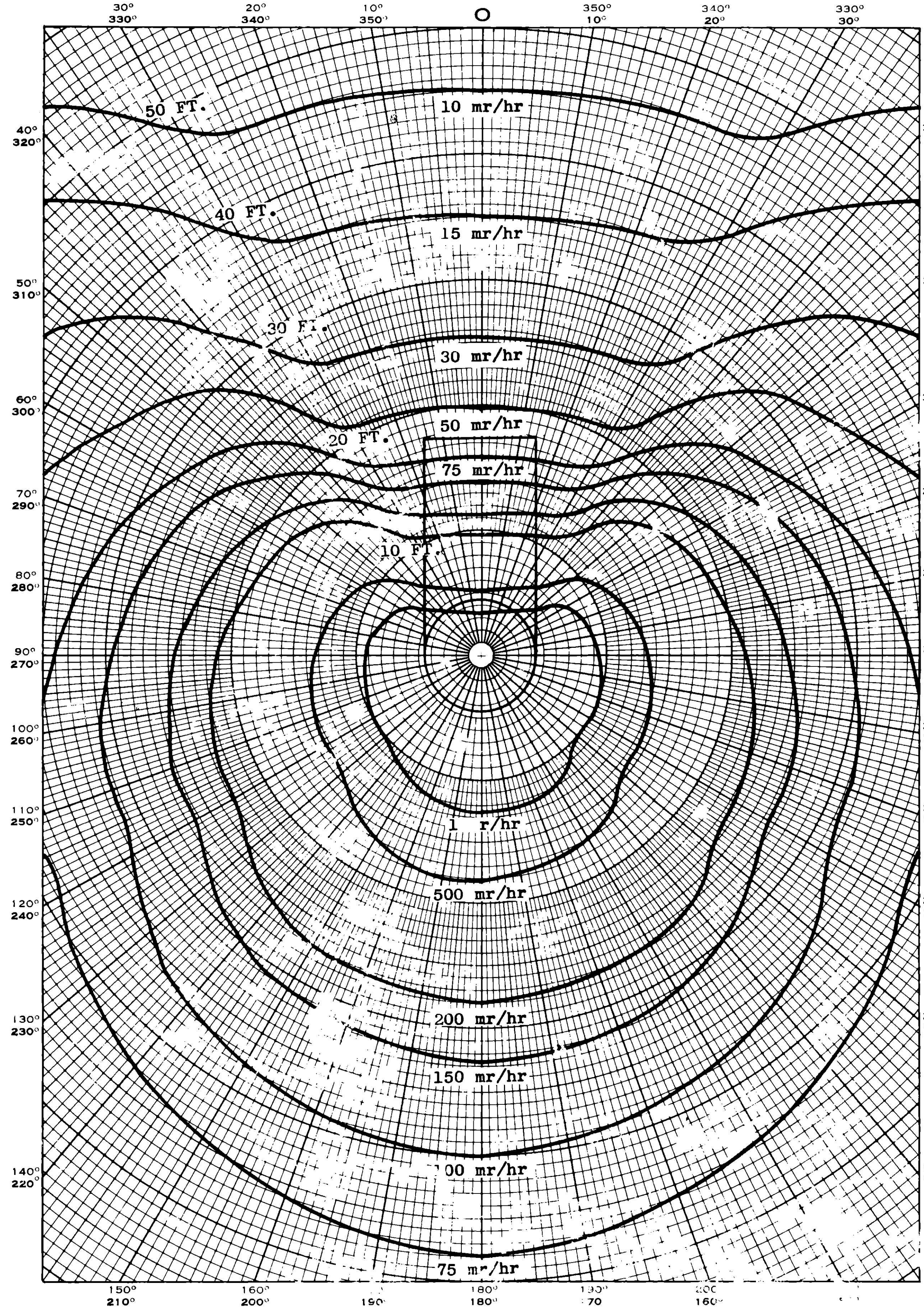


FIGURE 18

ML-1 SHUTDOWN DOSE RATE AT 25 FT. WITHOUT SHIELD WATER
AFTER 10,000 HOUR OPERATION (.03 & .08 COBALT IN STAINLESS STEEL)

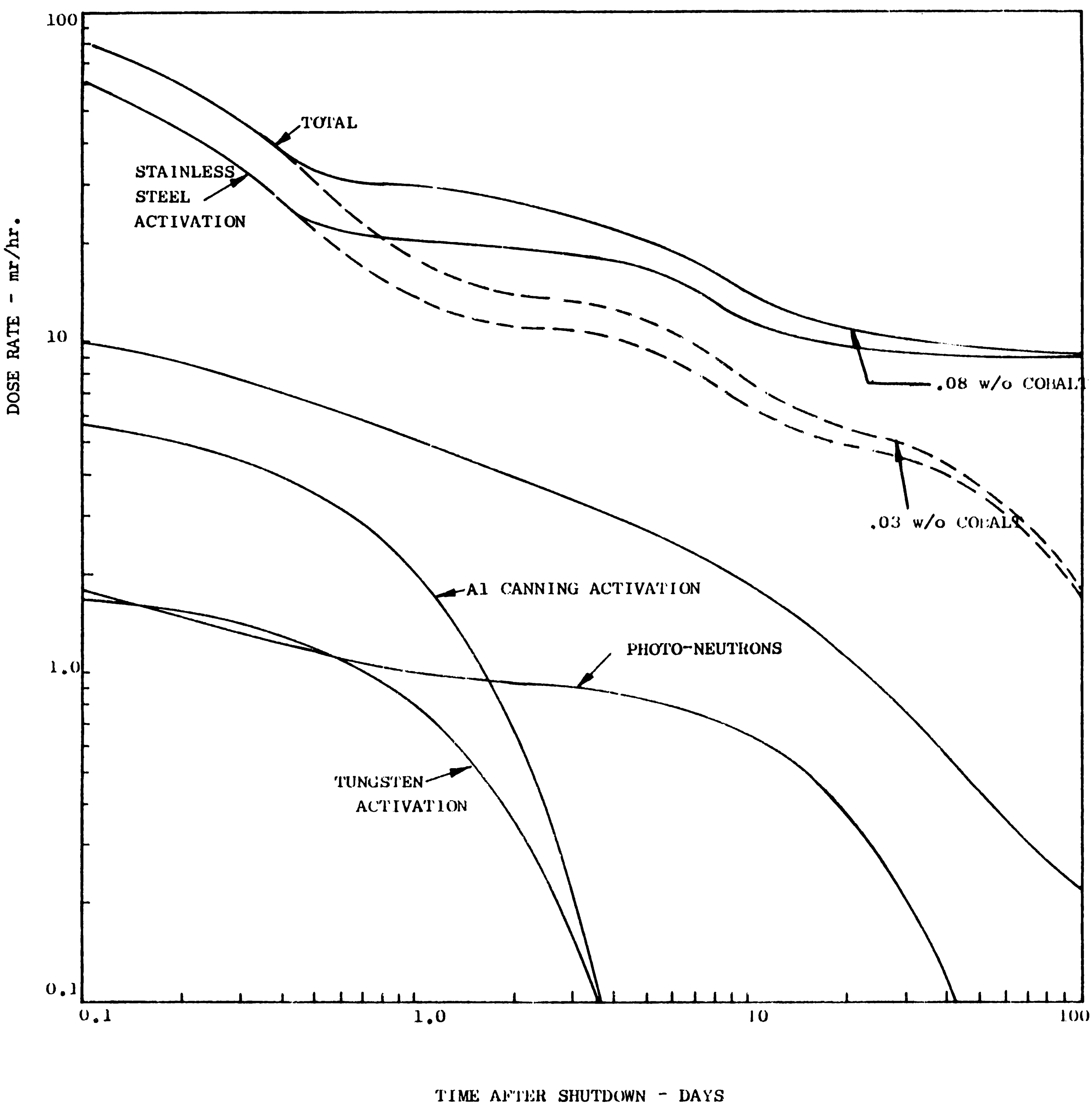


FIGURE 19

ML-1 SHUTDOWN DOSE RATE AT 25FT WITHOUT SHIELD WATER
AFTER 1000 HOUR OPERATION (.03 & .08 w/o COBALT IN STAINLESS STEEL)

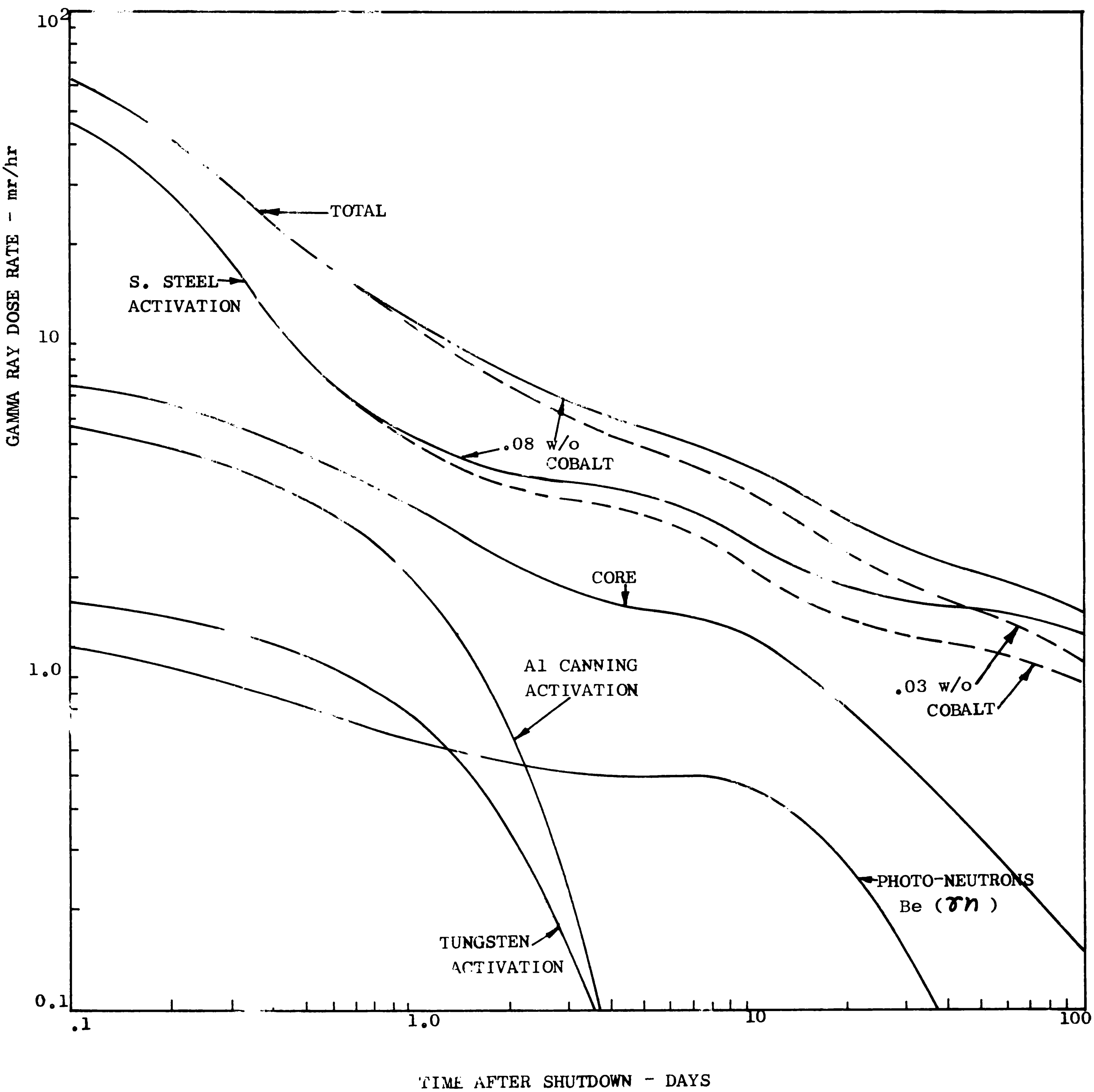


FIGURE 20

ML-1 SHUTDOWN DOSE RATE AT 25FT WITHOUT SHIELD WATER
AFTER 200 HOUR OPERATION (.03 & .08 w/o COBALT IN STAINLESS STEEL)

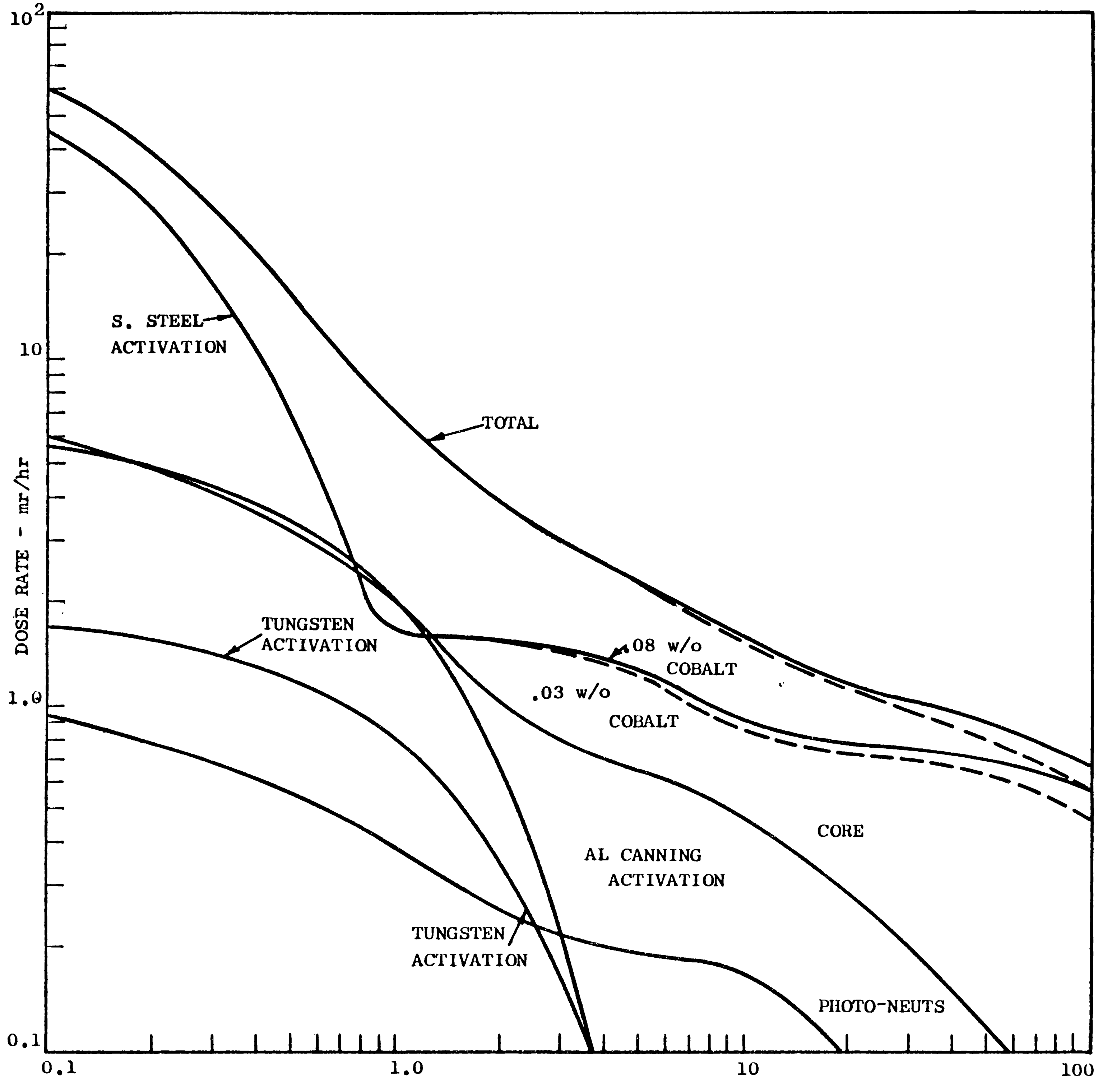


FIGURE 21

TABLE 2

SOURCES AND MAGNITUDE OF SHUTDOWN DOSE

SOURCE	DOSE CONTRIBUTION (mr/hr)
Fission product gammas	5.0
Photo-neutrons	1.0
Activation of control blade shaft	3.5
Control blade slots	1.0
Plenum activation (fast neutrons)	5.1
Plenum activation (thermal neutrons)	1.7
Gas duct activation	6.0
Tungsten activation	0.8
Aluminum can (inner)	3.0
Aluminum can (outer)	1.1
Moderator duct	1.0
Inner stainless steel can	2.1
TOTAL *	31.3

* Effect of power conversion skid not included. The power conversion skid will reduce the shutdown dose rate by a factor of 3 in the cab direction.

Although some benefit is realized from the gamma shielding adjacent to the core, the primary operational shield consists of the 3-in.-thick borated water annulus, the surrounding 2-in. of lead, and the 2-1/2-ft of borated water surrounding the permanent shield assembly in the horizontal plane.

The main contributions to the total operating dose level come from capture gammas from thermal neutron absorption in the shield water. Boron capture results in a 0.48 mev gamma. Hydrogen capture results in a 2.2 mev gamma.

The outer 2-in. of lead shielding minimizes the effect of activation in the outer regions of the shield and pressure vessel components, and adds to the operational shield effectiveness. Nearly all the hydrogen and boron capture gammas originate within the 3-in. shield water annulus. The lead thickness outside the annulus was determined experimentally in the Lid Tank Shielding Facility at the Oak Ridge National Laboratory.

In addition to attenuating the neutron flux to a safe level for personnel in the control cab (500 ft from the reactor) the operational shield decreases the flux to a level so there is no radiation damage to, or high level activation of equipment located within and immediately surrounding the reactor shield tank. (A flux plot showing three different neutron energy groups throughout the gamma and neutron shield is given on Figure 22.)

The operational dose levels at various distances from the reactor centerline indicate that it may be desirable to employ some expediant shielding when operating the power plant in the field. Since the operational dose is predominantly a result of neutron capture in the shield water, and the operational neutron shield thickness is nearly uniform in all directions, the operational dose is nearly isotropic.

E. CONTROL BLADES

The ML-1 reactor is controlled by 6 pairs of semaphore-type neutron absorbing blades located in the moderator between the fueled pressure tubes. This control system was chosen to reduce radiation streaming by minimizing clear passages into the core regions. The shutdown radiation requirements could not be met by any simple reciprocating mechanism. Therefore, the ML-1 control blades are driven by rotating shafts, and are retracted into the reflector. There are 5 shim-scram pairs worth a total of 5% negative reactivity. This 5% negative reactivity provides a maximum k_{eff} of 0.971 in an unflooded core, with all shim-scram elements inserted in the core. The fine control blade pair provides another 0.5% reactivity. Additional reactivity compensation is supplied in the fuel elements by using a burnable poison (cadmium) to balance fuel burnup, samarium buildup and low cross-section fission product buildup. (See Figure 23.)

The amount of excess reactivity control required for the reactor is 4.3% as shown in Table 3 , Reactivity Requirements for ML-1. Burnable poison will account for 2.2% of this control, leaving 2.1% to be supplied by control blades. Since the 5 shim-scram rods will supply 5% negative reactivity this means that 2.9% remains for shutdown. Therefore, one or two pairs of control blades could fail to scram but shutdown would still occur. If the 0.5% regulating blade worth be considered, then as many as three other pairs of blades could fail and the reactor would still shut down. As each control blade pair is completely independent of the others, it is highly improbable that more than one pair would fail to function at any particular time.

The pair of regulating blades provides reactor power regulation. They can be fully inserted or fully withdrawn in 10 seconds. The five pairs of shim-scram blades are used to compensate for reactivity changes that occur during the lifetime of the reactor and for shutdown. Insertion or retraction requires four minutes. Under a scram condition, all five pairs are inserted in 0.35 seconds. The regulating pair is inserted more slowly. The control worth of the blades is shown in Figure 24 as a function of position. The fully inserted condition occurs at 10^{o}.

The regulating blades are of AISI Type 202 stainless steel. The shim-scram blades are an alloy of 80 wt% silver, 15 wt% indium and 5 wt% cadmium. Each blade extends between the fuel tubes approximately 10 inches into the core. The blades are approximately 4-in. wide, 1/4-in. thick at the tip and are tapered to 5/8-in. at the base.

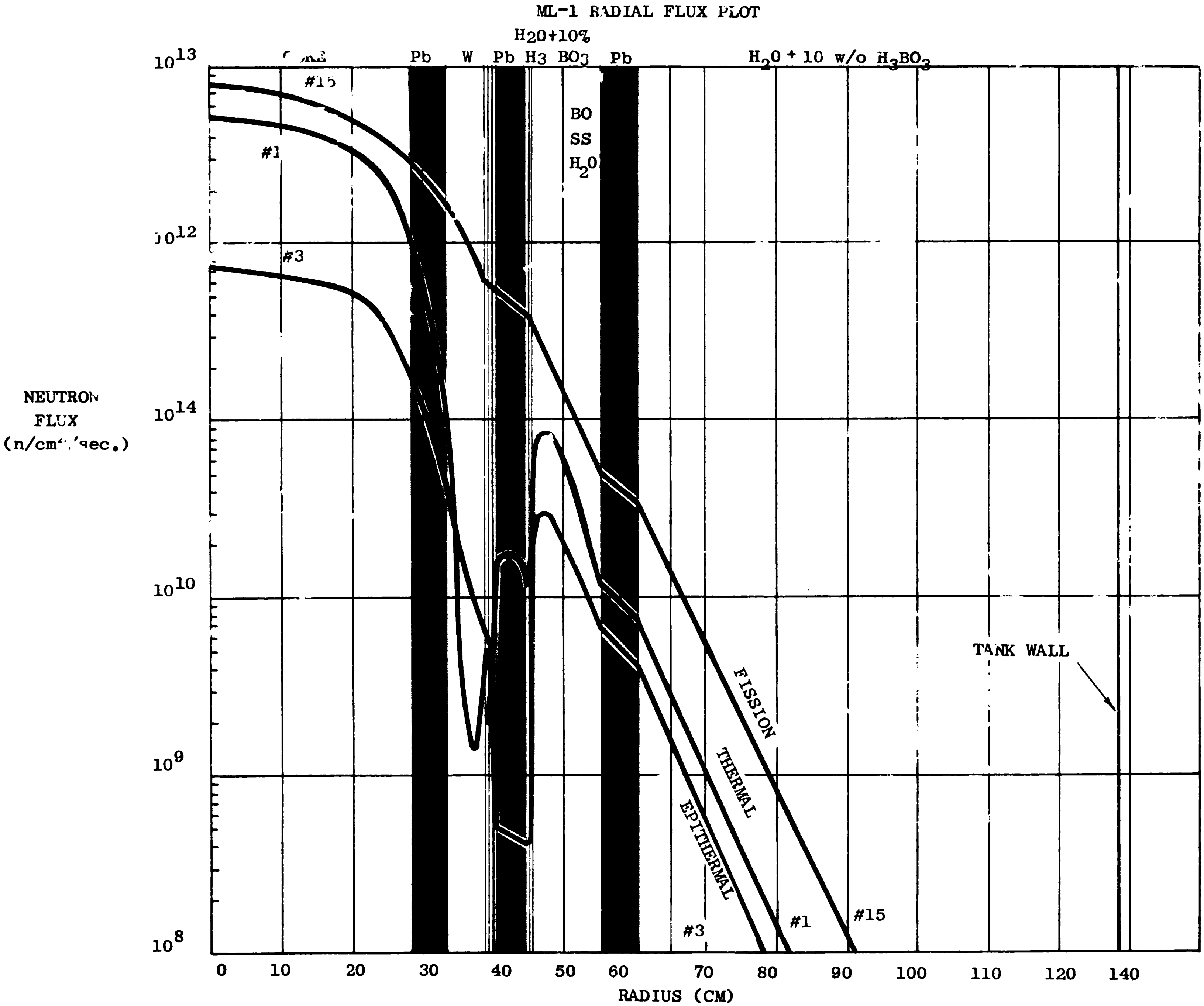
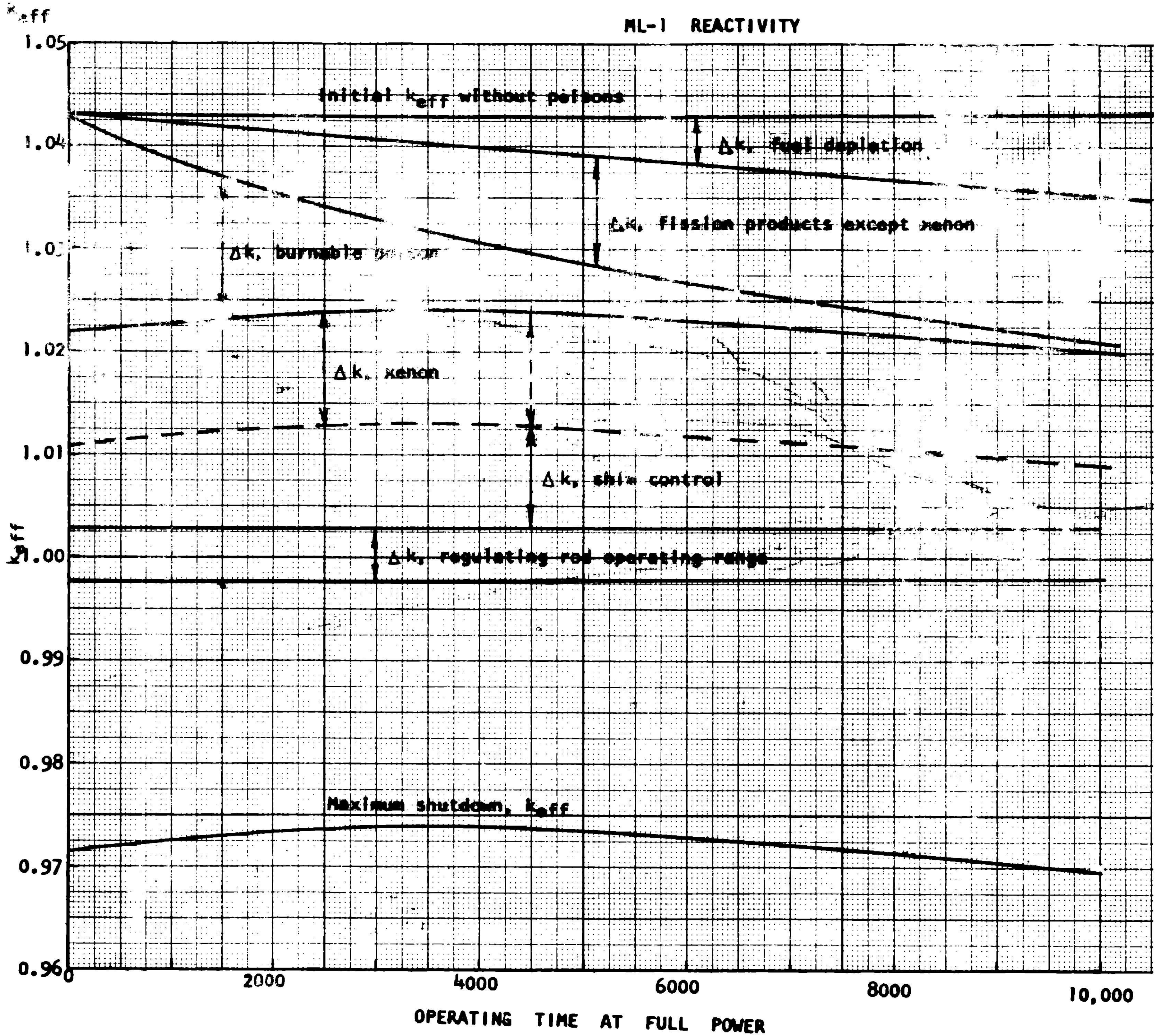

ML-1 RADIAL FLUX PLOT
CORE
Pb
W
Pb
H20+10% H3 BO3
Pb
H2O + 10 w/o H3BO3
BO
SS
H2O
#15
#1
#3
NEUTRON FLUX (n/cm2/sec.)
10^13
10^12
10^14
10^10
10^9
10^8
FISSION
THERMAL
EPITHERMAL
TANK WALL
#3
#1
#15
0
10
20
30
40
50
60
70
80
90
100
110
120
140
RADIUS (CM)

FIGURE 22


ML-1 REACTIVITY
k_{eff}
Initial k_{eff} without poisons
Δk, fuel depletion
Δk, fission products except xenon
Δk, burnable
Δk, xenon
Δk, shim control
Δk, regulating rod operating range
Maximum shutdown, k_{eff}
1.05
1.04
1.02
1.01
1.00
0.99
0.98
0.97
0.960
0
2000
4000
6000
8000
10,000
OPERATING TIME AT FULL POWER

REACTIVITY WORTH OF ML-1 CONTROL BLADES vs ANGULAR POSITION

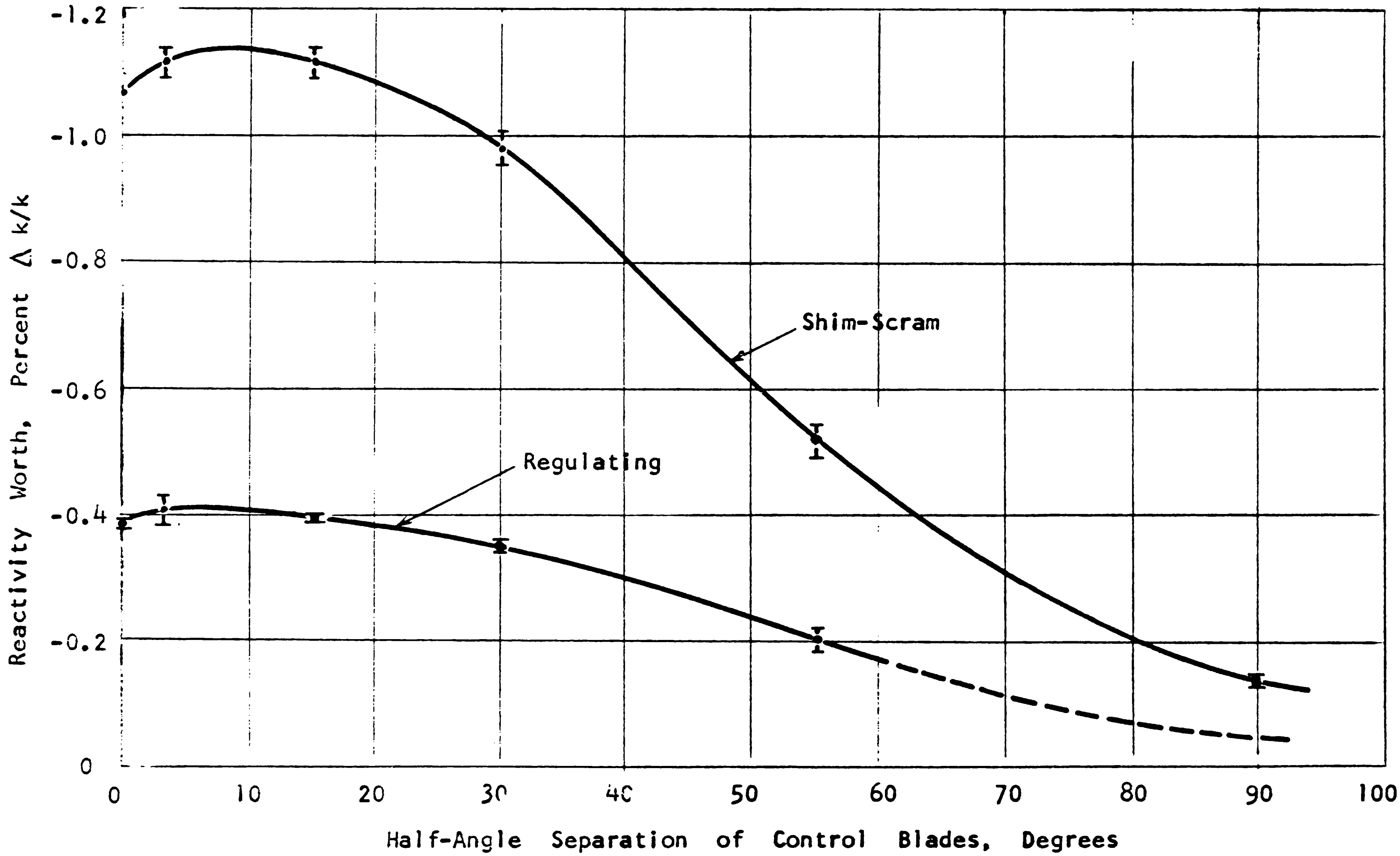


FIGURE 24.

CONTROL BLADE SYSTEM FOR THE ML-1

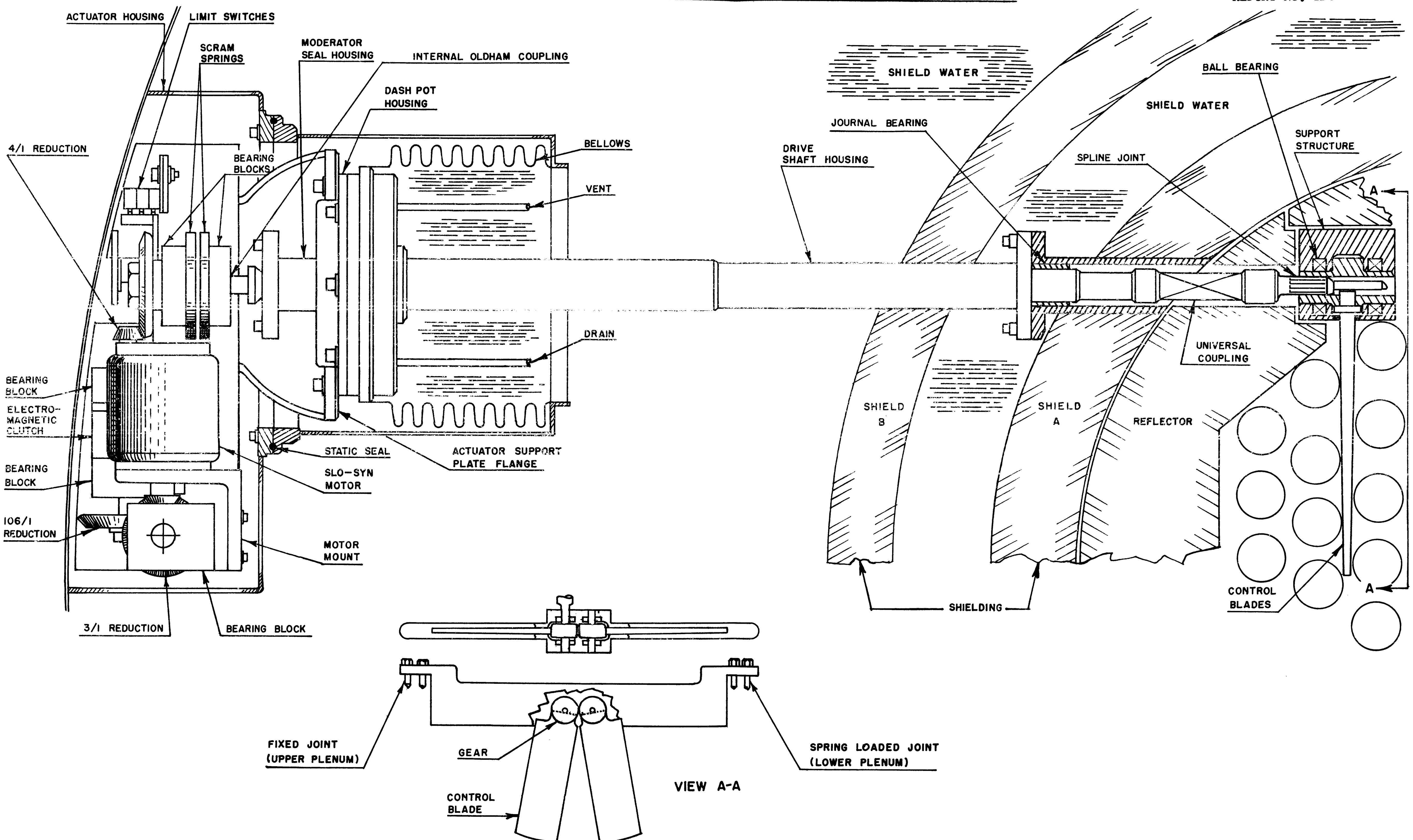


FIGURE 25

TABLE 3

EXCESS REACTIVITY REQUIREMENTS

(For 10,000 hr of full power operation of the ML-1)

	$\frac{\Delta k}{k}$
Xenon fission products	1.1%
Xenon override	0.1%
Samarium fission products	1.0%
Fuel depletion	0.8%
Low cross-section fission products	0.4%
Moderator temperatures	0.4%
Nitrogen or air pressure	0.1%
Control for power changes	0.4%
Total k_{excess} required	4.3%
Control, burnable poison	2.2%
Control, rods	2.1% + shutdown
Control, total	4.3%

The control blades are supported in a mount attached to the upper and lower tube sheets of the reactor core as shown in Figure 25. This figure also shows a plan view of the drive shaft, blade mount and actuator. The two blades are connected by ball-bearing mounted gears. One gear is joined to a drive shaft which tangentially pierces the radial shield and reflector. The mount is recessed into the reflector. The blades are rotated from the vertical retracted position into the fully inserted position through an arc of 80°. The clearance between the blades and the pressure tubes is nominally a minimum of 0.070-in. Proper alignment of the blades is assured in initial assembly by correctly positioning the gears to which the blades are attached. The 0.070-in. clearance is ample to allow for thermal distortion of the blades or the support structure.

The mount, the gears, and bearings are made of 17-4 PH stainless steel for corrosion resistance, low wear, and low thermal distortion. The driven gear is attached to the drive shaft by a female spline in the gear. A universal joint allows for manufacturing tolerances and thermal expansion between the blade mount, the reflector and the inner radial shield to which the drive shaft housing is fixed.

The shaft housing is composed of two parts, one welded to the moderator tank and the other joined by a flange to the first part and attached to the actuator housing recessed into the neutron shield tank.

The shaft housings can be assembled to the reactor with the radial shield. They are supported near the outer ends by gussets from the reactor support ring. The whole reactor assembly can be placed into the neutron shield tank and the bellows at the end of the shaft housings connected to the actuator housing. The shaft housing assembly is made of AISI Series 300 stainless steel.

Each actuator is suspended from its drive shaft housing. This reduces the flexibility required of the coupling between the actuator and shaft, and provides a compact arrangement. Each actuator is motor driven through a gear train and an electro-magnetic clutch. When the reactor is scrammed, the current to each actuator is interrupted, releasing the clutch and allowing double, clock-type springs to fully insert all blades. Scram can be achieved with only one of the two springs operational. Each actuator is provided with a water dashpot to absorb stopping shock. Moderator water is sealed by a rotary face seal at the dashpot housing. The dashpot is connected by a drain line to the moderator pump suction flange and by another line to the moderator reservoir. Thus circulating flow will tend to keep the dashpot free of foreign matter. The regulator actuators are identical to the shim-scram actuators except that they have a 54/1 gear reduction instead of 1272/1 reduction and a lighter scram spring.

The components of the system are mechanically indexed from the control blades to the position indicator to maintain the same relative position between the blades and the position indicator regardless of parts replacement. The position indicator is a variable induction, angular position transducer.

Each actuator is mounted in a housing recessed into the shield tank outer wall. An actuator can be quickly and easily disconnected from its dashpot housing as a unit by removing a cover on this wall. A mechanical stop prevents the scram spring from unwinding, and an auxiliary spring on the drive shaft prevents movement of the blades from the scrammed position when an actuator is removed. In addition, the upper blade is heavier than the lower so that the blades rotate into the core if the drive shaft is removed. With the actuator removed, the moderator seal can be replaced. All servicing except shaft replacement can be accomplished by maintenance personnel without special shielding.

F. MODERATOR WATER SYSTEM

1. General

Circulation of the moderator water is required during and after operation of the reactor to remove the heat generated in, or transferred to, the water inside the reactor, and in the shield tank. The total volume of the system is 450 gallons. To minimize weight, aluminum valving and piping is used where possible throughout the moderator system. Stainless steel is used wherever aluminum cannot be employed. The moderator system is equipped with a bypass cleanup system to maintain moderator water purity.

Manually controlled drains provide complete drainage of the moderator system exclusive of the reactor core. A separate drain allows the core to be drained.

Temperature levels given in succeeding paragraphs are for 100°F ambient temperature conditions.

2. Steady State Operation

The moderator water is circulated in a closed loop as shown in Figure 25 by a 300 gpm, 10 hp, sealless, centrifugal pump operating at a total discharge head of 70 feet of water, about 30.3 psi.

The moderator water enters the reactor at approximately 180°F, removing 1.20×10^6 Btu/hr generated in, or transferred to, the water inside the reactor as a result of fission product gamma heating, neutron heating, and heat conduction through the walls of the pressure tubes.

The moderator water leaves the reactor at about 190°F and enters the moderator water heat exchanger at 190°F. Total pressure drop across the reactor is equivalent to a head of about 25 ft of water (10.8 psi). The path of moderator flow through the reactor is shown in Figure 12.

The moderator heat exchanger is a compact, three pass, cross-flow water to air unit of aluminum with a minimum heat transfer capacity of 1.5×10^6 Btu/hr. The moderator water flows through layers of externally finned tubes. Two fans supply 78,600 lb/hr of cooling air. The outlet temperature of the reactor is automatically controlled by varying the opening of the heat exchanger louvers. In addition, reducing the number of fans in operation provides coarse manual control at low ambient temperatures. Total pressure drop across the moderator heat exchanger is equivalent to about 14 ft of water. The moderator heat exchanger is located on the power conversion skid adjacent to the oil cooler (Figure 27) because of the restrictions to reactor package weight.

The shield water heat exchanger is located inside the shield tank and removes the nuclear heat generated in the shield water. Total pressure drop across the heat exchanger (on the moderator side) is equivalent to about 6 ft of water. The water leaves the exchanger at about 180°F. This unit is discussed in more detail in Section III-G.

The moderator water next enters the upper surge tank, an integral part of the shield tank extension, and then flows into the lower surge tank. The lower surge tank is a circular tank located near the top of the shield tank. The upper surge tank holds 200 gallons, and the lower surge tank 110 gallons. The surge tanks provide the expansion volume required by temperature changes, allow for any loss of moderator water, and provide a heat sink for removal of afterheat in case of a complete power failure.

The upper surge tank is vented to the atmosphere through a line incorporating an air-cooled condenser. Non-condensibles, such as dissolved oxygen, escape through the vent line. Most of the water vapor

SHIELD WATER AND MODERATOR WATER SYSTEMS

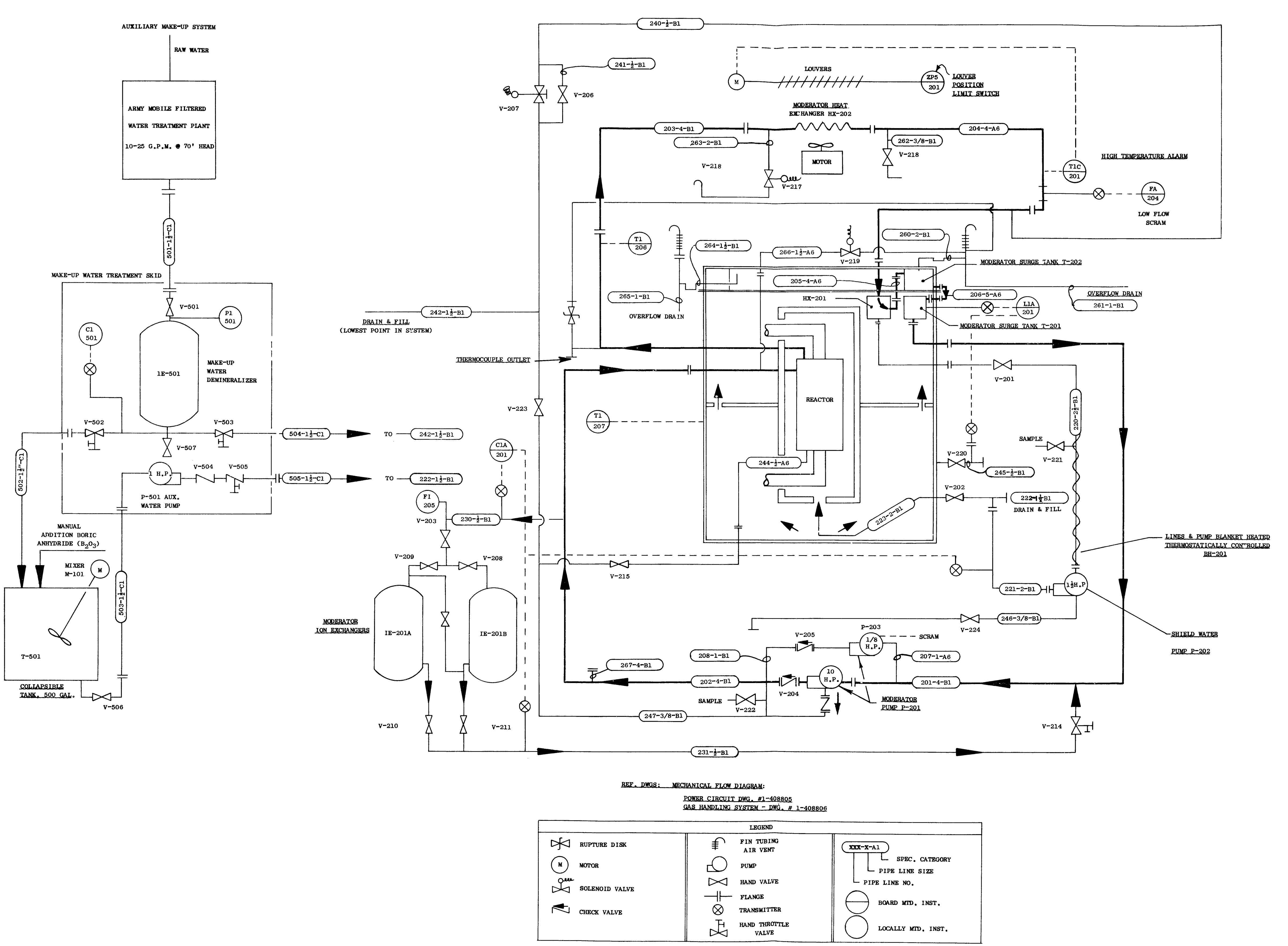


FIGURE 26

ARRANGEMENT OF EQUIPMENT ON THE ML-1 POWER CONVERSION SKID

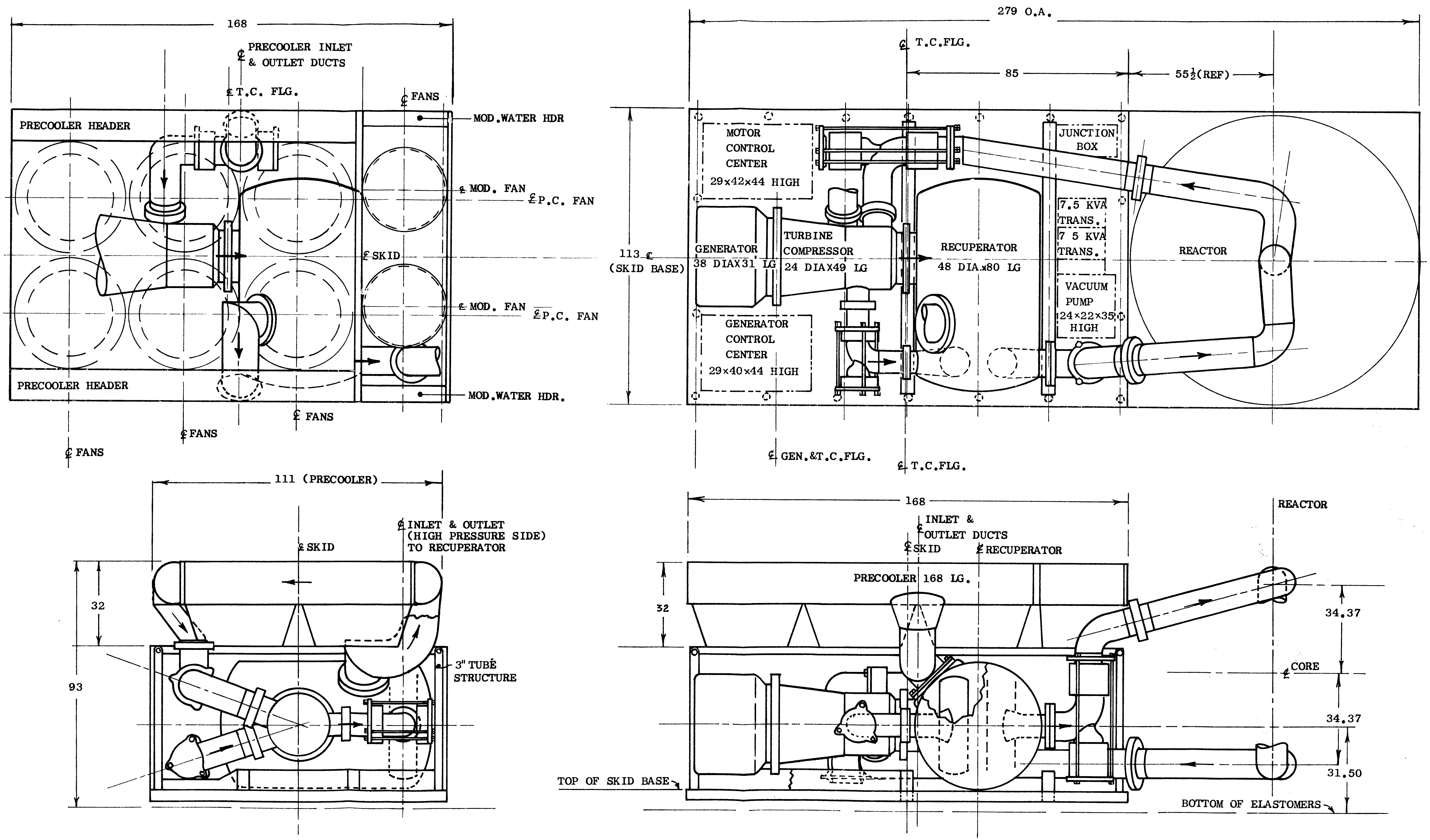


FIGURE 27

is condensed and returned to the tank. The upper surge tank is provided with a level indicator to aid in filling the system and to detect leaks.

Moderator water leaves through the lower surge tank and is routed directly to the suction side of the moderator pump, completing the moderator circuit.

A low-flow alarm, located downstream of the moderator heat exchanger, is incorporated in the moderator system. This alarm automatically scrams the system if moderator flow rate drops below a pre-set value (approximately 275 gpm). The low flow alarm is located as far as possible downstream from the pump to detect system leak, rupture or stoppage.

Approximately 3 gpm are continuously by-passed around the moderator pump and passed through two mixed bed demineralizers to maintain system water purity at about 1 megohm resistivity. The demineralizers can be valved either in series or parallel, as determined by initial operating experience. These mixed bed demineralizers use a strongly acidic cation resin and strongly basic anion for removal of either cationic and anionic soluble corrosion products. Water purity is continually monitored by conductivity indicators located on the inlet and outlet sides of the demineralizers. The resin charge is removed from the demineralizers for shipment.

A safety burst disk, set to rupture between 29 and 31 psig, is incorporated in the moderator system and is located downstream of the reactor exit. The burst disk will not permit loss of the moderator water in case of rupture.

The control blade dashpot housing assembly is connected to the suction side of the moderator pump and is vented to the lower surge tank. This assures proper initial filling and provides a small amount of circulation through the dashpot housing during steady state operation. (See Figure 25 Sect. III-E.)

The neutron detection chambers located outside the primary shielding are also connected to the suction side of the moderator pump and are vented to the lower surge tank.

3. <u>Scram Condition</u>

Forced circulation is provided through the reactor core following reactor scram by a standby pump to remove afterheat.

The power requirements of the main moderator pump prohibit its use following a scram.

When a scram is imposed on the system, the main moderator pump is shut off and the standby pump, operating on emergency power, is automatically started. The standby pump is switched to standby power when it becomes available.

The standby pump is a 15 gpm, 1/8 hp, sealless, centrifugal unit operating at a total discharge head of approximately 8 feet of water.

The moderator flow path during scram conditions is the same as that described for the steady state condition.

4. Complete Power Failure

If a complete power failure occurs, three solenoid valves open to prevent damage to the system.

One of the solenoid valves vents the inlet side of the reactor, bleeding any steam formed in the reflector-shield annulus. This prevents a vapor trap and assures positive feed of moderator water into the reactor core.

The second solenoid valve, located at the top of the moderator heat exchanger, allows steam to escape from the reactor core.

The surge tanks are sized to supply moderator water for after-heat removal for a minimum of 24 hours after complete power failure.

The third solenoid valve opens and drains the moderator heat exchanger to preclude freezing of the moderator water in the exchanger. The solenoid valve located at the top of the moderator heat exchanger prevents syphoning when the heat exchanger is drained, and in addition acts as a vent.

G. SHIELD WATER SYSTEM

1. General

The shield water tank contains the reactor pressure vessel assembly and shutdown shield, gas ducts, moderator and shield water system piping, moderator surge tanks, and the shield water heat exchanger (see Figure 26). The tank has a maximum diameter of 9 feet and including the shield tank extension, holds 2500 gallons. The shield tank extension is removed during fuel element removal and transport by airplane. The shield tank lid can be interchangeably mounted on the tank extension or on the main shield tank. During operation, the shield tank is filled with a 10% boric acid solution.

2. Startup

The shield tank is initially filled with a 2% boric acid solution prepared outside the tank. The remaining solute required to make up a 10% solution is added through the top of the shield tank. For a description of the water makeup system, see Section VI-E.

Before and during reactor startup, the shield water is well below saturation temperature (113°F). A 100 gpm, 1½ hp, sealless, centrifugal pump, operating at a total discharge head of 16 feet of water, circulates the shield water slurry during this period. The pump aids in dissolving the solute as the shield water temperature rises and provides forced circulation through the shield water heat exchanger during steady state operation. (See Figure 26.)

3. Steady State Operation

Nuclear heat generates about 150,000 Btu/hr in the shield tank under steady state conditions. The heat loss from an uninsulated tank at temperatures above the saturation point considerably exceeds the heat generated under conditions of extreme cold and high winds. However, without wind, the heat loss from an uninsulated tank is less than the heat generated, even under conditions of extreme cold, resulting in the liquid boiling (See Table 4). It obviously is necessary to insulate the shield tank, and incorporate a shield water heat exchanger to assure satisfactory all-weather operation.

The shield water heat exchanger is a compact, aluminum, cross-flow, single pass, water to boric acid unit with a minimum heat transfer capacity of 150,000 Btu/hr. The exchanger is connected to the suction side of the shield water pump and draws water from the top of the shield tank. The shield water, at maximum ambient temperature, enters the exchanger at 190°F, and leaves at 187°F. It passes through the pump and re-enters at the bottom of the shield tank, encouraging natural convective flow. Total pressure drop across the heat exchanger (shield water side) is equivalent to about 3 ft of water (about 1.3 psi).

The shield tank is vented to the atmosphere at all times to simplify mechanical design. The vent line incorporates an air cooled condenser to minimize evaporation losses. The shield tank is also provided with a level indicator, and a conductivity indicator is located in the pump discharge line to indicate the amount of solute dissolved in the shield water.

4. Shutdown

The shield water pump is shut off at scram. All external lines and components containing shield water are heated to maintain the boric acid in solution. This will prevent fittings, bearings, etc., being plugged with solute as would be the case if the fluid dropped below saturation temperature (113°F). The thermostatically controlled heater requires a maximum of 200 w standby power. The heater is not required during steady state conditions.

The shield tank is insulated to maintain temperatures in excess of 113°F for at least 24 hr after scram. The reactor can be approached after 24 hr and the tank drained if necessary. The shield tank insulation also aids in bringing shield water up to saturation temperature during startup.

TABLE 4

STABILIZED SHIELD WATER TEMPERATURES

(For various shield tank surface treatments, with and without the shield water heat exchanger.)

VARIABLES	UNITS								
Ambient air temperature	^{o}F	-65	-65	-30	-30	70	70	100	100
Assumed moderator heat exchanger outlet temperature	^{o}F	160	160	165	165	170	170	180	180
Wind speed	mph	4 or less	80	4 or less	80	4 or less	80	4 or less	80
TANK CONDITION									
Aluminum surface, no insulation, no shield water heat exchanger	^{o}F	Boiling	+13	Boiling	+48	Boiling	+148	Boiling	+178
Aluminum surface, no insulation, with shield water heat exchanger	^{o}F	163	140	169	153	177	167	187	180
Aluminum surface, ½" of Johns Manville RF-300 insulation, no shield water heat exchanger	^{o}F		<——— Boiling ———>						
Aluminum surface, ½" Johns Manville RF-300 inuslation with shield water heat exchanger	^{o}F	168	166	172	171	179	178	189	188

IV THE POWER CONVERSION EQUIPMENT

IV. THE POWER CONVERSION SKID

A. GENERAL

The power conversion skid supports and encloses the power conversion equipment during both operation and shipment. The three major items of equipment are the turbine-compressor set (T-C set) which includes a reduction gearbox; the alternator and starting motor; and the recuperator and pre-cooler. The skid also contains a lubrication system for the T-C set and alternator; a vacuum pump for purging all interconnecting piping, including the control by-pass; and electrical switchgear. The general arrangement of equipment on the skid is shown in Figure 27, page 60.

The rotating equipment is located "in-line", and the outlet from the turbine is connected directly to the recuperator. The reduction gearbox is mounted to the compressor at the high-speed end, and to the 500 kva alternator at the low-speed end. The gearbox also provides a drive for the lubricating oil pump.

The recuperator is rigidly fixed to the structure of the skid floor on the vertical centerline of the rotating equipment. The alternator is mounted on sliding feet to accommodate thermal expansion. The equipment is self-supporting between the alternator and the recuperator. The pre-cooler forms the roof of the skid. (The design characteristics of the power conversion skid are summarized in Section II-C.)

B. TURBINE-COMPRESSOR SET

The T-C set includes a compressor, a gas turbine, and a reduction gearbox. Two types of T-C set are being developed for the ML-1, an axial flow set and a radial flow set. The rotational speed is 22,000 rpm for the axial flow set and 18,000 rpm for the radial flow set. In both sets, the gearbox output drive shaft speed is 3600 rpm for the alternator and 1800 rpm for the lubrication pump.

1. Axial Flow T-C Set

The principal components of the axial flow T-C set are: a rotor assembly on which are mounted the rotor blades for the axial compressor and turbine; a bearing housing for the compressor;

the compressor inlet; the stator assembly for the compressor; the bearing housing for the turbine; the turbine exhaust annulus; and the reduction gear assembly. The T-C set, complete with the reduction gear assembly, is structurally self-supporting and is housed in a barrel-type pressure container 52-in-long by 28-in. in diameter. The total weight of the set, including the pressure container is 1800 lb. (The T-C set is shown in Figure 28.)

The main shaft and compressor rotor is a single forging. The forged compressor rotor blades are mounted in circumferential grooves in the rotor. The first-stage turbine rotor disc, and the second-stage turbine disc including the stub shaft, also forgings, are bolted to the compressor rotor. Pilot diameters on each part maintain concentricity, and radial pins transmit torque. The forged, shrouded turbine-rotor blades are mounted in broached "fir tree" slots in the rotor discs. Two cylindrical labyrinths and one radial labyrinth seal, at each end of the shaft, control gas leakage and prevent leakage of oil into the nitrogen loop. The cylindrical labyrinths are opposite to a stainless-steel honeycomb seal which is brazed to the case. The plain radial bearings are of babbitt to ensure long life. The thrust bearing is a tilting-pad bearing, similar to the Kingsbury bearing, sized to accommodate the 4000-lb axial load for the long life required. The lubrication system includes filters rated to remove particles above 25 microns. All the bearings are replaceable to facilitate maintenance.

The cast steel compressor-bearing housing contains the compressor journal bearing, the thrust bearing, part of the labyrinth seal, and carries the necessary connections for lubricating oil supply and drain. The stationary planet carrier of the reduction gear is bolted to a conical projection from this bearing housing. The bearing housing is bolted to the compressor inlet.

The compressor inlet is a steel casting which serves as a mounting for the shutdown seal and two labyrinth seals. In addition, when it is bolted to the inlet bearing housing, the compressor inlet supports the T-C set. Clean nitrogen from the compressor bleeds is supplied to the labyrinth seals through internal porting in the casting. The compressor inlet is bolted by its outer flange to the barrel and separates the compressor inlet plenum from the gearbox. It provides structural support for the turbine-compressor set.

The compressor stator case is a two-piece steel casting to facilitate assembly. The case incorporates cored manifolds to permit high-pressure gas to be bled from the 3rd or 7th stages. The stator blades are cut from a rolled strip, with a blade section common to all stages. The blades are furnace-brazed into half-ring assemblies which are slid into grooves cut in the stator case.

The reduction gear consists of the internal parts of a standard DeLaval-Stoeckicht planetary reduction gear. To reduce weight, the standard gear case has been eliminated. The case around the turbine and compressor has been extended over the reduction gear assembly so the case can be bolted to the alternator. The high-speed sun gear is coupled to the rotor of the T-C set by a short sleeve with

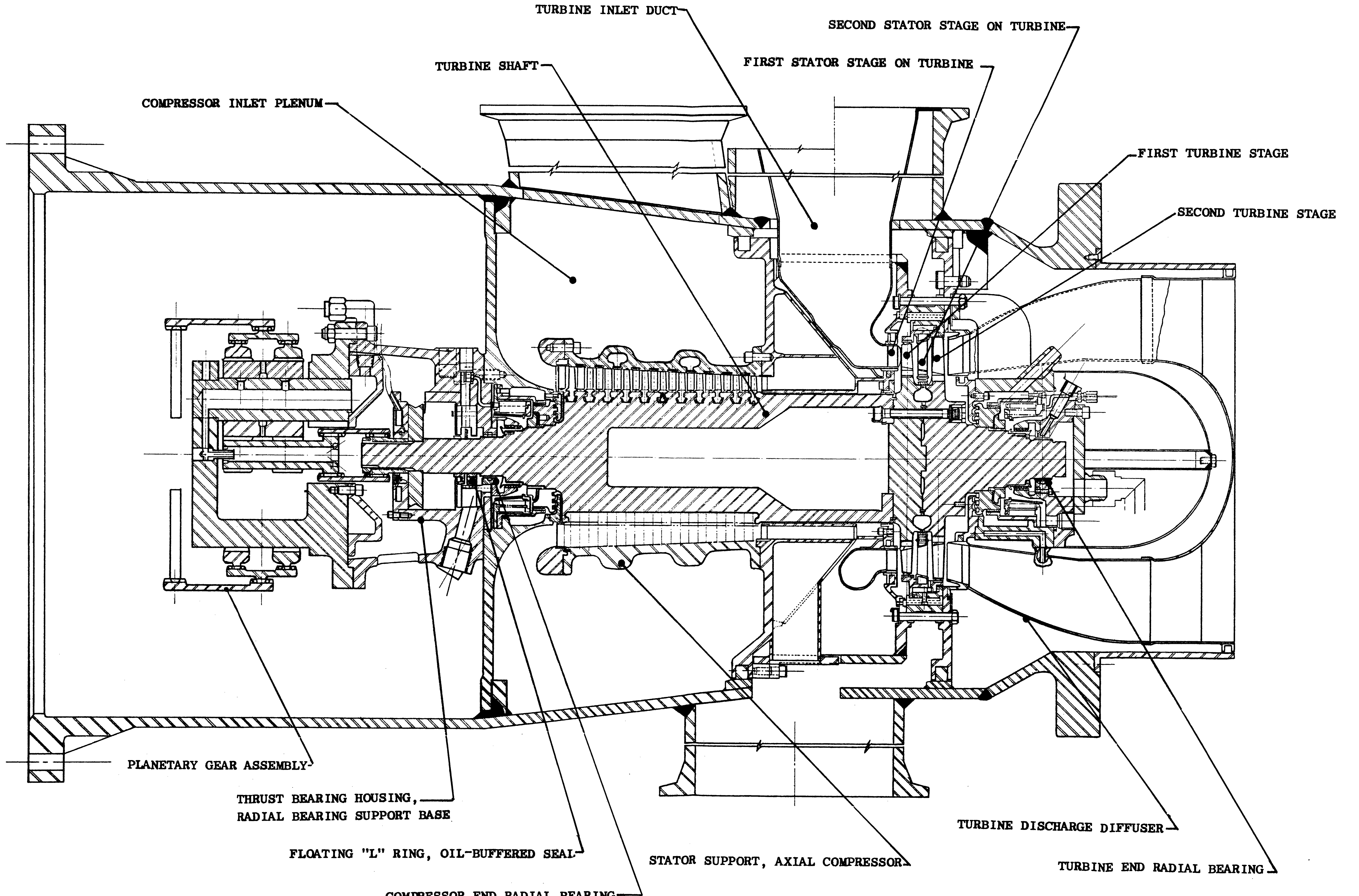

TURBINE INLET DUCT
SECOND STATOR STAGE ON TURBINE
FIRST STATOR STAGE ON TURBINE
TURBINE SHAFT
COMPRESSOR INLET PLENUM
FIRST TURBINE STAGE
SECOND TURBINE STAGE
PLANETARY GEAR ASSEMBLY
THRUST BEARING HOUSING,
RADIAL BEARING SUPPORT BASE
FLOATING "L" RING, OIL-BUFFERED SEAL
COMPRESSOR END RADIAL BEARING
STATOR SUPPORT, AXIAL COMPRESSOR
TURBINE DISCHARGE DIFFUSER
TURBINE END RADIAL BEARING

FIGURE 28

THE RADIAL FLOW TURBINE COMPRESSOR SET

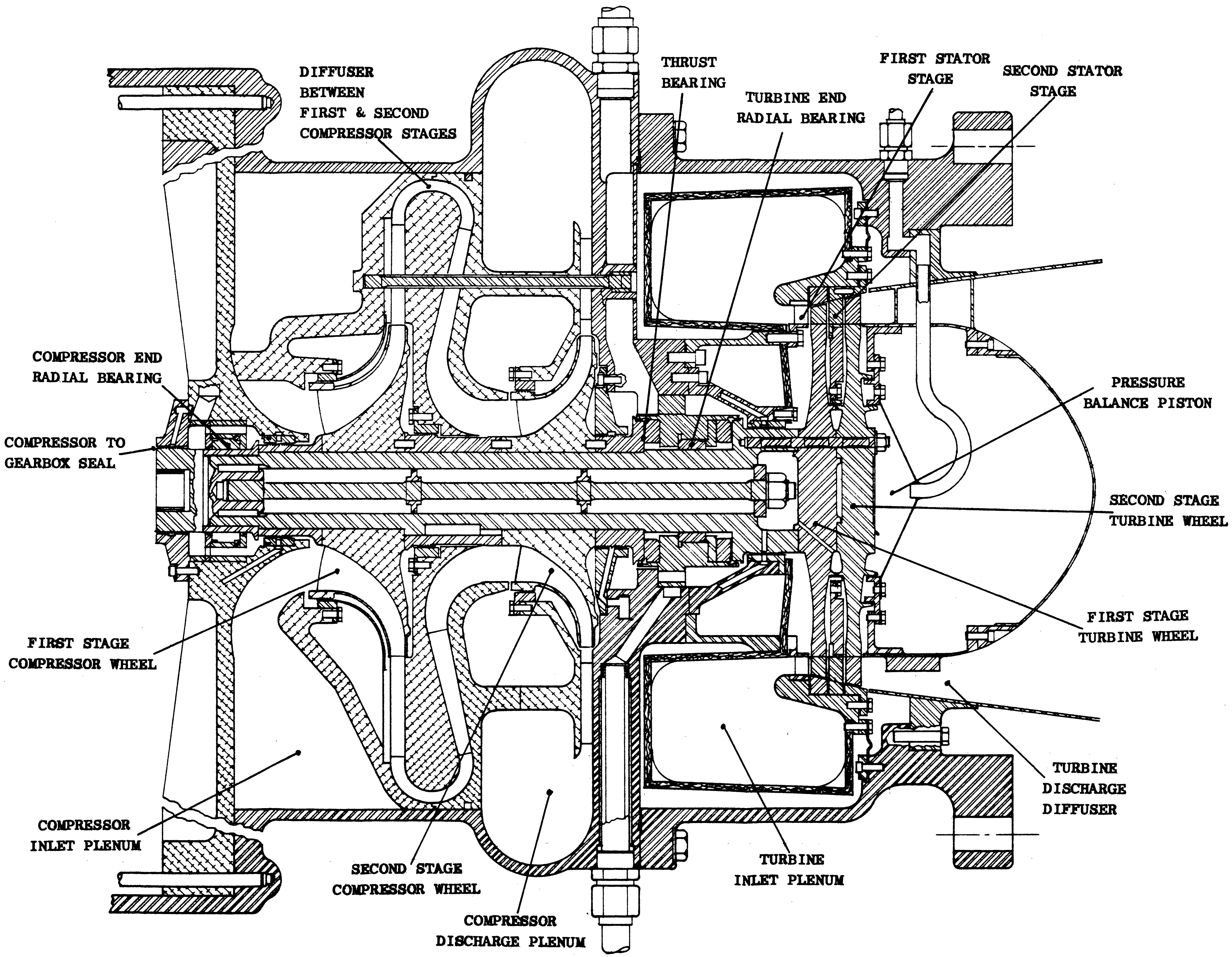


FIGURE 29

internal teeth. This sleeve can accommodate 0.002-in. of misalignment due to dimensional tolerances between the planet carrier and bearing housing. The pressure container around the whole T-C set and gearbox is provided with lubricating oil supply and drain connections. These external connections are at the alternator end of the pressure container.

The compressor discharge volute bolts to the compressor case and seals with a piston-ring-type seal at the outer case. The volute assembly separates the compressor inlet from the compressor discharge and turbine inlet region. A labyrinth seal is provided in the volute assembly to control gas leakage between the compressor discharge and the turbine inlet. The intermediate case bolts to the compressor discharge volute assembly and to the turbine stator assembly. This case has two perforations to allow access to the turbine inlet volute and the compressor discharge volute.

The turbine stator assembly includes a diaphragm separating the turbine inlet-compressor discharge area from the turbine discharge. The stator blades are held in split-ring assemblies which are supported to allow radial expansion. The four arms supporting the hub assembly bolt to the turbine diaphragm as do four keys to support for the bearing at the turbine stub-shaft. The keys fit into keyways fastened to the outer case and provide for axial and radial expansion of the T-C set relative to the outer pressure case.

The oil-cooled bearing hub contains two cylindrical labyrinths, one radial labyrinth and a shut-off seal. Suitable inlet and outlet connections are provided to supply nitrogen to the labyrinth seals and the oil supply and drain lines.

The hub support arms and the plumbing lines pass through the turbine exhaust diffuser annulus. Fairings, provided around the support arms and the plumbing lines for insulation and streamlining, divide the exhaust diffuser into four flow passages. The annulus is re-formed downstream of the support arms. An extension sleeve is bolted on the turbine exhaust flange to protect the diffuser. This arrangement permits a piston-ring-type seal, located at the end of the diffuser, to control the amount of cooling flow through this area.

2. <u>Radial-Flow T-C Set</u>

The radial-flow T-C set is a reaction-type, two-stage, axial-flow turbine coupled to a two-stage radial compressor mounted on the same shaft (Figure 29). The turbine is designed with a constant blade-root diameter of 12.14-in. The mean diameters of the first- and second-stage rotors are 12.90-in. and 13.20-in. respectively. Each turbine rotor has 83 blades. The nozzle rings each have 79 blades.

The construction features of the turbine are as follows: The turbine support structure is cylindrical, without horizontal joints, to avoid thermal distortion. Axial thermal distortion is minimized by locating the thrust bearing immediately inboard of the overhung turbine rotors. The turbine-nozzle ring assembly supports the stator assembly and the wheel shroud rings. The turbine-nozzle ring assembly and inner-stage diaphragm are supported by a conical member mounted to, and located by, the thrust bearing support structure. The turbine inlet duct, a non-structural member, has been designed to minimize heat losses. The hollow wall of this duct will be evacuated to further reduce heat transfer. An extension of this duct is a heat shield between the turbine wheels and bearing.

The barrel-type main housing of the T-C set is cast in stainless steel. The main bearing support is cast into the main housing. The compressor bearing is installed in the gearbox housing. The turbine and compressor wheels, mounted on a common shaft, are supported by two tilting-pad radial bearings. Tilting-pad thrust and anti-thrust bearings are also included. The T-C set is flange-mounted to a recuperator without other supports. Three lugs are provided on each housing casting to aid in handling. All stressed members in the turbine are constructed of nitriding-resistant materials.

The turbine rotors are Incoloy 901 forgings. The rotor blades are precision cast in Inco 713 alloy, a modified form of Inconel "X". The blades are assembled to the rotors with bulbroot attachments. The nozzle blades are precision cast in Inconel. The nozzle rings and inter-stage diaphragm are welded assemblies. The turbine rotors are bolted to the flanged ends of the hollow rotor shaft.

An external connection is provided to supply working gas (at separately controlled pressure) to a balance chamber fitted to the downstream side of the second-stage turbine wheel. This balance chamber exerts a thrust on the main shaft proportional to the controlled pressure, reducing the load to insure axial stability. Gas passes through the balance chamber labyrinths and along the second-stage turbine rotor, serving to cool it.

Working gas is supplied under pressure to the cavity inside the flanged end of the shaft. This gas flows through drilled holes in the first-stage turbine rotor and through the turbine interstage labyrinth. A close-fitting wheel shroud directs this gas alongside both rotors. Thus, the gas cools both the labyrinth and the rotors.

Lubricating oil is supplied to the turbine end bearing through a double-walled feed passage. Seal-cooling gas passes through the outer portion of the passage and insulates the bearing lubricating oil from the housing, thus a minimum of heat is picked up by the oil at the back end of the unit. Due to the materials and the moderate working temperatures of this unit, no provision is made for cooling either the turbine nozzles or the turbine wheel blades.

Since axial length available at the turbine exit is limited, a set of vortex generator vanes is installed in the turbine exhaust to diffuse the gas discharge. Tests of these vortex generator vanes have shown that satisfactory diffusion can be achieved.

The compressor wheel diameters are 11.9 and 11.2-in. with eye diameters of 7.4 and 6.7-in. Twelve full-length and twelve half-length blades are used in each impeller.

The compressor support structure is cylindrical to ensure accurate alignment of the inter-stage passages, diffusers, and seals. The shrouded impellers are precision cast in aluminum. The inter-stage baffle plates, diffusers and return guide vanes are fully-machined aluminum castings. The compressor wheels are pinned to shaft spacers which are, in turn, keyed to the rotor shaft.

Incorporated within the main turbine-compressor housing is a complete reduction gear unit. Power from the T-C set is transmitted to a helical pinion. The pinion is mounted directly on the T-C set shaft. The helix angle was chosen so that the gear thrust will be opposed to the normal turbine thrust. Meshing with the pinion are three secondary reduction gears on shafts, equally spaced around the pinion center. Helical pinions on three shafts mate with the low-speed gear. A double reduction gear was chosen. Radial loads normally found in a straight double reduction system are balanced out by locating the pinions equally around the center of the high-speed gear. Load sharing of the gears is ensured by axial shimming to obtain uniform tooth contact. A drive shaft at right angles to main shaft is provided to supply the auxiliary power take-off for the lubricating oil pump. The main support plate for the gearing pilots into the main turbine-compressor housing and carries the compressor end bearing of the turbine-compressor set. The secondary gearbox supports are pinned to the main support plate. Gear units are removable as complete assemblies. Gearbox supports are aluminum alloy castings. Gears are manufactured from certified alloy steel forgings. Gear profiles are precision generated by grinding.

C. ALTERNATOR - STARTING MOTOR

The ML-1 Alternator is a totally enclosed, electro-magnetically excited, brushless, synchronous alternator. At 3600 rpm it will generate 500 kva of electrical power. It is designed to operate as a 400 kw, 0.8-pf, 60-cycle, 3-phase, 2400/4160 volt, continuous-duty generator in ambients from $-35^{\circ}F$ to $+100^{\circ}F$, and can be externally connected to operate in either a wye connection or a delta connection. (The alternator is shown in Figure 30.) At 3000 rpm, the generator will produce 333 kw at 0.8-pf, 50 cycle, 3-phase, 2000/3467 volts of electrical power. The brushless alternator design best meets the requirements for maximum reliability and minimum maintenance. An axial-air-gap version best met the requirement for absolute minimum length.

The alternator is housed in a gas-tight case flange-mounted to the gearbox case. Also enclosed in the gas-tight case is a 480-volt line-to-line, 3-phase, 60-cycle 50 hp starting motor mounted on a generator shaft. This starting motor is capable of rotating the T-C set and alternator up to rated speed.

The drive-end housing and the gearbox are the heat sink for the stationary field coil mounted on the drive-end housing. The armature is isolated behind an 0.100-in. thick diaphragm so it can be submerged in transformer oil. This results in a maximum temperature difference of 125°F between the alternator housing and the hottest spot in the armature. A system of fins and shrouds maintains the housing temperature at less than 25°F above ambient air temperature.

The alternator is separately excited during the starting transient, but is self-excited in operation.

A transformer delivers 480-v, 50/60 cycle, 3-phase power to a three-phase, full-wave, bridge rectifier. The rectifier, in turn, delivers d-c power to the field through a magnetic amplifier voltage regulator. The voltage regulator incorporates voltage-regulation, field-forcing, and current-sharing circuits, but does not control load sharing. The load sharing is accomplished by the characteristics of the T-C set speed controller.

D. LUBRICATION AND CLEAN-UP SYSTEM

The lubrication system supplies oil to the turbine-compressor set, including the gearbox and the alternator. The Stratos system shown schematically in Figure 31, is typical of the two systems. Oil is supplied to the system by a gear-type pump driven by the gearbox at 1800 rpm. An auxiliary pump (motor-driven) provides lubrication during start and stop operation to prevent bearing damage. Regulators are utilized to maintain a pressure differential of 30 psi across the bearings.

The dual filtration circuit (parallel connected) provides 25 micron oil filtration with a provision to permit changing each element during operation.

The oil is passed through an air-cooled oil cooler on the discharge side of the pump to reduce the oil temperature to approximately 150°F. The cooler is capable of removing 293,000 Btu/hr.

The entry of bearing lubricating oil into the gas cycle is prevented by two stages of labyrinth seals at each bearing on the T-C set shaft. The seals are supplied with regulated nitrogen from the compressor discharge through external connections. The oil in the bearing exit cavities is maintained at a lower pressure and, therefore, cannot enter the working gas. Individual feeds and drains are provided for each bearing, and individual feeds and vents are provided for each seal. It therefore is possible to hold each bearing cavity and its adjacent seals at any desired pressure level.

Nitrogen is supplied to the labyrinth seal by an auxiliary compressor during startup and shutdown when main compressor gas is not available. When the system compressor develops a minimum of 45 psia, the auxiliary compressor will automatically shut off.

THE 500KVA ALTERNATOR FOR THE ML-1

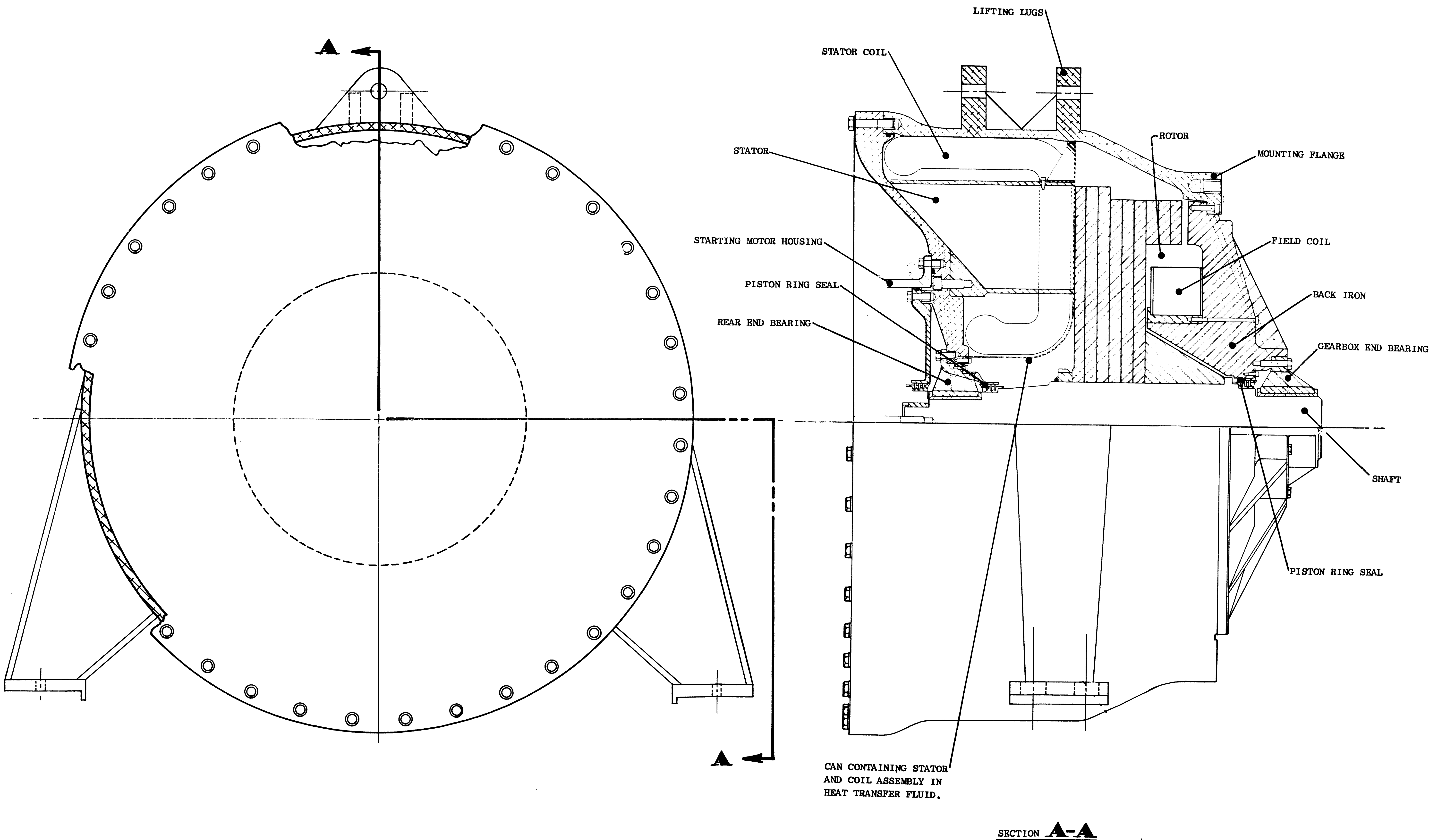
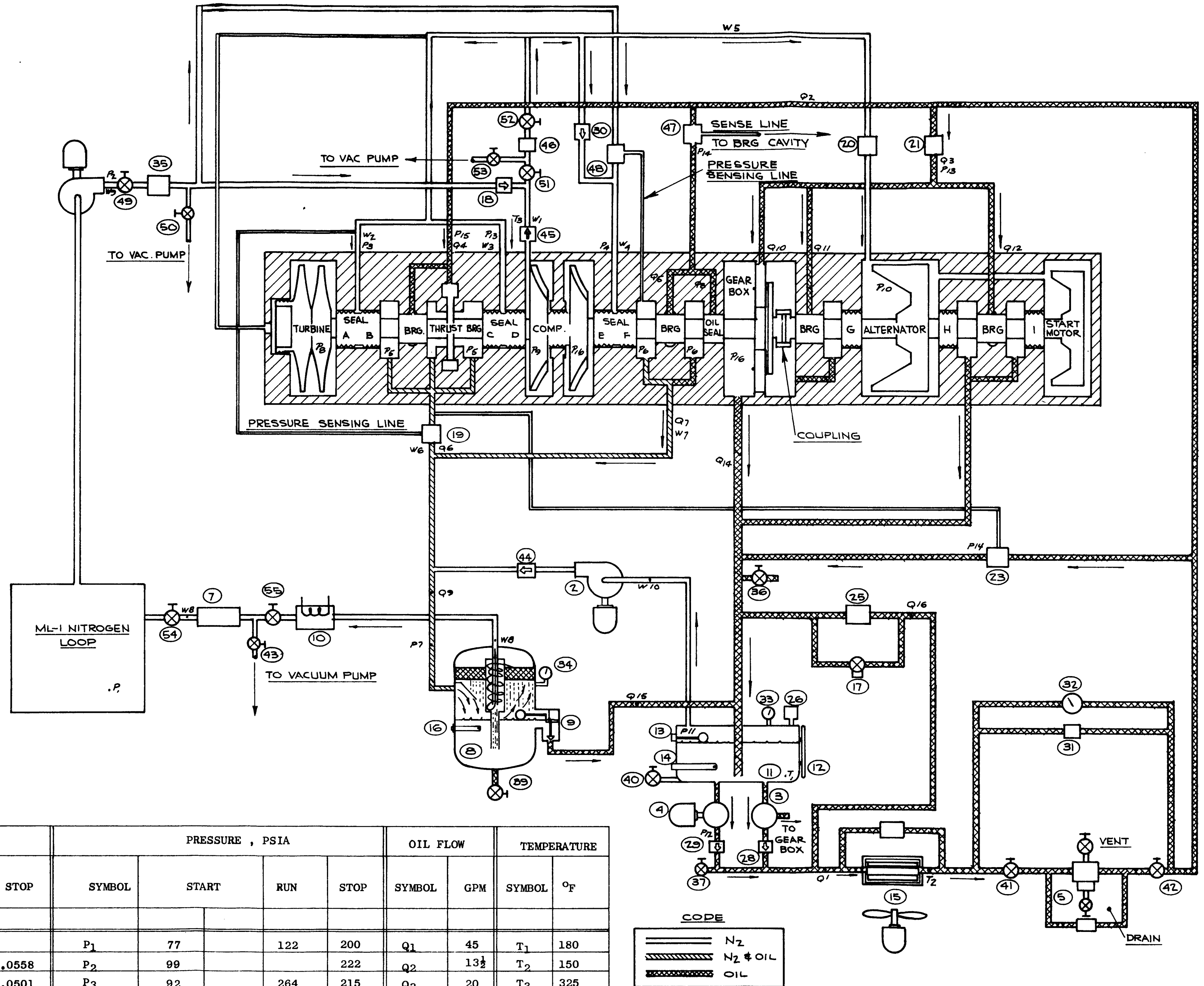


FIGURE 30

SCHEMATIC OF THE LUBRICATION AND CLEAN-UP SYSTEM FOR THE ML-1



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

ITEM	COMPONENT
1	SEAL COMPRESSOR/MOTOR
2	SUMP COMPRESSOR/MOTOR
3	MAIN OIL PUMP
4	AUXILIARY OIL PUMP/MOTOR
5	FILTER WITH BYPASS VALVE
6	
7	NITROGEN FILTER (MOLECULAR SIEVE)
8	SEPARATOR
9	FLOAT CONTROL
10	REFRIGERATION COOLER
11	OIL SUMP
12	LEVEL INDICATOR (VISUAL)
13	REMOTE LEVER INDICATOR AND ALARM
14	IMMERSION HEATER
15	OIL COOLER
16	IMMERSION HEATER
17	BY-PASS SOLENOID VALVE
18	CHECK VALVE (NITROGEN)
19	DIFFERENTIAL PRESSURE REGULATOR
20	PRESSURE REGULATOR (NITROGEN)
21	PRESSURE REGULATOR (OIL)
22	
23	DIFFERENTIAL PRESSURE RELIEF VALVE
24	
25	RELIEF VALVE - SAFETY
26	SUMP RELIEF VALVE
27	THERMOSTATIC BY-PASS VALVE
28	CHECK VALVE - (OIL)
29	CHECK VALVE - (OIL)
30	CHECK VALVE - (NITROGEN)
31	DIFFERENTIAL PRESSURE SWITCH
32	DIFFERENTIAL PRESSURE GAGE
33	SUMP PRESSURE GAGE
34	SEPARATOR PRESSURE GAGE
35	NITROGEN FILTER
36	MANUAL OIL FILL VALVE
37	MANUAL OIL DRAIN VALVE
38	
39	MANUAL OIL DRAIN VALVE
40	MANUAL OIL DRAIN VALVE
41	MANUAL SHUT-OFF VALVE
42	MANUAL SHUT-OFF VALVE
43	MANUAL SHUT-OFF VALVE
44	CHECK VALVE (NITROGEN)
45	CHECK VALVE (NITROGEN)
46	NITROGEN FILTER
47	DIFFERENTIAL PRESSURE REGULATOR
48	DIFFERENTIAL PRESSURE REGULATOR
49	MANUAL SHUT-OFF VALVE
50	MANUAL SHUT-OFF VALVE
51	MANUAL SHUT-OFF VALVE
52	MANUAL SHUT-OFF VALVE
53	MANUAL SHUT-OFF VALVE
54	MANUAL SHUT-OFF VALVE
55	MANUAL SHUT-OFF VALVE

FIGURE 31

The nitrogen bleed gas is purified after it leaves the seals and then returned to the loop. The clean-up system includes a separator and a filter. The separator mechanically separates bearing oil from the nitrogen and returns the oil to the sump. The nitrogen is filtered, to reduce the oil content to acceptable limits, before it is returned to the system. A small-capacity nitrogen compressor is used to return nitrogen to the separator from the oil sump. This is necessary because nitrogen is continuously carried in solution by the oil as it is returned to the sump. Nitrogen is also supplied to the alternator case and flows across the alternator seals to the sump to prevent the entrance of oil.

The lubricating oil will have a viscosity equivalent to SAE 20, and a minimum flash point of 400°F. The maximum operating temperature of the oil will be 180°F, eliminating any fire hazard if there is leakage of oil. It is estimated that about 60 gallons of lubricating oil and two replacement oil filter cartridges will be required every thirty days of operation.

E. RECUPERATOR

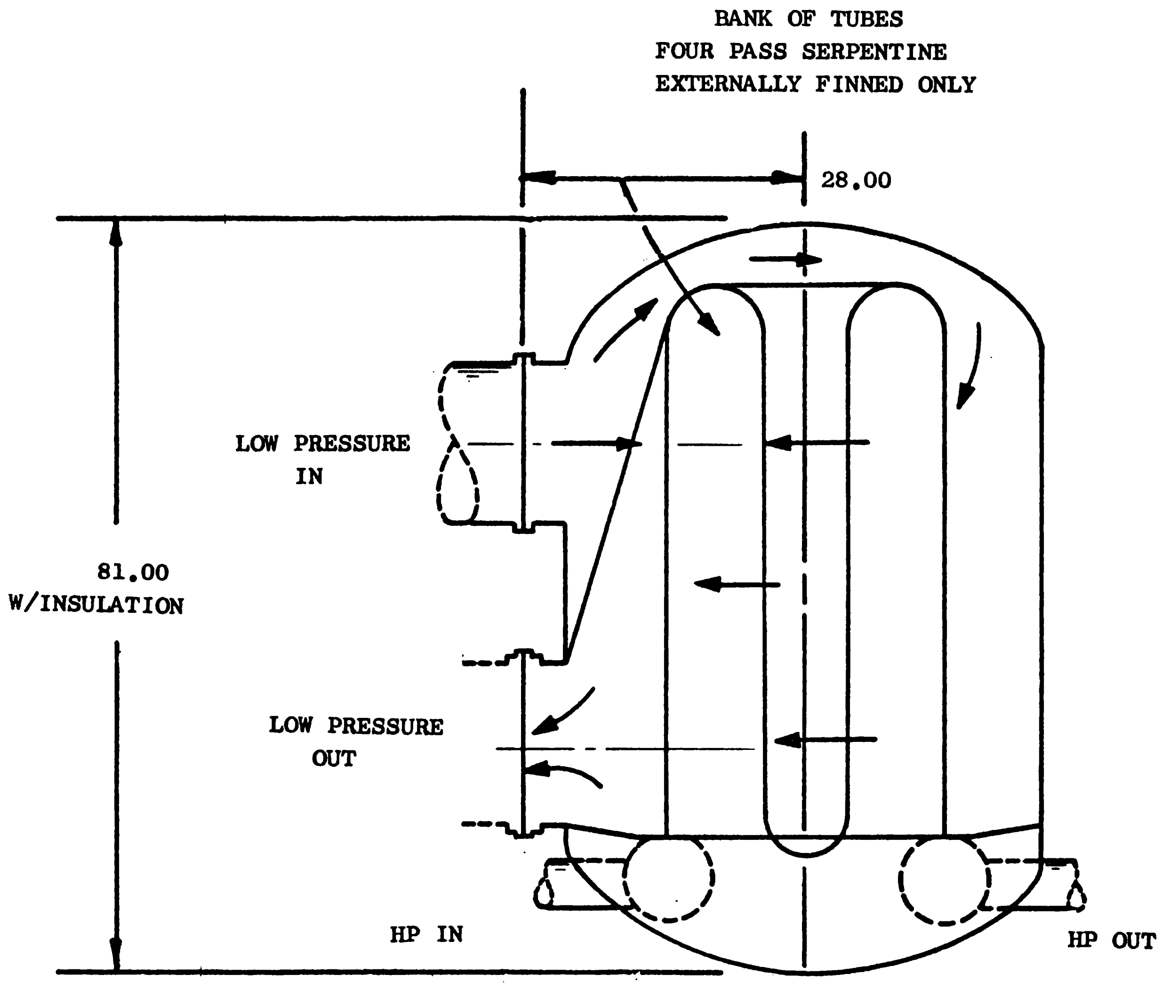
The recuperator is a gas-to-gas regenerator that transfers heat from the turbine discharge stream to the compressor discharge stream, thus pre-heating the gas entering the reactor, as shown in Figure 32. This exchanger is a shell-and-fin, tube-type consisting of four tube passes and one shell pass. The high-pressure gas flows through the tubes, and the low-pressure gas flows around the tubes on the shell side. The recuperator is constructed of AISI Series 300 stainless steel. The recuperator core is made up of 3/8-in. OD tubes. Each tube has three 180° return bends making a four-pass serpentine. There are 840 tubes per pass or a total of 3360 tube passes. Each tube pass has an effective length of 44-inches. The tubes are welded into the tube sheet. The 8-in. diameter, high-pressure headers are contained entirely within the shell. The low-pressure inlet nozzle is a 20-in. pipe connected directly to the turbine exhaust. The turbine exhaust diffuser protrudes 2-in. into the recuperator shell.

The low-pressure gas, as shown in Figure 32, is deflected around the end of the shell by internal baffles. The gas then flows directly across the tubes to the outlet duct. The high-temperature end of the shell will be internally insulated to maintain a temperature of approximately 450°F.

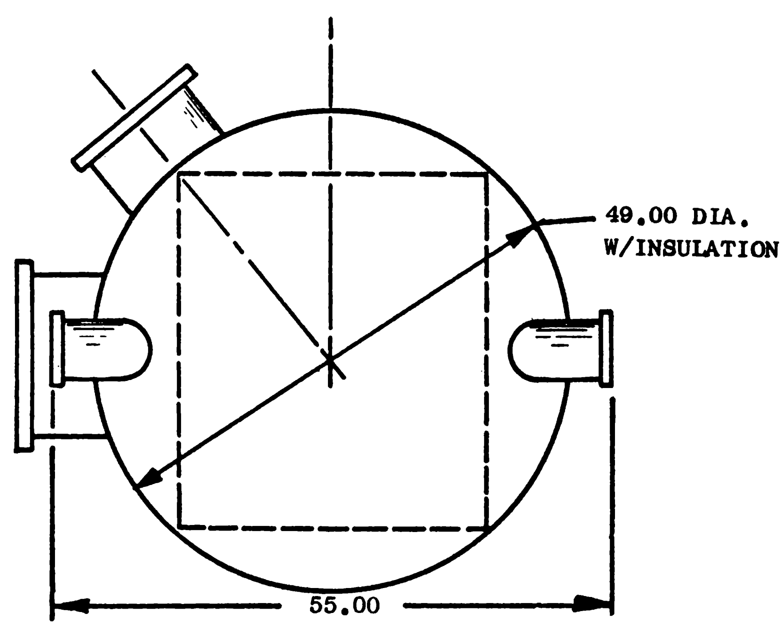
The recuperator has an overall length of 81-in. including the 1/2-in. thick insulation on the heads, and a maximum outside diameter of 49-in., including the 1/2-in. thick insulation. The calculated heat exchanger effectiveness is 80.75%. The calculated pressure drop on the high pressure side is 1.61% $\Delta p/p$ and the pressure drop on the low pressure side is 1.06% $\Delta p/p$.

The recuperator is supported by a fixed system which allows the turbine-compressor, generator and recuperator system to expand toward the generator. The recuperator flange supports the T-C set. The recuperator longitudinal support point occurs at the recuperator mount

RECUPERATOR SCHEMATIC



ELEVATION VIEW



BOTTOM VIEW

FIGURE 32

located on the extended centerline of the turbine-compressor. The minimum allowable shut-down pressure is one inch of water (0.036 psi).

F. PRE-COOLER, MODERATOR COOLER, OIL COOLER ASSEMBLY

The pre-cooler, moderator cooler and oil cooler are on the same frame. The overall length of the three exchangers is 168-in. and the overall width is 113-in. It is 32-in. thick - 15-in. for the exchanger core and 17-in. for the fan plenums. Of the total length, the pre-cooler accounts for 128-in., the oil cooler for 12-1/2-in., and the moderator cooler the remaining 27-1/2-in. The general configuration and relative locations of these exchangers is shown in Figure 33. The total weight is about 5800 lb.

The pre-cooler is a single-pass, cross-flow exchanger with nitrogen gas inside the tubes and atmospheric air outside the tubes. The pre-cooler is constructed of aluminum: the headers are of aluminum Type 2219 alloy; and the tubes of Type 3003 aluminum, an extrudable alloy. The tubes are 3/8-in.-OD with six, 0.040-in., longitudinal, internal fins and eleven external circumferential fins per inch. These external fins are 0.012-in. thick and 1-1/4-in.-OD. The core contains 1132 tubes distributed in 13 horizontal layers. Eight 7.5 hp fans are located under the exchanger core. Rated air flow is 289,000 lb/hr. Controllable louvers are located on top of the exchanger. Air flow across the exchanger can be controlled by adjusting the louver opening and by operating combinations of the fans.

G. MAIN PIPING SYSTEM

The main components are connected by stainless steel piping, with the exception of the pre-cooler inlet and outlet stubs. Aluminum ducting is provided at these points. The piping contains a bellows expansion joint wherever it is necessary to absorb thermal expansion. The expansion joints are pressure-balanced to eliminate pressure forces on the equipment and structure. Thus the only piping forces on the equipment are due to the spring constants of the bellows.

Gas by-pass plumbing - with control valve, overspeed valve and pressure relief valve - is provided between the compressor discharge pipe and the pre-cooler as part of the speed control system.

Tubing and piping is provided between the bearings of the rotating components and the various components of the lubrication system. This includes the oil sump (located on the skid floor below the alternator), main and auxiliary pumps, and oil separator.

H. SKID STRUCTURE ASSEMBLY

There are three main sub-assemblies to the power conversion skid structure: the floor structure, the truss assembly and the covering assembly. The floor of the skid is made of 6061-T6 aluminum box

ML-1 PRE-COOLER SCHEMATIC

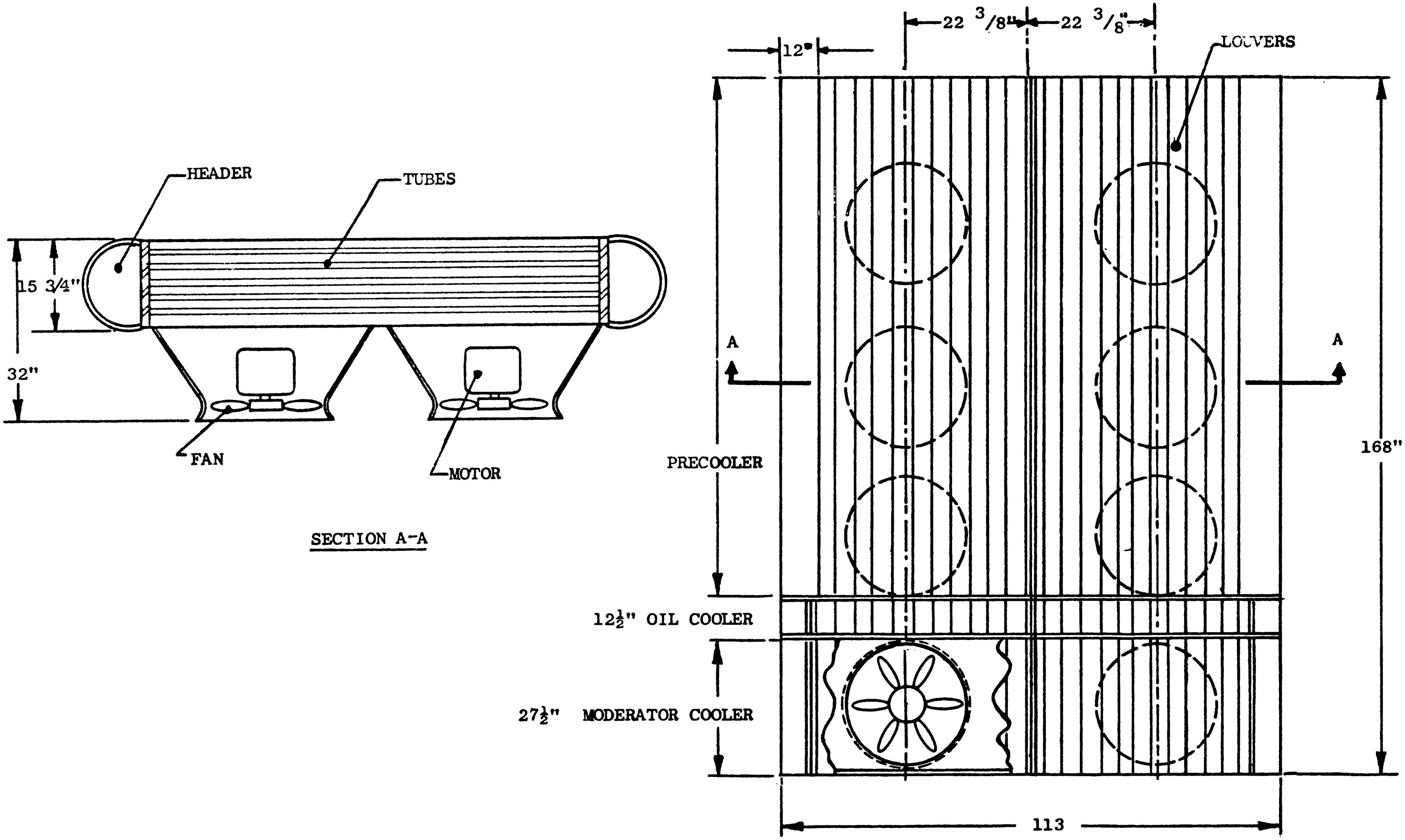


FIGURE 33

beams and angle sections on which the main components are mounted. The floor is covered with thin-gauge aluminum sheeting. The sides and ends of the skid are composed of tubular aluminum members assembled in a truss pattern to support the pre-cooler and to resist any loads imposed on the system. These members can be removed for access to the recuperator as well as to the control centers for the electrical motor and the generator.

Aluminum honeycomb sandwich material covers the exterior surfaces of the skid to provide a weather-tight enclosure. These sides swing out on hinges to provide intake of cooling air for the pre-cooler. The openings are screened to prevent the entry of foreign matter.

I. ELECTRICAL SWITCH GEAR

The output of the three-phase, 2400/4160 volt, wye-connected, 60 cycle, 400 kw, alternator is fed through a circuit breaker to the external load and parallel stations. The power for the plant auxiliary equipment is tapped off at the alternator side of the main circuit breaker and is transformed down to 480 and 120 volts, three phase. Figure 34 is a curve showing the total auxiliary equipment load demands. (Details are are shown in Figures 35 and 36.) Nearly all of the auxiliary motors and heaters operate at 480 volts. A transfer switch located on the secondary side of the 4160/480 volt transformer allows the auxiliary equipment to be driven either by the main alternator or by an auxiliary power supply (See Figure 37).

The alternator is protected from internal and external faults and from motorizing off-parallel generators by using static protective relays. The plant lightning protection system is self-contained within the switchgear.

To conserve weight and space, all switchgear (except the transformers, which radiate heat) are open type and mounted in two weather tight aluminum enclosures.

TOTAL LOAD DEMAND ON AUXILIARY EQUIPMENT

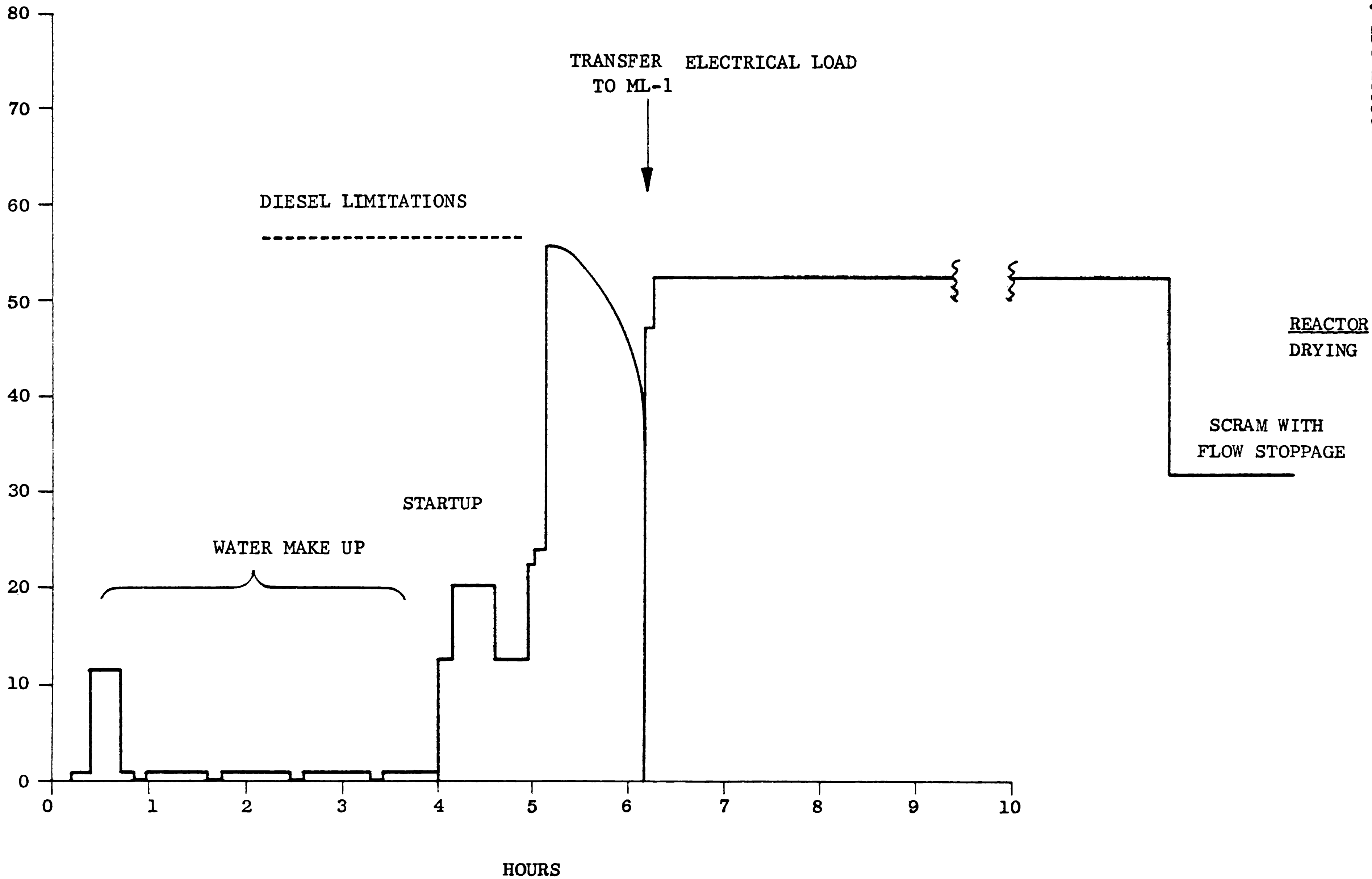


FIGURE 34

ML-1 AUXILIARY POWER REQUIREMENT SCHEDULE

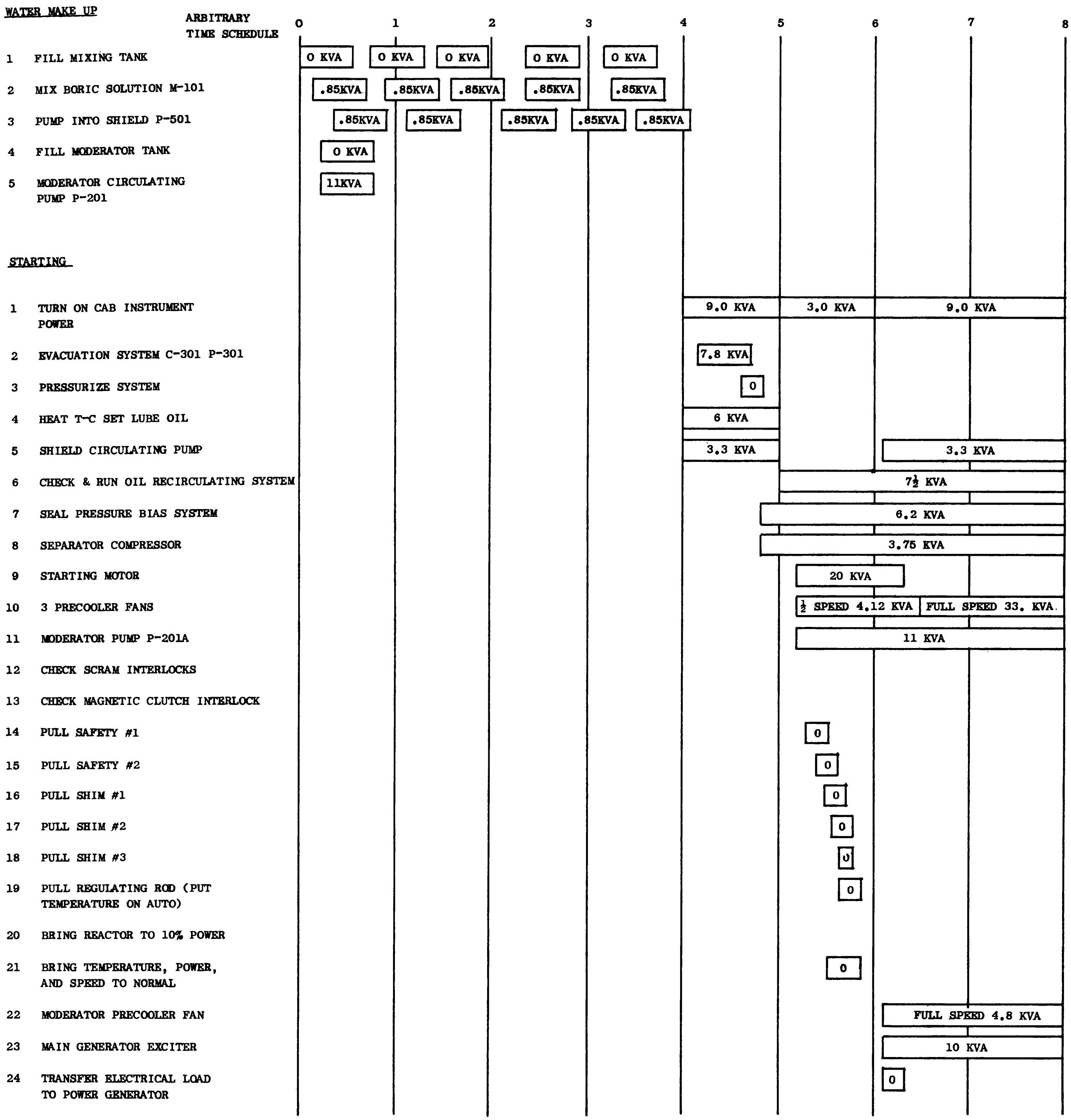


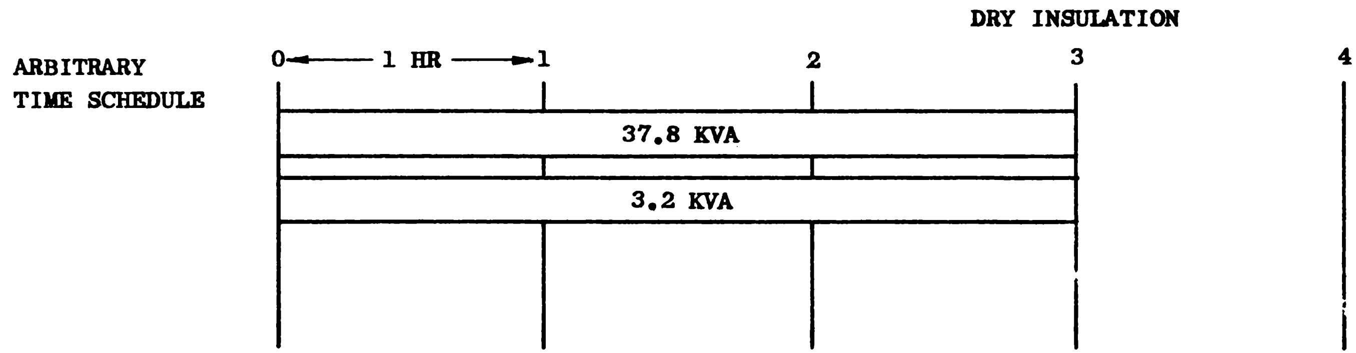
FIGURE 35

ML-1 AUXILIARY POWER REQUIREMENT SCHEDULE

GAS DRYING

(1) HEATER (DRYING)

(2) BLOWER



SCRAM WITH GAS STOPPAGE (WORST SCRAM CASE)

(1) SMALL MODERATOR PUMP P-201A

(2) CAB POWER

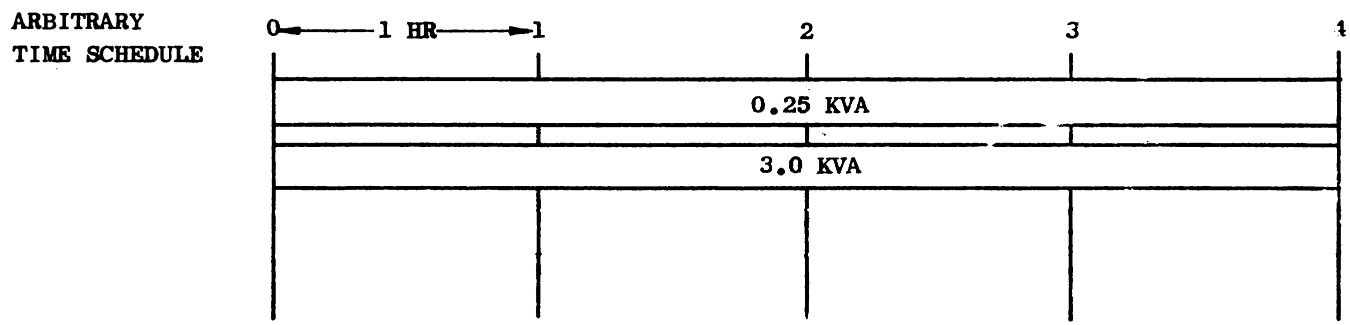


FIGURE 36

ELECTRICAL POWER FOR THE ML-1

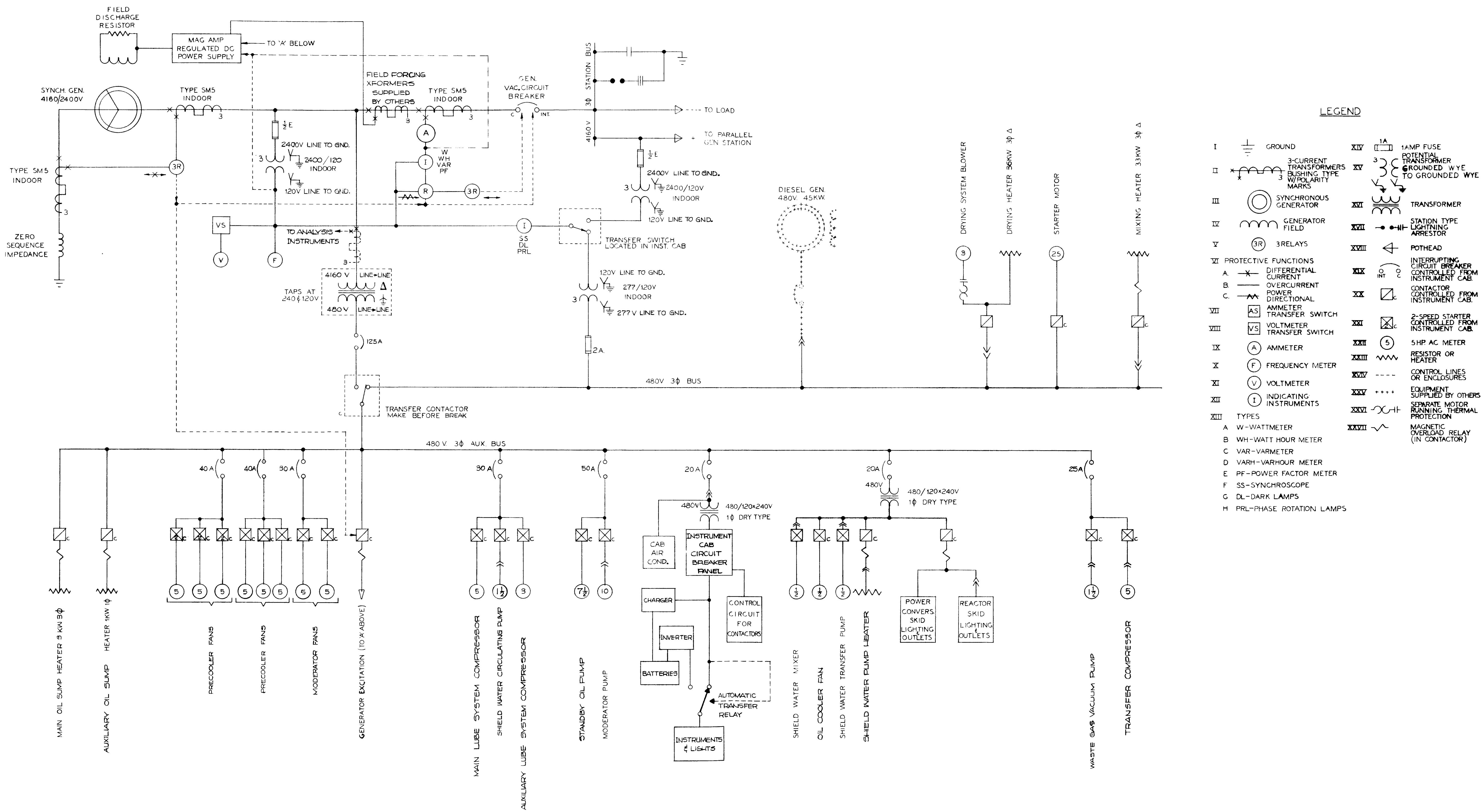


FIGURE 37

V CONTROL AND INSTRUMENTATION

V. CONTROLS AND INSTRUMENTATION

A. GENERAL

Instrumentation and control circuits for the ML-1 are designed to use transistors and military quality relays to assure reliability, ruggedness and minimum weight. All control circuits are interlocked to provide safe control sequences during calibration and operation. The control blades cannot be withdrawn from the core until all safety conditions are satisfied. The safety controls include run-safe switches; controls for temperatures, pressures and liquid levels; and a count rate sensor to establish that a neutron source is in the core.

The control cab is connected to the power plant by four 550-ft cables, including one control cable, one low-level signal control cable, one low-level power cable, and one high-level power cable. The transducers produce signal levels sufficient for transmission through the 550-ft cables, or pre-amplifiers are used where the signal level is extremely low. The cables are designed to minimize signal attenuation and meet ML-1 environmental conditions.

The cables are stored on a skid containing two reels. The reel skid is placed near the control cab and the cable pulled to the power plant for operation. Connections are made at fittings provided on the power conversion skid and the control cab. The cables will withstand abrasion and bending without any change in electrical characteristics. Each signal cable is self-shielded to reduce electrostatic pickup. Low impedance circuits are used for signal transmission.

Circuit breakers for the generator, pumps and other large motors are mounted on the power conversion skid. Heavy duty, aircraft-type breakers are used to reduce weight.

Instrument racks in the control cab are shock mounted so the instruments meet the shock and vibration requirements listed in Appendix A.

When the power plant is shut down, a 3 kwhr battery inverter system supplies power to the following instrumentation: neutron monitors in the intermediate channels, control blade position indicators, amplifiers for the reactor outlet temperature thermocouples, blade position motors, and pressure indicating systems.

B. CONTROL CAB

The design of the control cab satisfies the following criteria: one man operation; controls within easy reach; logical grouping of controls; ready accessibility to all rack-mounted instruments; controlled environment; 2½-ton maximum weight; dimensions compatible with the bed of an M-35 truck; and acceptable dose rate for the operator.

The instruments, controls and power circuits in the control cab allow the operator to control the reactor and power generating equipment, and include: the nuclear amplifiers and meters; the blade position indicators; the safety circuits and interlocks; process indicators for flow, temperature, pressure, liquid level in the tank, and radiation level; and all indicators and controls for electrical power distribution.

The cab structure is similar to the shelter shown in Figure 38. The shelter meets Signal Corps and Air Force requirements for land and air transport shelter. The shelter weighs less than 1200 lb empty; has a capacity of 6300 lb; has inside dimensions of 134-in. long by 76-in. wide by 73-1/2-in. high; and an inside volume of 433 cu ft. Air conditioning, heating and lighting is installed in the shelter to provide for optimum operation of temperature-sensitive equipment.

The control console is designed to group all instruments and controls within easy reach of the operator. Figure 39 shows a photograph of the control console mockup. The console is designed as a unit and has three major panel assemblies: process panels (graphic and secondary); a nuclear instrumentation panel; and power instrumentation and control panels. The assemblies provide accessibility from the front to minimize maintenance work behind the console. The console desk also contains switches, indicating lights, blade position indicators and other controls for power plant operation.

C. POWER PLANT CONTROL SYSTEM

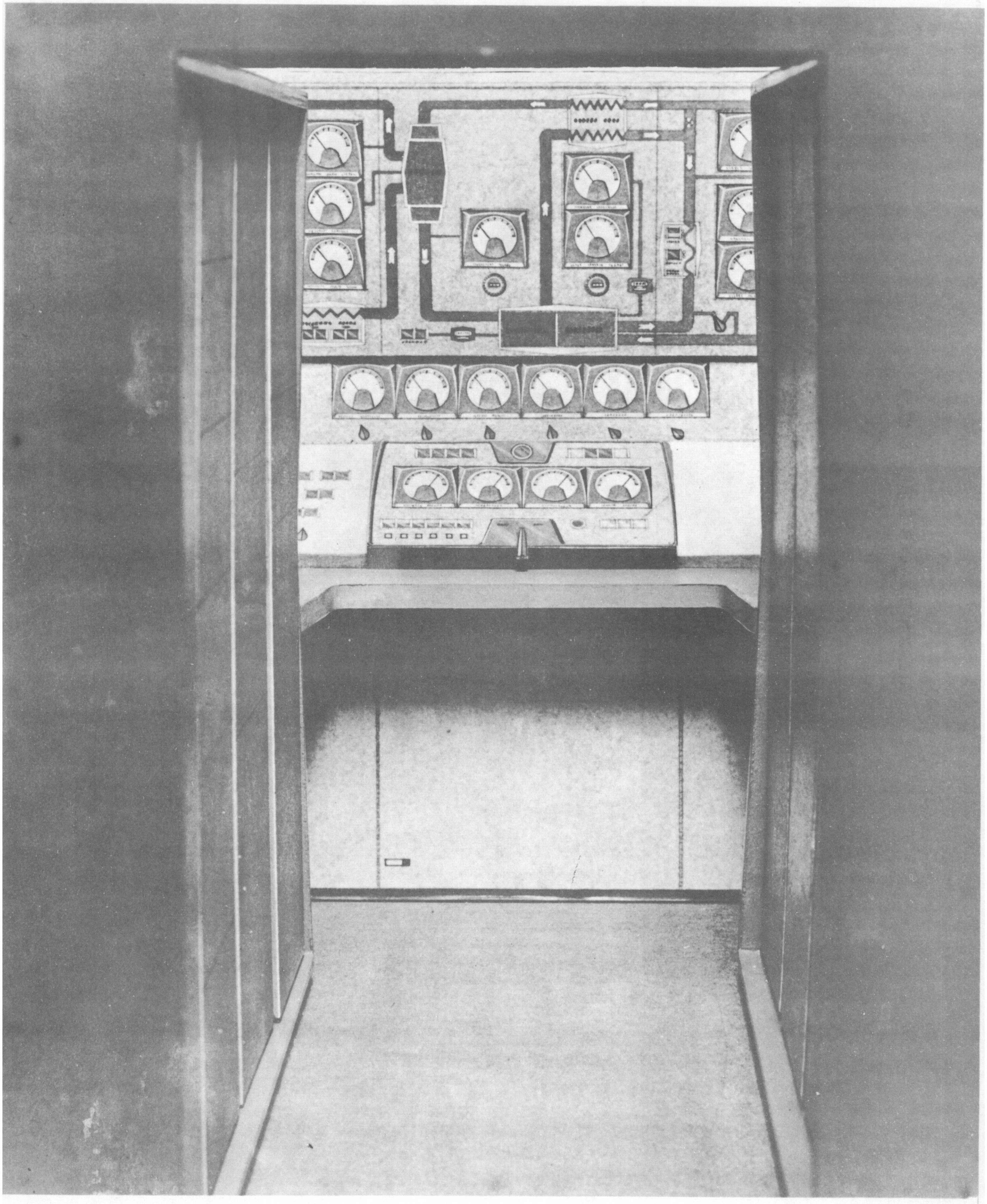
The power plant control system consists of three automatic servo-loops with two corresponding safety circuits in addition to the scram circuits (Figures 40 and 41.) The control system is based on the concept of maintaining a constant inventory of working fluid in the system (constant mass). Plant leakage is balanced by admitting gas from the makeup system through the manually operated admission valve.

Direct manual control is used during startup and shutdown operations. Normal automatic power plant operation is accomplished by a speed control servo-loop, a reactor outlet temperature servo-loop, and a moderator temperature control servo-loop. These loops are designed to give long-term service requiring only monitoring from the operator.

The first automatic loop, turbine speed control, is controlled by by-passing a portion of the coolant flow from the discharge of the compressor to the inlet of the pre-cooler. Approximately 20% coolant flow by-pass will compensate for full electrical load drop. The by-pass valve is controlled by signals from an inductance pickup mounted in the gearbox. The block diagram of the transfer functions,

THE CONTROL CAB FOR THE ML-1

FIGURE 38



MOCK-UP OF THE ML-1 CONTROL CONSOLE

FIGURE 39

CONTROL DIAGRAM - ML-1

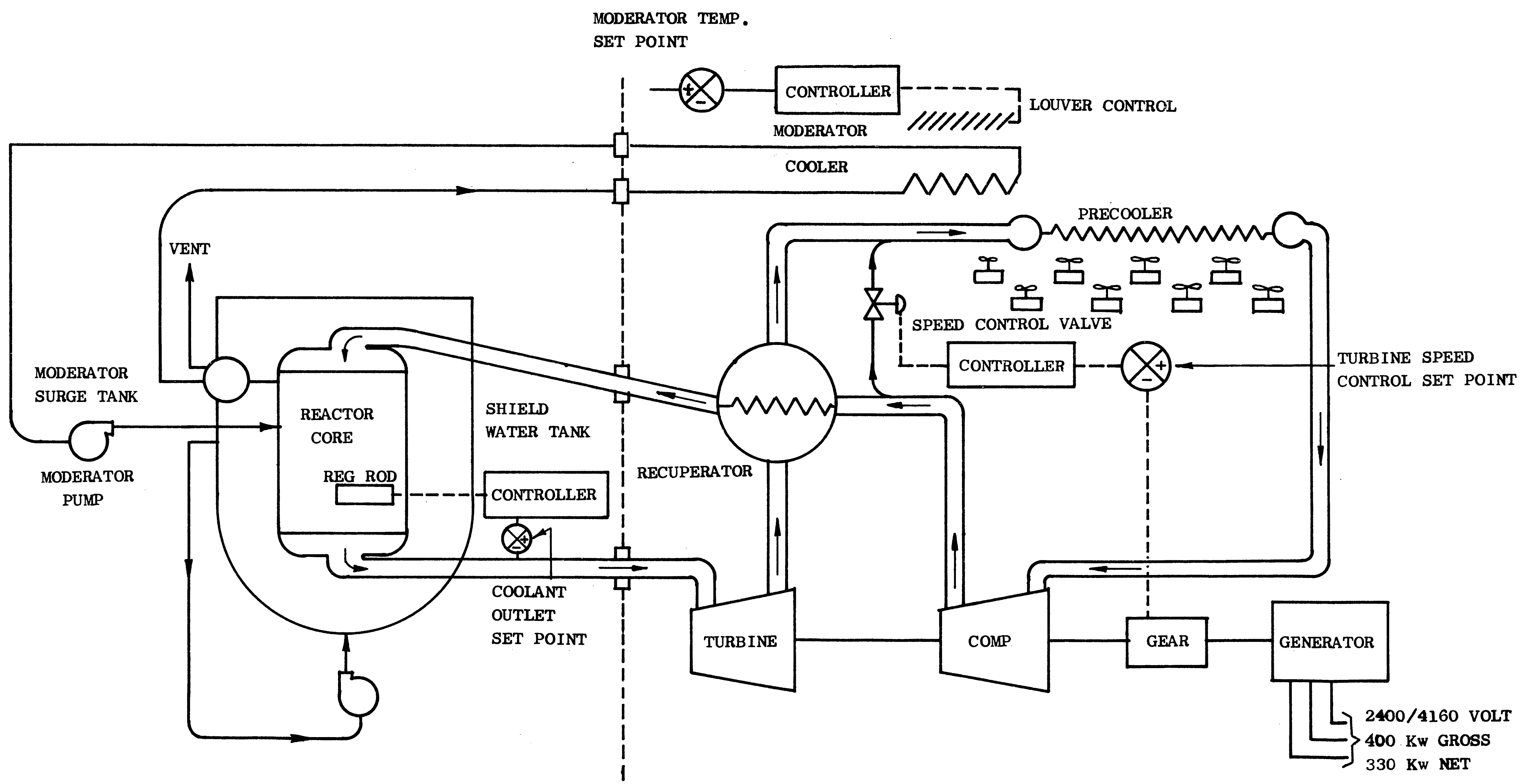


FIGURE 40

BLOCK DIAGRAM: CONTROL SYSTEM FOR THE ML-1 CONTROL BLADES

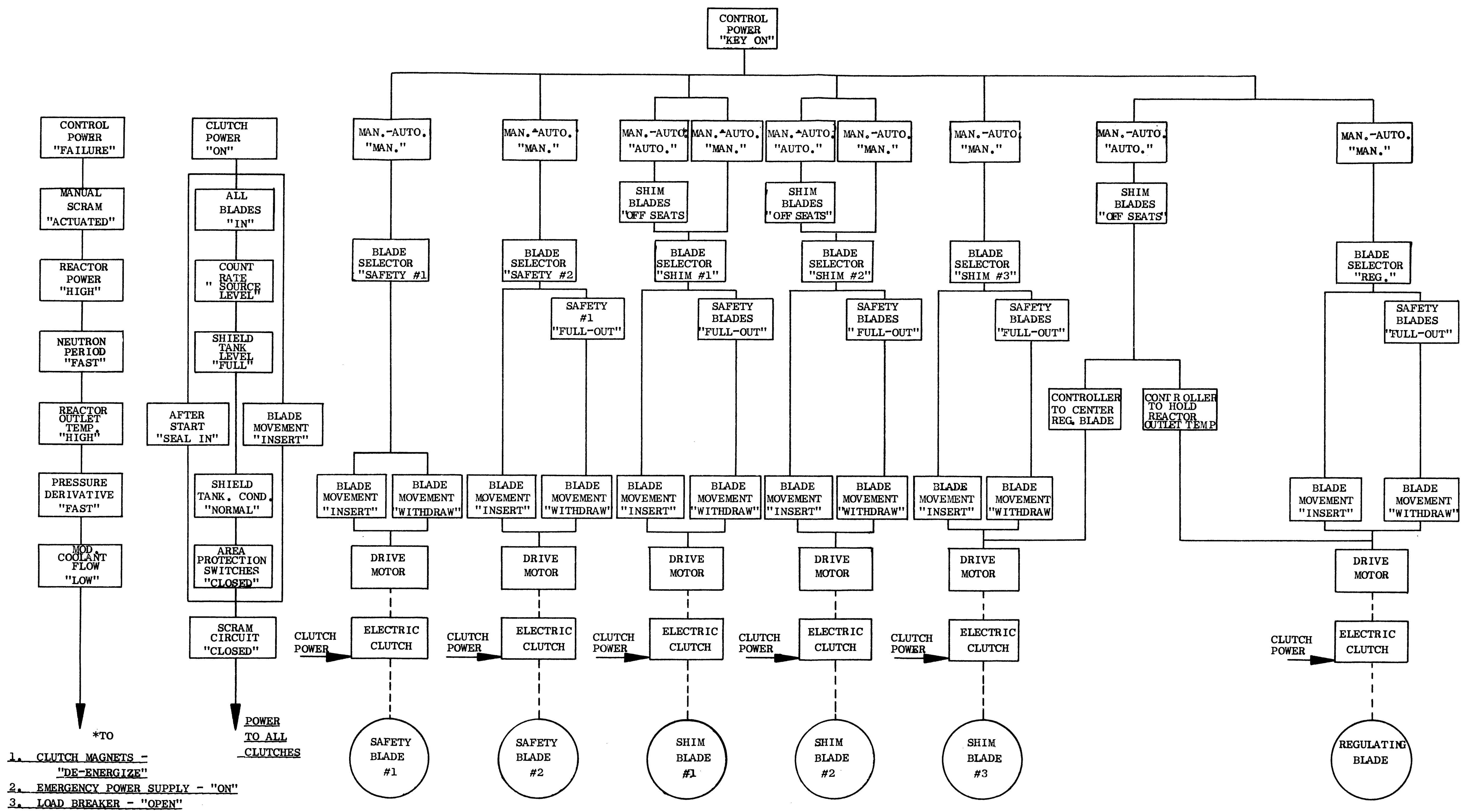


FIGURE 41

incorporated in the speed controller, is given in Figure 42. The Nichols plot, shown in Figure 43, is based on this block diagram. The first factor of the controller gain, $(1 + \frac{1}{.875})$, contains the proportional and re-set corrections. In addition a lead network is provided in the controller to compensate for the longest lag time in the loop.

Analog computer analysis was performed to evaluate the speed control servo-loop for speed error and speed of response. A by-pass valve with a speed of response in the 0.5 to 1.0 sec range and a turbine shaft assembly polar moment of inertia of approximately 2 ft-lb-sec^2 will give the desired speed control. For steady state, a 1/3% speed variation can be easily maintained. For a 50% full load variation, the speed variation will not vary more than 3% with speed recovery in 4 sec.

A safety feature of the speed control system is the turbine over-speed by-pass valve. The valve is in parallel with the turbine, and is set to open at 110% rated speed level. A broken load shaft would cause the turbine to increase in speed to 110% in 0.16 sec and to 125% in 0.40 sec if no valve action were provided. To prevent excessive overspeed, a solenoid valve with a 0.1 sec time constant is incorporated in the system.

The second automatic servo loop, the reactor outlet temperature loop, controls the reactor outlet temperature by positioning the regulating blades. A block diagram of transfer functions for the temperature control loop is given in Figure 44. A Nichols chart, plotted from the transfer functions (Figure 45) indicates the stability of the loop. The controller gain was calculated to be 2×10^{-4}% reactivity/$^{\circ}$F reactor outlet temperature. This servo loop can control the 1200°F exit temperature to within $\pm$ 25° for 15% step coolant weight rate change which results from a full load change. The weight rate change is produced by automatically closing or opening the by-pass control valve. The temperature recovery occurs within 40 seconds after the disturbance.

The temperature loop is provided with a safety circuit to re-set the regulating blades to a position 30% withdrawn at steady state. The shim blade compensates for the drift of the regulating blade from its 30% position by slowly moving in response to a position signal from the regulating blade. This insures that the regulating blades will never control more than 0.35% positive reactivity and that they never reach the limit of travel.

The third automatic loop controls the moderator and shield water temperature by changing the position of the dampers regulating air flow through the moderator cooler. If the temperature drops below minimum with the dampers fully closed, the fans are shut off as well.

Since recording equipment is not provided, the operators will log meter readings at regular intervals during reactor operation.

There are three types of information available to the operator, each of which is logically grouped in a particular console area. These are:

BLOCK DIAGRAM OF THE SPEED CONTROL SERVO LOOP FOR THE ML-I SYSTEM

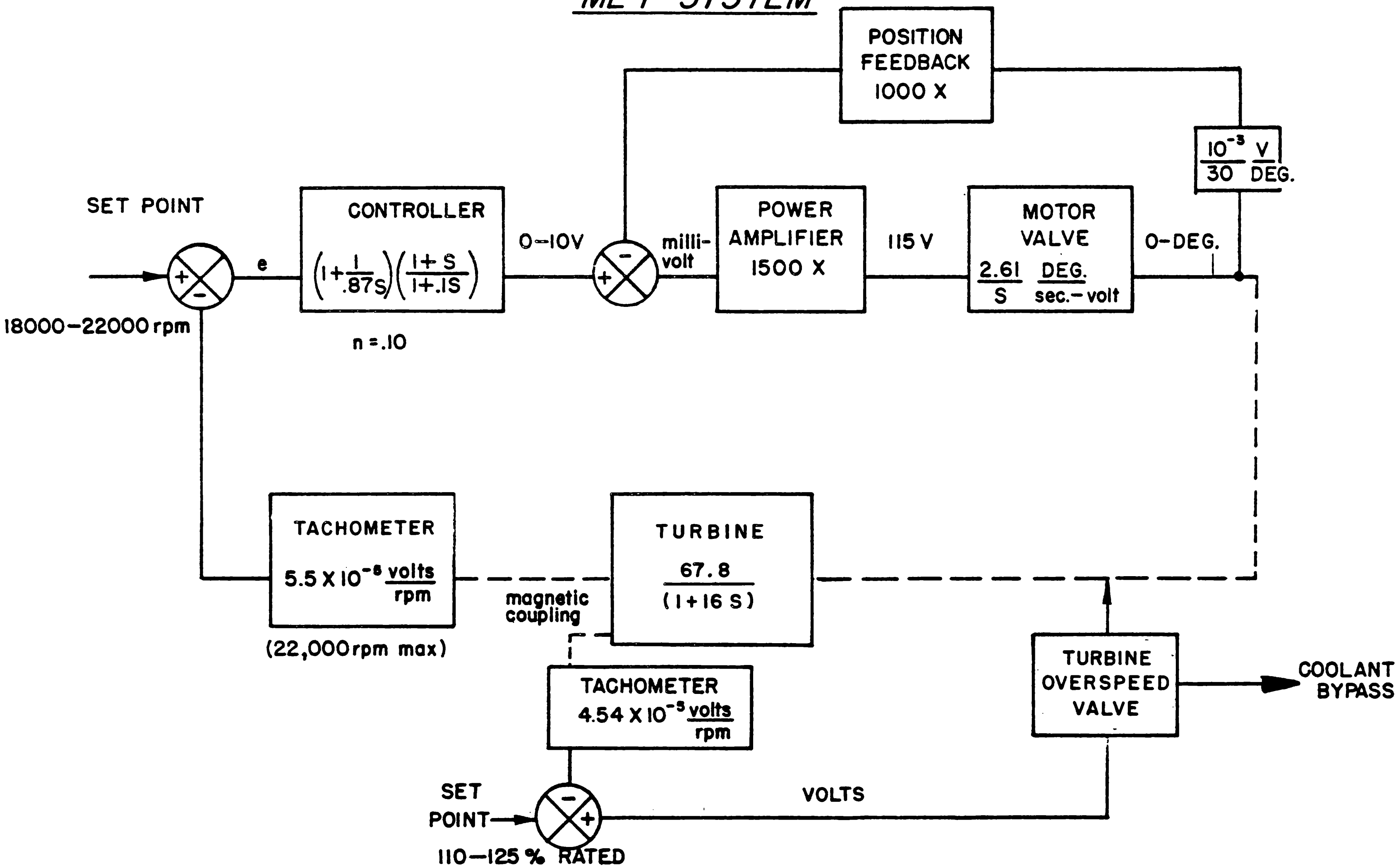


FIGURE NO. 42

NICHOLS DIAGRAM OF THE SPEED CONTROL SERVO LOOP

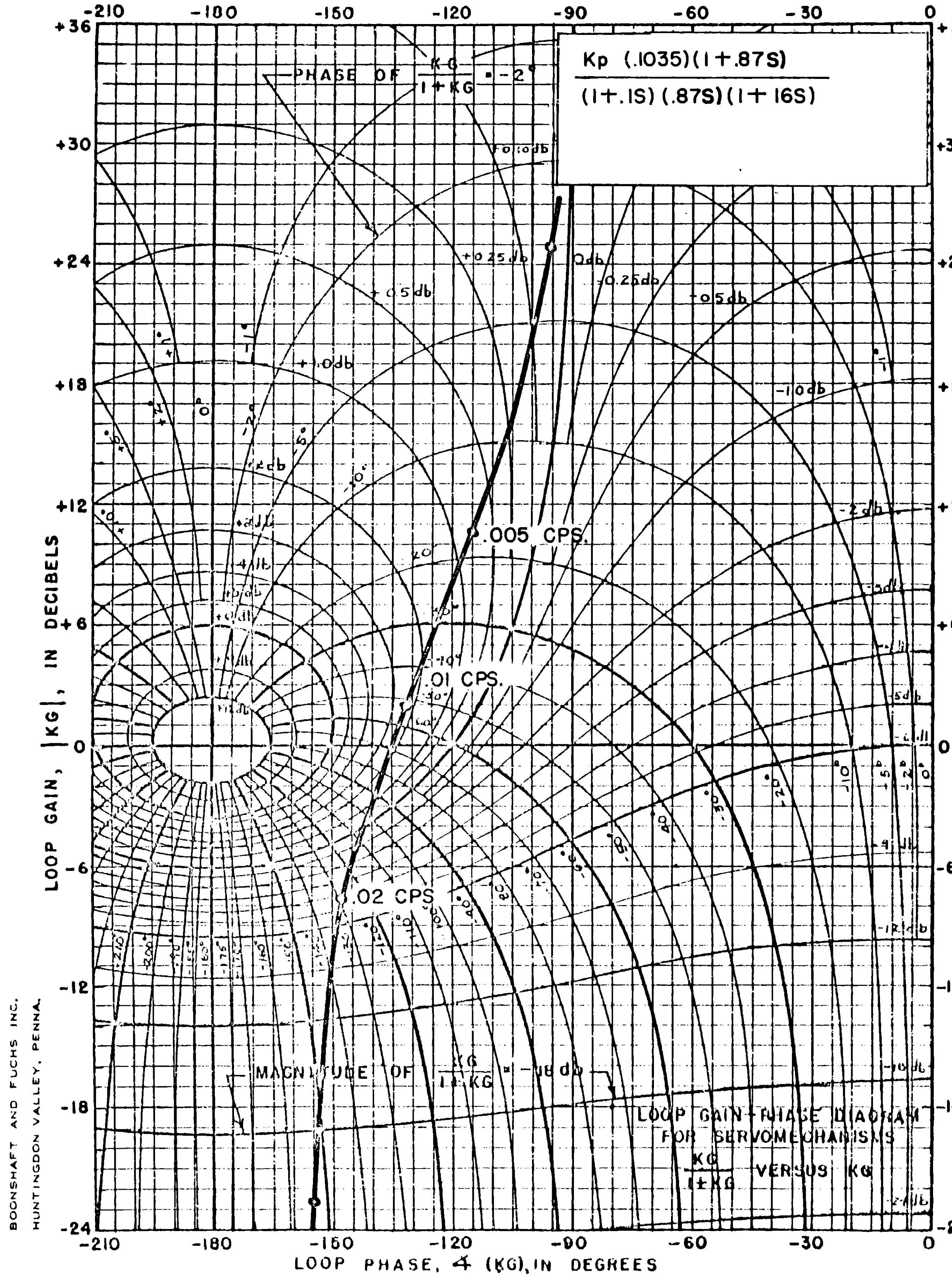


FIGURE 43

BLOCK DIAGRAM OF THE TEMPERATURE CONTROL SERVO LOOP
(TRANSFER FUNCTION BLOCK DIAGRAM)

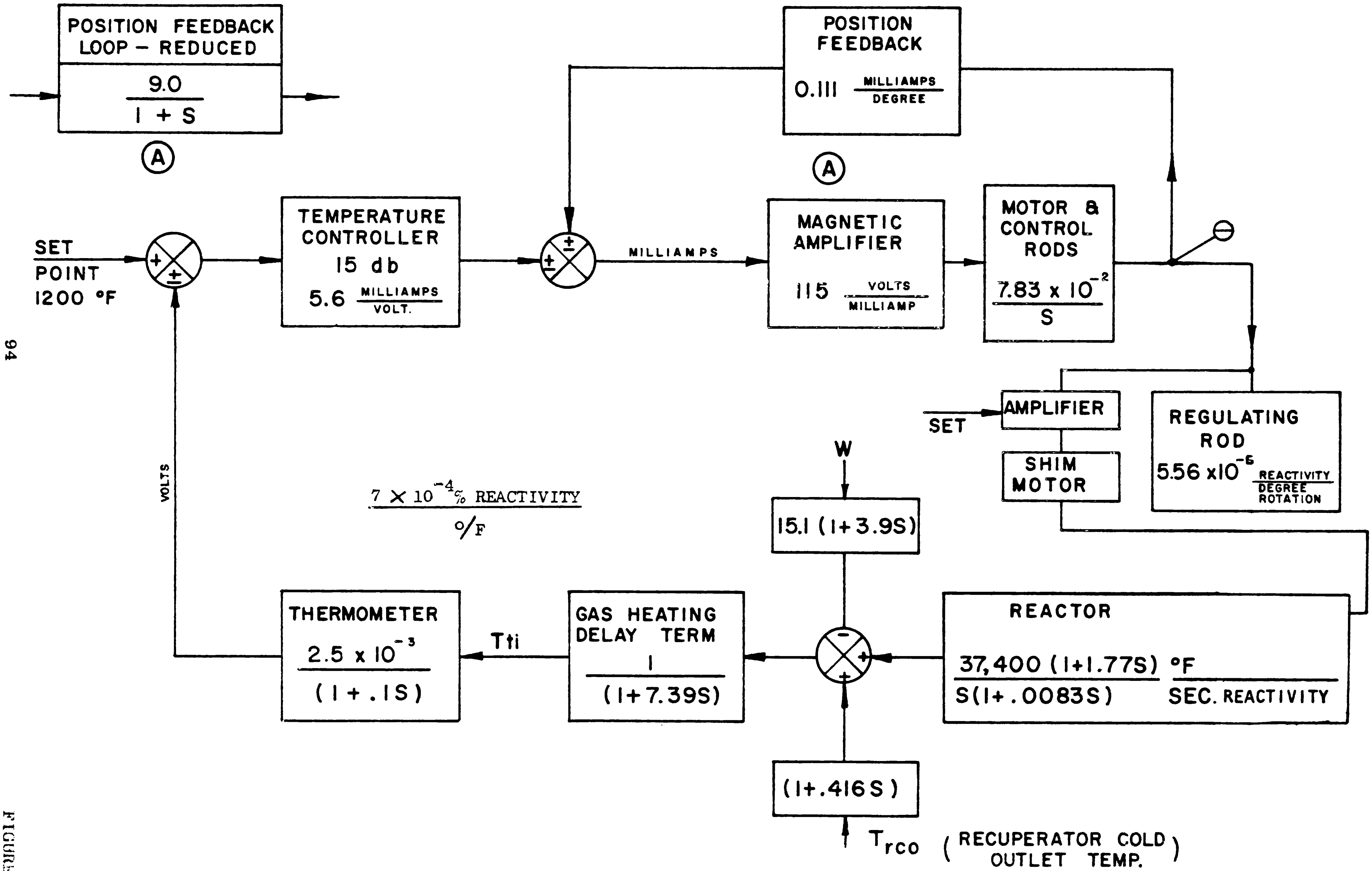


FIGURE 14

NICHOLS DIAGRAM OF THE TEMPERATURE CONTROL SERVO LOOP

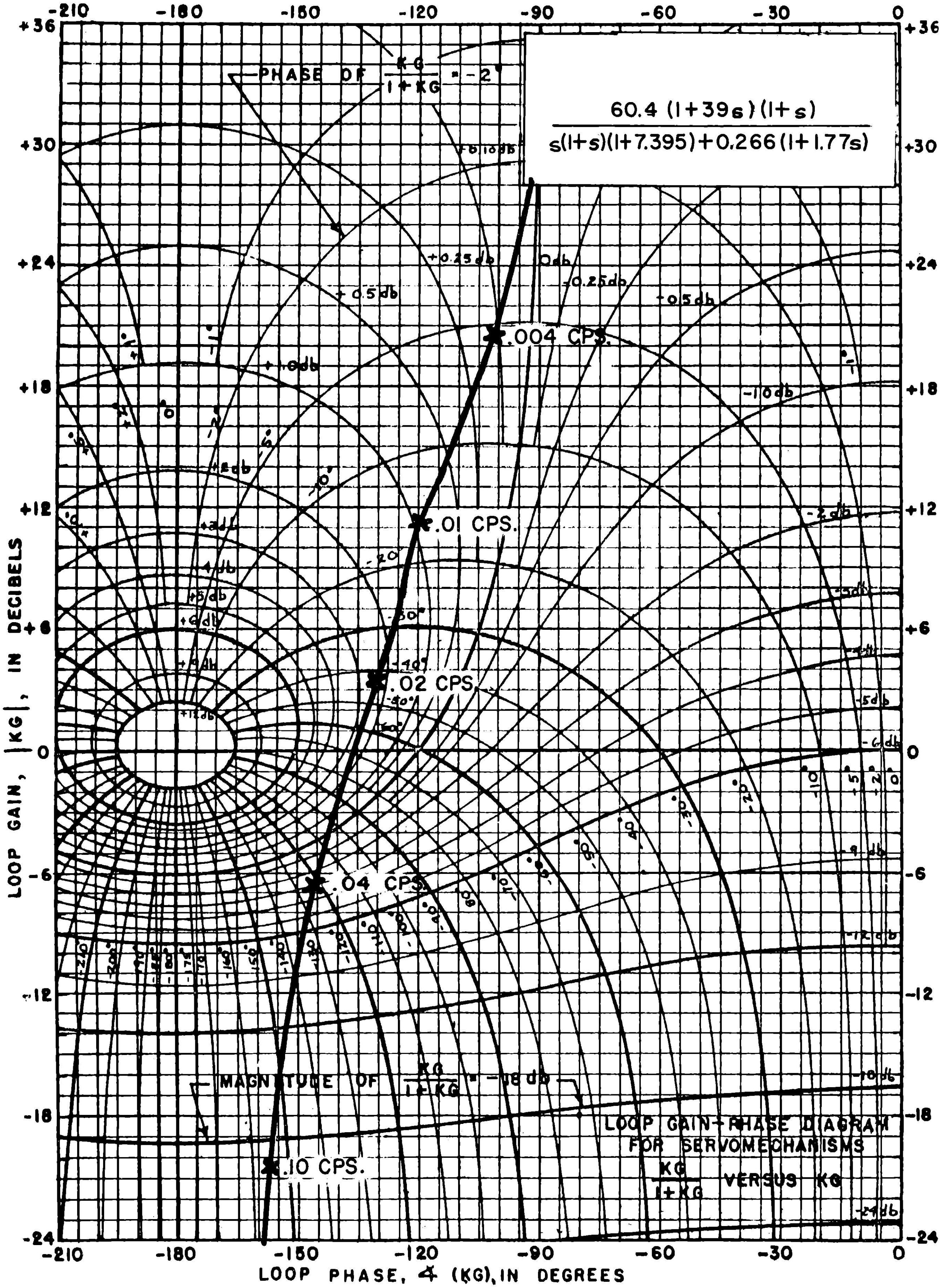


FIGURE 45

1. Neutron Measurements

Reactor neutron flux (as measured by the seven neutron detectors) will be displayed directly over the center console section that contains the control blade drive switches, control blade drive automatic controls, and position indicators. Meters provided are log count rate, reactor period, Log N power, and high level power. The annunciating panel to alert the operator (visually and aurally) when a malfunciton exists in some portion of the system is also located in this area.

2. Process Loop Parameters

The process loop parameters are the main loop flow rates, pressures, and temperatures. Set point controls and dynamic controls for these process variables are located adjacent to their respective indicators on a graphic panel which illustrates the process loop.

3. Electrical Power Load

Meters to measure electrical output to the transmission line, frequency, voltage and current; the overload relays; fault detectors, and synchroscope will all be mounted adjacent to each other. Switches to control the moderator system, lubrication system, lighting system, alternator loading adjustment, load transfer switches, etc., are provided at the console. An intercommunication system connecting the reactor area with the control cab will be located at the operation console.

D. OPERATIONAL INSTRUMENTATION

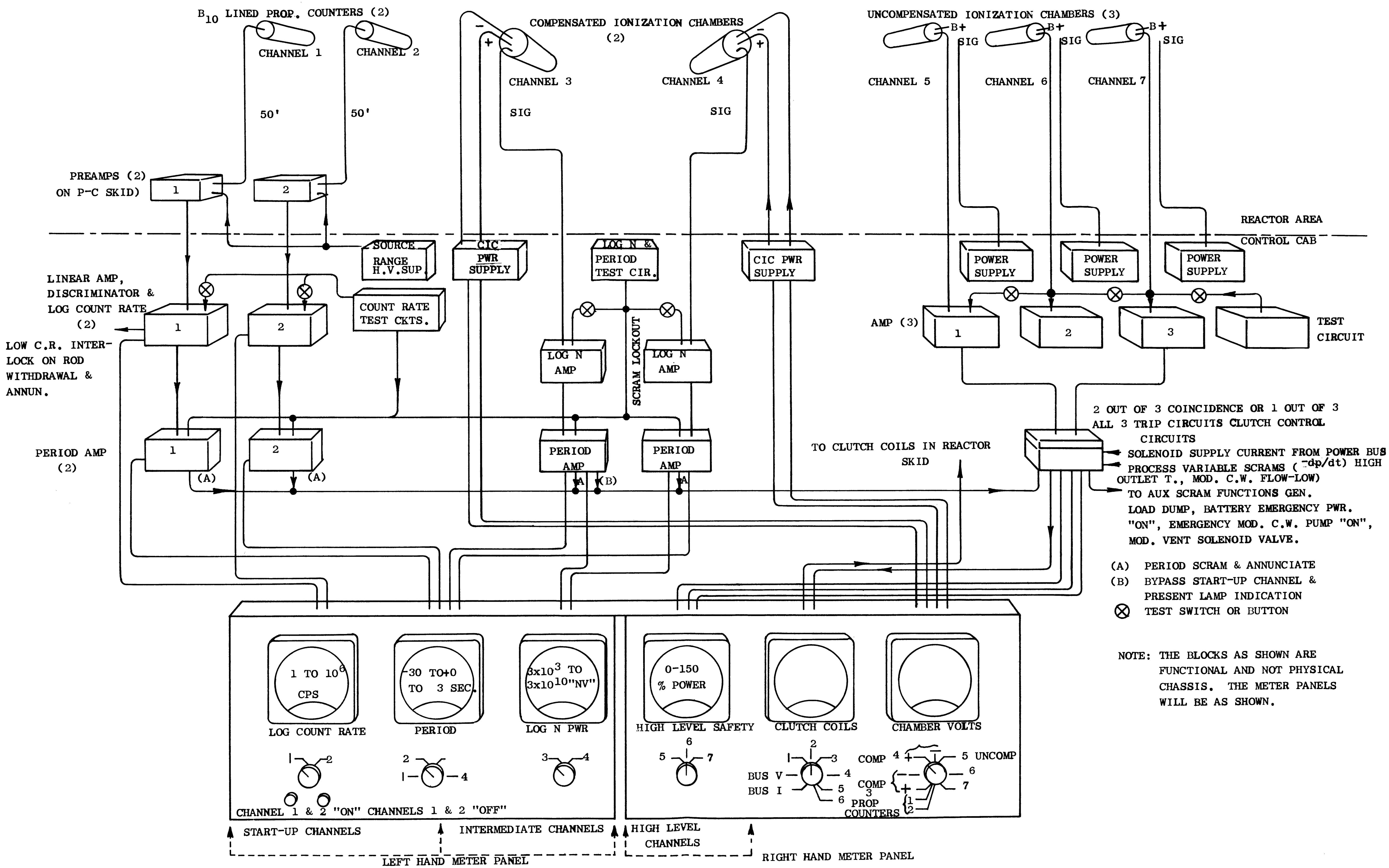
1. Nuclear Instruments

Nuclear instruments use both transistorized circuits and electromechanical relays to provide monitoring and safety control for the reactor. The circuit has fail-safe features so that malfunctions that compromise safety cause the reactor to shutdown. Minor troubles are indicated to the operator. Corrective action may then be taken without jeopardizing the system or the safety of personnel and still permit power generation. The four safety features included in the nuclear control system are: fail-safe design; use of monitoring and test circuits; use of duplicate channels and comparison of signals between channels; and use of highly reliable components.

Fail-safe circuitry used on the instrument control circuits causes the output signals to indicate abnormal conditions. When the failure occurs in a sensitive portion of the safety circuits, these abnormal conditions cause the control and safety rods to be inserted into the reactor.

Monitoring switch positions are available to determine that the control circuits are operating properly. This includes checking voltage and current in the important stages of instrumentation.

NUCLEAR INSTRUMENTATION BLOCK DIAGRAM FOR THE ML-1



NOTE: THE BLOCKS AS SHOWN ARE FUNCTIONAL AND NOT PHYSICAL CHASSIS. THE METER PANELS WILL BE AS SHOWN.

FIGURE 46

Duplicate channels to measure the same variable initiate signals that may be used to check one channel against another in pre-start and intermediate power ranges. Three channels are used to measure neutron flux for the high level reactor safety circuits, two of which must be tripped to initiate reactor shutdown. This type of coincidence circuit is combined with fail-safe designs to provide a control system that will keep the power plant operating except when a malfunction exists that would be injurious to the reactor and the power system. There are seven channels of nuclear information and safety (Figure 46). The proportional counter channels are duplicated because a start-up accident is the most serious probable type of accident. The neutron detectors are located in waterproof housings mounted in the shield water immediately outside the lead shield. The signal and voltage leads from the chamber are encased in a waterproof metallic hose. A pulse amplifier is mounted on the power conversion skid to amplify signals to be transmitted to the control cab. At the control cab, the pulse is received by the linear amplifier discriminator. The discriminator rejects pulses of small magnitude - such as those caused by gamma flux - and passes those of large magnitude caused by neutron flux. The pulses from the linear amplifier are integrated and the logarithm of the current amplified in the log count ratemeter circuit.

A source interlock trip circuit, part of the log count ratemeter, permits withdrawal of the control blades only if the neutron source in the reactor is sufficient to permit safe start up. The signal from the log count rate stage is differentiated and amplified to produce a period signal. Reactor period and the log count rate are both displayed on meters on the control console. Two channels of period safety trips are provided to effect a reactor shutdown if the reactor period becomes potentially dangerous. The controls can be adjusted over a wide range of settings. The adjustments can be made only from behind the front panel of the instruments, thus inadvertent misadjustment is prevented.

The proportional counter is protected by a circuit in the counter power supply that disconnects the high voltage to the counter if the flux is in the intermediate or high level range, and re-connects the voltage when the reactor is decreasing in power. The start-up channels cover a range from 1 to 100,000 counts per second and overlap the intermediate channel by a decade. A calibrating circuit injects pulses at a known rate through the pre-amplifiers for monitoring and calibrating the instruments. The period trip circuits have a built-in time delay only in the start-up channels. This time delay averages out the noise and statistical variations of neutron flux. The reactor is scrammed if the instrument continues to indicate a reactor period shorter than the set point after a reasonable time delay. A scram signal removes the current from the blade solenoids in less than 50 milliseconds.

The two intermediate range (or Log N) channels use gamma-compensated ionization chambers as neutron detectors. These detectors are housed in waterproof housings mounted outside the reactor shield. The Log N amplifier has a range of seven decades, from 10^{-11} to 10^{-4} amperes, and a trip level that can be used for low flux level experiments.

A period circuit differentiates and amplifies the log current and provides a signal to the period meter and safety trip circuits. The meter indicates from -30 seconds to infinity to +30 seconds. Suitable calibrating signals are provided to check the log extraction stages and period stages as part of the instruments to monitor and check the circuits.

The high level safety channels use three uncompensated ionization chambers as neutron detectors. Each chamber transmits a signal (proportional to the neutron flux of the reactor) to three separate stages of amplification and safety control. The high level channels have a range of three decades, including a one decade overlap with the intermediate channels. Calibration signals can be applied to supply currents above and below scram levels, thus checking the operating characteristics of the circuit. Each channel can be tested separately. Scram signals from the individual trip circuits are accumulated in a coincidence circuit so that two of the three signals must be present before the reactor is scrammed. A decreasing signal is used for each trip so that a power failure (producing a decreasing signal) will result in reactor scram. Once a scram trip occurs, a lock-out circuit is energized to prevent re-energization of the solenoids until the circuit is manually re-set by the operator. Meters are provided to monitor the solenoid current and voltage. A scram signal in-put produces a response in less than 20 milliseconds.

2. Process Instruments

The first process instruments included in the design were those required to measure and control those parameters needed for plant safety and control. The next chosen were those parameters needed to diagnose malfunction of the main plant components. The process instruments are listed in Table 5 on the following page. The process instruments were limited to the above. Some additional analysis instrumentation is included for experimental operation at NRTS. This analysis instrumentation is not prototype.

A graphic panel representing the main piping loops, appropriate meters and controls will be mounted on the control panel in front of the operator. The set point potentiometers for the two main automatic servo loops, and the reactor outlet temperature and the turbine speed controllers are all located near the center of the graphic panel and directly under the corresponding indicators. The louvers for the pre-cooler are controlled by switches located at the pre-cooler symbol on the panel.

The position of the by-pass control valve, the two extreme pressures and the two extreme temperatures of the main nitrogen loop can be read from indicators also located on the graphic panel. On the right of the operator will be a smaller graphic panel for the gas make-up loop. Switches controlling the solenoid valves will be mounted on this panel. The visual indication will permit the operator to switch in the correct piping for a variety of operations. About 16 solenoid valves will be operated by switches on this panel, and six or more functions will be performed.

A large group of meters above this panel indicate lubrication oil pressures at various points, temperatures of the bearings, and

Table 5: Process Instruments

Identification	Description	Range
PIA 101	Compressor outlet pressure indicator and alarm	0-450 psia
PI 102	Compressor inlet pressure indicator	0-450 psia
PIA 301	Gas make-up press indicator and alarm	0-2500 psia
PI 302	Gas evacuation system	0-100 mm-hg
TIC 101	Reactor outlet temperature controller and alarm	600-1500°F
TIA 102	Compressor inlet temperature indicator and alarm	-45-175°F
TI 601	Lube oil cooler temperature indication	0-200°F
TIA 602	Bearing temperature indicator and alarm	100-300°F
TIC 201	Moderator water temperature indicator and control	32-250°F
TI 202	Moderator outlet temperature indicator	32-250°F
TIA 203	Shield wate temperature indicator and alarm	32-250°F
VPC 101	Nitrogen admission valve position indicator controller	0-100% open
QA 101	Compressor vibration alarm	0-2000 cps
VPI 101	By-pass valve position indicator	0-100% open
SA 101	Turbine high speed alarm	110% overspeed
SIC 102	Turbine speed controller	0-25000 rpm
LIA 601	Sump oil level indicator and alarm	0-100% full
LIA 201 a	Moderator surge tank level indicator and alarm	full to -10"
LIA 201 b	Shield water level indicator and alarm	full to 10"
FA 201	Moderator water flow alarm	80% flow
CIA 201 a	Moderator water conductivity indicator and alarm	0-100 ppm
CIA 201 b	Shield water conductivity indicator and alarm	0-10%
ZIC 101	Pre-cooler louver position indicator and control	full open to full closed
OI 101	Oxygen analyzer	0-5% 0-25%
ZPI-201	Moderator louver position (limits only)	full

similiar parameters of the minor loops.

The annunciators are also located on this panel. Six of these critical parameters will also initiate a scram. One, the turbine overspeed, shuts down the rotating machinery by throwing the overspeed by-pass valve in case the speed controller fails allowing the turbine speed to increase above 110% of rated value. The remaining annunciators do not perform any automatic function.

Two racks on the right of the annunciators contain the electronic units required for process transducers and indicators.

3. Electrical Instruments

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) One synchroscope to insure that the phase rotation speed and voltage of the ML-1 alternator matches that of the distribution network to which the plant is connected.

2) One frequency meter to insure that the frequency of the system will work in synchronization with other supplies.

3) One voltmeter to read the output voltages of the synchronous generator. This meter reads the line to neutral voltages in each of the three phases.

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

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

7) Three single-phase (two quadrant) power factor meters to measure the power factor of each phase. Each phase is monitored because the polyphase power factor meter reads correctly only under balanced conditions, not necessarily the operating condition of this system.

8) One watthour meter to record the total output of the system.

High power disconnects are provided to protect the alternator from sudden load short-circuits.

E. ANALYSIS INSTRUMENTATION

A facility is provided at the NRTS test site to house analytical instruments necessary only for the protorype power plant. These instruments receive and record or indicate such information as the neutron log count rate from a start-up channel, reactor period, Log N power, reactor outlet temperature, recuperator and pre-cooler pressure drop, etc. The data collected are used to prove that ML-1 meets operational specifications and to improve the basic design of ML-1A.

Readout instruments include an eight-channel direct writing oscillograph, a digital voltmeter, an oscilloscope, and null-balance type recorders. A list of parameters is given in Table 6. In designing the additional analysis instrumentation, maximum use has been made of the existing prototype measurements. The redundance in measurement assures analytical accuracy. The analysis instruments are installed in 9 racks. Space for spare racks is provided for additional instrumentation.

F. HEALTH PHYSICS INSTRUMENTATION

The ML-1 plant requires a minimum of health physics instrumentation for radiological safety in the field. A ten-channel remote area monitoring (RAM) system is provided to indicate gross changes in the gas coolant activity during operation, to monitor the radiation level in the control cab during operation, and to monitor power plant equipment radiation levels at shutdown.

One detector is mounted in the control cab and nine detectors are located near equipment on the power conversion and reactor packages. The signal and power leads for these detectors are routed in the main power and signal cables to the control cab. One indicating meter, with selector switch, is provided for readout of any of the 10 signals. In addition, a neutron-threshold and high range gamma detector for personnel dosimetry will be provided in the event of a nuclear excursion.

The activity of the gaseous and particulate matter leaving the operating site will be monitored by instruments located near the power conversion skid (pre-cooler monitor). The readout device will be a two pen recorder located in the auxiliary building at the ML-1 site. The pre-cooler air monitor will continuously monitor the air leaving the pre-cooler to detect fission product gas and particulate activity from the reactor coolant system. An air sample is routed through an activated charcoal bed and moving filter paper. Fission product iodine will be absorbed on the activated charcoal bed, and particulate matter, such as strontium-90, will be collected on the filter paper. The activity will be measured by scintillation counters with the outputs recorded in the auxiliary instrumentation building. Experience gained at NRTS will determine whether this system is necessary to augment the remote area monitoring system in the field.

TABLE 6: ANALYSIS INSTRUMENTATION PARAMETERS

Item	Measured Parameter	Range	Meas. Accuracy	Comments
1.	Turbine inlet temp.	600 to 1300°F		Sensor described in process instrumentation section
2.	Turbine outlet temp.	600 to 900°F	± 1.0%	Mount 3, thermocouples 120° apart
3.	Recuperator (low) out temp.	400 to 600°F	± 1.0%	Inlet temp. assumed same as turbine outlet temp.
4.	By pass valve temp.	200 to 500°F	± 1.0%	Temperatures required for measurement of precooler inlet temp.
5.	Compressor outlet temp.	100 to 400°F	± 1.0%	Two thermocouple probes.
6.	Compressor inlet temp.	-50 to 150°F	± 1.0%	Resistance element described in process instrumentation section
7.	Recuperator (high) inlet temp.	100 to 400°F	± 1.0%	Recuperator (high) outlet same as compressor outlet temperature
8.	Compressor inlet differential pressure from pitotstatic tubes	0-0.5 psi	± 1.0%	Measures velocity required for flow calculation (3 each)
9.	Compressor outlet pressure	0-350 psia	± 0.5%	
10.	Compressor inlet pressure from pitotstatic tube, total	0-350 psia	± 0.5%	Used to calculate compressor efficiency from three separate probes
11.	Reactor differential press.	0-50 psia	± 1.0%	
12.	Precooler differential press.	0-5 psi	± 1.0%	
13.	Recuperator (high) differential press.	0-10 psi	± 1.0%	
14.	Recuperator (low) differential	0-5 psi	± 1.0%	
15.	T-C speed error	0 to ± 6%	± 2.0%	Signal from control cab
16.	Turbine speed	0 to 22000 rpm	± 2.0%	Signal from control cab
17.	Reactor outlet temp. error	0 to ± 100°F	± 2.0%	Signal from control cab
18.	Reactor outlet temp.	100° - 1200°F	± 1%	Signal from control cab
19.	By-pass valve position	0 to 100%	± 2.0%	Signal from control cab
20.	By-pass valve position	0 to 10%	± 2.0%	
21.	Indicating watt-hour meter	0 to 2500 kwh		Measures generator net output
22.	Generator frequency recorder	56 to 64 cycles/sec; 45 to 55 cycles/sec		
23.	Recording wattmeter	0 to 600 kw	± 1.0%	Measures either total or net polyphase power
24.	Recording varmeter	0 to ± 500 Kvc	± 1.0%	Measures either total or net polyphase reactive power
25.	Recording voltmeter	0 to 3 kv	± 1.0%	Measures line to neutral volts.
26.	Ambient air temp.	-30 to 100°F		Required for precooler effectiveness calculation.
27.	Compressor inlet pressure	10-100 psia	± 0.5%	Required for compressor efficiency calculation
28.	Turbine inlet pressure	100-300 psia	± 0.5%	Required for turbine efficiency calculation
29.	Moisture in main coolant	0-10 ppm	± 5.0%	
30.	Hydrocarbons in main coolant	0-10 ppm	± 2.0%	Required for evaluation of T-C seals

The other health physics equipment needed for operation at NRTS includes:

1) Twenty-four self-reading slow-neutron dosimeters and a charger;

2) Film badges with X-ray, gamma, beta, and neutron combination film packs (the film badges serve as a check on the dosimeters and yield more accurate long term exposure data);

3) A hand and foot counter located in the test building and used for making rapid surveys of personnel leaving the test building;

4) Two portal monitors, one in the auxiliary instrumentation building, the other in the test building (this equipment will be used to rapidly survey personnel);

5) Two line operated rate-meters: one in the "cold" change room of the test building so personnel can make a final personal check after showering; the other in the auxiliary instrumentation building (at the air conditioner filter) to monitor the air entering this building;

6) The GCRE-I scintillation well counter and 100 channel analyzer are used to make routine checks on the filter paper and activated charcoal traps; and,

7) Special safety equipment including ultra-filters, air-paks, and disposable clothing.

VI SUPPORT EQUIPMENT

VI. SUPPORT EQUIPMENT

A. GENERAL

Maintenance supplies and certain support equipment is required for the ML-1 power plant. Space and weight limitations make it impossible to locate this equipment on the three major packages. Such support equipment includes make-up water treatment equipment; the nitrogen gas make-up system; waste gas storage equipment; cable reel, bulk anhydrous boric acid (B_2O_3) and ion exchange resin. There are certain supplies needed during operation, including spare ion exchange resin; spare filter cartridges; miscellaneous hand tools; protective clothing; and air masks. In addition, special equipment is needed for changing fuel elements in the field and for drying out the reactor after fuel replacement. The latter category of special equipment is not carried as standard ML-1 cargo during movement from one site to another because it is needed only for fuel element replacement.

The ML-1 auxiliaries are mounted on individual bases equipped with suitable framework, shock mounts and runners. The separate packages provide maximum flexibility and allow a number of simultaneous operations. For example, the borated water solution can be added to the neutron shield tank with the make-up water equipment while the cable is being unrolled from the cable reel, and the gas systems are being connected.

Auxiliary gas handling equipment is required to supply gas to the main power loop, to evacuate the loop during initial startup, and to store potentially contaminated gas during shutdown. A process flow diagram of the various systems is shown in Figure 47.

B. GAS MAKE-UP SYSTEM

Leakage rates of the reference coolant are expected to be from 0.005 to 0.01 scfm. A nine-bottle manifold of reference gas (99.5 vol% N_2 + 0.5 vol% O_2) will furnish one charge and make-up for 60 days at the maximum (0.01 scfm) expected leak rate. An additional bottle of oxygen is provided to make up for oxygen depletion due to oxidation. The operating position of the gas make-up skid is near the power conversion equipment skid. The connection for adding oxygen to the nitrogen manifold is located to provide a common feed line to the main gas system. These valves will reduce the gas pressure to slightly above the compressor inlet pressure. A manual, remotely-operated admission valve is provided in the gas make-up line. This valve is operated manually in the control cab whenever oxygenated nitrogen or pure oxygen is admitted to the main gas system. Figure 48 shows the make-up system assembly and skid base structure. This equipment will weigh about 2000 lbs.

C. WASTE GAS STORAGE SYSTEM

The gas storage system will store two complete system charges of reference gas and will permit loop depressurization in about five hours. The ML-1 plant may be started at reduced system mass because of the size of the start-up motor. Accordingly, each time the power plant is shut down, the gas would be transferred to the storage system before startup. ML-1 experience may prove that radioactive gas can be discharged directly to the atmosphere and that plant shutdowns are infrequent enough to eliminate the need for large amounts of nitrogen for system charging. If such is the case, the gas storage system will not be included in future plants.

A diaphragm compressor, rated at 2 scfm and 3000 psig discharge, is utilized for transferring the gas to small 3000 psi spherical storage tanks. The compressor is operated remotely from the control cab and has local start-stop control. A re-cycle line is provided for re-cycling the gas back to the loop through the admission valve. The storage tanks and gas transfer compressor are located on a common skid (Figure 49). The storage system will weigh about 2000 lbs.

D. GAS EVACUATION SYSTEM

An air-cooled vacuum pump, nominally rated at 30 scfm and capable of drawing 5 mm of vacuum on the power plant circuit, is provided on the power conversion equipment skid. This pump will be used to evacuate the system during initial system charging and during decontamination operations when fission product gasses have escaped from leaking fuel elements. The outlet of the vacuum pump is manifolded so that the pump may discharge either to the atmosphere or to the suction side of the transfer compressor. A small surge tank with a volume of about 1 cu ft is provided between the vacuum pump and compressor to eliminate unstable operation when the two units are coupled together. A single pump down-evacuation cycle gives a gaseous decontamination factor of about 900.

E. WATER MAKE-UP SYSTEMS

There are three basic applications for water in the ML-1 plant: the neutron shield water, the moderator water, and the reactor flooding system. All three applications require filtering and demineralizing the raw water to remove suspended and soluble matter. This treatment of the moderator and the neutron shield water prevents fouling of heat transfer surfaces, prevents stress corrosion and pitting corrosion (certain to occur with high chloride concentrations), and minimizes water decomposition as well as radioisotope production from neutron activation of impurities. Treatment of the water used for reactor flooding prevents

MECHANICAL FLOW DIAGRAM FOR THE GAS HANDLING SYSTEM

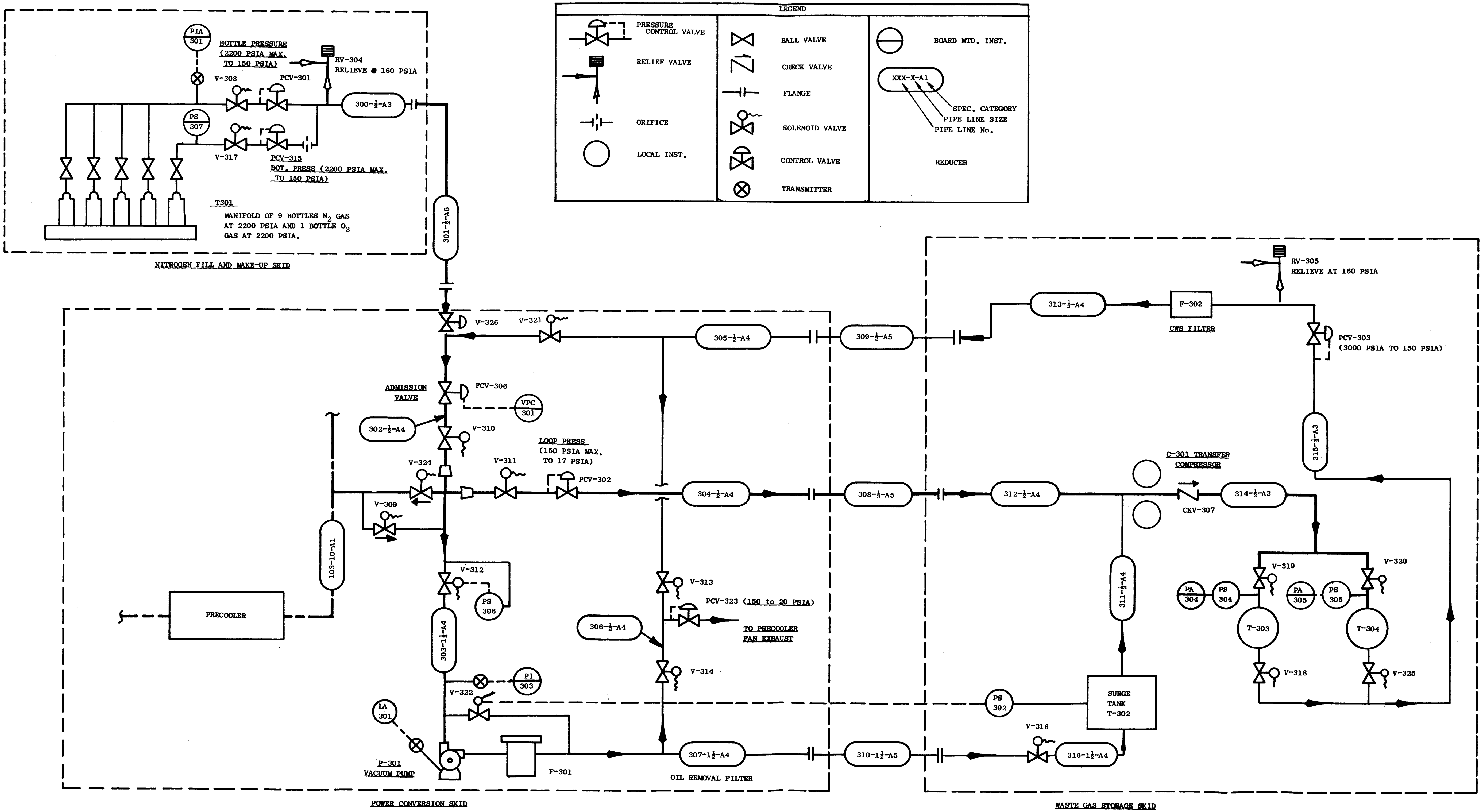


FIGURE 47

THE ML-1 GAS MAKE-UP SKID

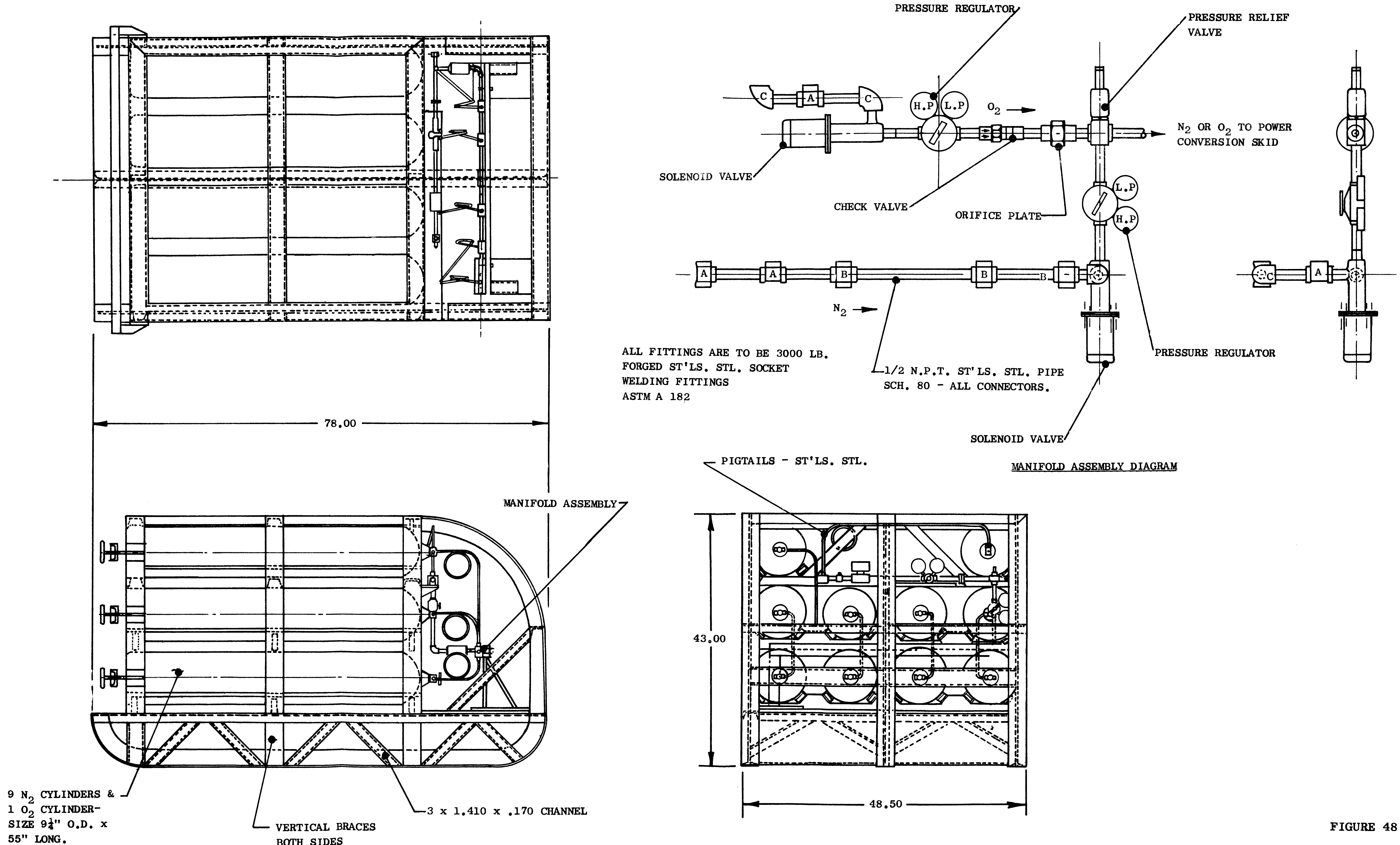


FIGURE 48

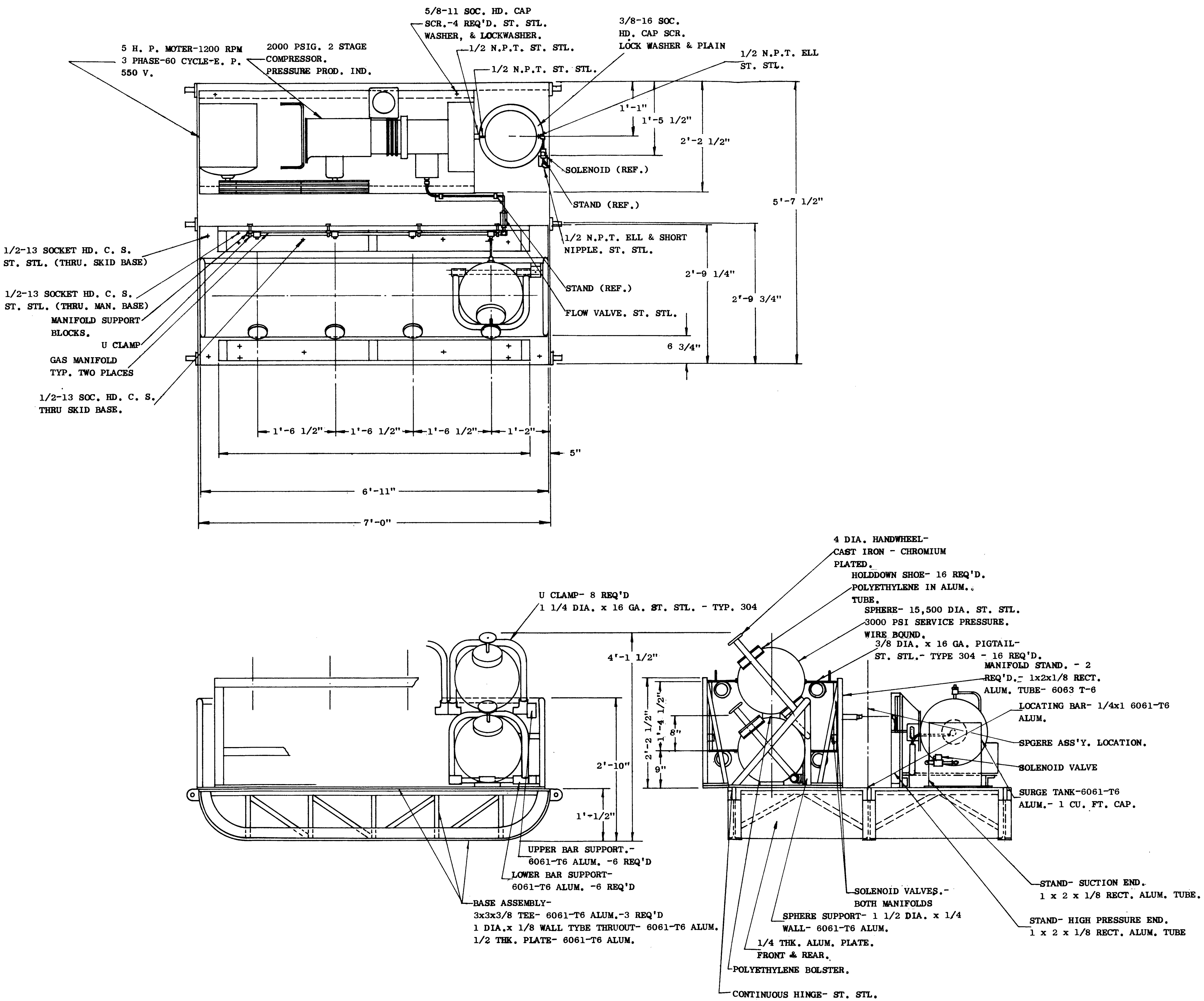

5/8-11 SOC. HD. CAP
SCR.-4 REQ'D. ST. STL.
WASHER, & LOCKWASHER.
1/2 N.P.T. ST. STL.
1/2 N.P.T. ST. STL.
3/8-16 SOC.
HD. CAP SCR.
LOCK WASHER & PLAIN
1/2 N.P.T. ELL
ST. STL.
5 H. P. MOTER-1200 RPM
3 PHASE-60 CYCLE-E. P.
550 V.
2000 PSIG. 2 STAGE
COMPRESSOR.
PRESSURE PROD. IND.
1'-1"
1'-5 1/2"
2'-2 1/2"
SOLENOID (REF.)
STAND (REF.)
5'-7 1/2"
1/2 N.P.T. ELL & SHORT
NIPPLE. ST. STL.
1/2-13 SOCKET HD. C. S.
ST. STL. (THRU. SKID BASE)
1/2-13 SOCKET HD. C. S.
ST. STL. (THRU. MAN. BASE)
MANIFOLD SUPPORT
BLOCKS.
U CLAMP
GAS MANIFOLD
TYP. TWO PLACES
1/2-13 SOC. HD. C. S.
THRU SKID BASE.
2'-9 1/4"
2'-9 3/4"
STAND (REF.)
FLOW VALVE. ST. STL.
6 3/4"
1'-6 1/2"
1'-6 1/2"
1'-6 1/2"
1'-2"
5"
6'-11"
7'-0"
4 DIA. HANDWHEEL-
CAST IRON - CHROMIUM
PLATED.
HOLDDOWN SHOE- 16 REQ'D.
POLYETHYLENE IN ALUM.
TUBE.
SPHERE- 15,500 DIA. ST. STL.
3000 PSI SERVICE PRESSURE.
WIRE BOUND.
3/8 DIA. x 16 GA. PIGTAIL-
ST. STL.- TYPE 304 - 16 REQ'D.
MANIFOLD STAND. - 2
REQ'D.- 1x2x1/8 RECT.
ALUM. TUBE- 6063 T-6
LOCATING BAR- 1/4x1 6061-T6
ALUM.
SPGERE ASS'Y. LOCATION.
SOLENOID VALVE
SURGE TANK-6061-T6
ALUM.- 1 CU. FT. CAP.
U CLAMP- 8 REQ'D
1 1/4 DIA. x 16 GA. ST. STL. - TYP. 304
4'-1 1/2"
2'-10"
1'-1/2"
2'-2 1/2"
1'-4 1/2"
8"
9"
UPPER BAR SUPPORT.-
6061-T6 ALUM. -6 REQ'D
LOWER BAR SUPPORT-
6061-T6 ALUM. -6 REQ'D
BASE ASSEMBLY-
3x3x3/8 TEE- 6061-T6 ALUM.-3 REQ'D
1 DIA.x 1/8 WALL TYBE THRUOUT- 6061-T6 ALUM.
1/2 THK. PLATE- 6061-T6 ALUM.
SOLENOID VALVES.-
BOTH MANIFOLDS
SPHERE SUPPORT- 1 1/2 DIA. x 1/4
WALL- 6061-T6 ALUM.
1/4 THK. ALUM. PLATE.
FRONT & REAR.
POLYETHYLENE BOLSTER.
CONTINUOUS HINGE- ST. STL.
STAND- SUCTION END.
1 x 2 x 1/8 RECT. ALUM. TUBE.
STAND- HIGH PRESSURE END.
1 x 2 x 1/8 RECT. ALUM. TUBE

FIGURE 49

undue formation of film on fuel element surfaces (and subsequent hot spots) and insures water of the high clarity needed for the fuel replacement operation.

Water to be used for neutron shield water receives further treatment after filteration and demineralization. Sufficient quantities of a water soluble boron compound will be added to this water (anhydrous boric acid, B_2O_3) to attain the 10 wt% boric acid concentration required for operational shielding. The solution must be heated to achieve the solubility temperature of 120°F under cold ambient conditions. The neutron shield tank is initially filled with 2 wt% boric acid solution, prepared in batches in an auxiliary water tank. This solution contains sufficient boron to prevent a nuclear excursion in case the gas passages are inadvertently filled with water when the moderator passages are flooded with water. Boron capture of the neutrons offsets the moderating effect of the water.

Once the tank is filled, the solute required for a 10 wt% boric acid concentration is added through the top of the neutron shield tank. Reactor heat raises the temperature of this slurry above 120°F, at which temperature all the B_2O_3 will be in solution.

Filtered water will be furnished in the field by either a 600 or 1500 gph mobile Army water plant or some other source of pure water. The ML-1 make-up equipment will be used to demineralize this water and prepare the boric acid solution for the neutron shield tank. 50 gpm demineralizer and transfer pump is mounted on a skid base. A 500 gal collapsible tank is used for boric acid make-up. Flexible hose is used for transferring water. A flow sheet of the make-up water system is shown in Figure 26, page 59. This equipment (excluding the initial supply of ion exchange resin and boric acid) weighs about 950 lb. About 1200 lbs of anhydrous boric acid will be required to obtain the 10 wt% concentration. A maximum of 900 lbs of ion exchange resin will be required for demineralizing high solids water.

F. AUXILIARY POWER SYSTEM

A 45 kw auxiliary diesel-generator or other auxiliary power supply will be used to start the power plant and to supply power for support equipment during normal startup and shutdown. This generator set - MIL Spec. MIL-G-14609 (CE) - will be furnished by the Army.

The generator set is complete with starting batteries, starting motor, fuel tank, control panel, etc. The engine is started from a pushbutton on the control panel and is provided with a winterization system for starting at temperatures below -25°F.

The power output of the generator is 480 volts, 60 cps, 3 phase, 4 wire neutral grounded, wye connected. The current is fed from 4 studs located on the control panel, through a 550 ft cable to the power conversion skid. The power is distributed to the rest of the ML-1 system from there (See Figure 37, page 83).

G. CABLE REEL SYSTEM AND EQUIPMENT

A power-operated cable reel assembly is provided on a skid with runners (Figure 50). Two reels on the skid store four 550-ft lengths of power and instrumentation cable for the ML-1 during transport. The cable reel skid is unloaded and placed adjacent to the control cab during plant set-up operations. The power drive clutch is disengaged and the cable is pulled off of the reel by a jeep or similar small vehicle. The cable ends are then pulled to the ML-1 plant. During plant shutdown, before relocation, the power drive clutch will be engaged and the cables rewound on the reels using power furnished by the auxiliary generator. The cables will be completely detached from the reel during plant operation. The cable reel and cable weigh about 6000 lb.

H. FUEL ELEMENT REPLACEMENT EQUIPMENT

A 10-ft extension to the neutron shield tank, work platform, hoists and special handling tools are provided for use during replacement of fuel elements in the field. Use of this equipment is covered under Section IX-C.

I. REACTOR DRYING SYSTEM AND EQUIPMENT

After flooding the reactor for replacing fuel elements, the gas system of the reactor is dried by open-cycle flow of hot air. The hot air is supplied by a 36 kw electrical heater and a 236 cfm (1000 lb/hr), 2 hp rotary type blower. This equipment is transported as part of the fuel replacement kit and weighs about 900 lb. This equipment is all mounted on a common base equipped with shock mounts and runners (Figure 51). When most of the water has been removed from the system by this process, the vacuum pump is used to remove the last traces of moisture. Vacuum drying may suffice for ML-1, and the blower-heater unit may not be needed for the ML-1A plant. Tests of both vacuum and hot air drying of the ML-1 are scheduled at NRTS.

ML-1 CABLE REEL ASSEMBLY

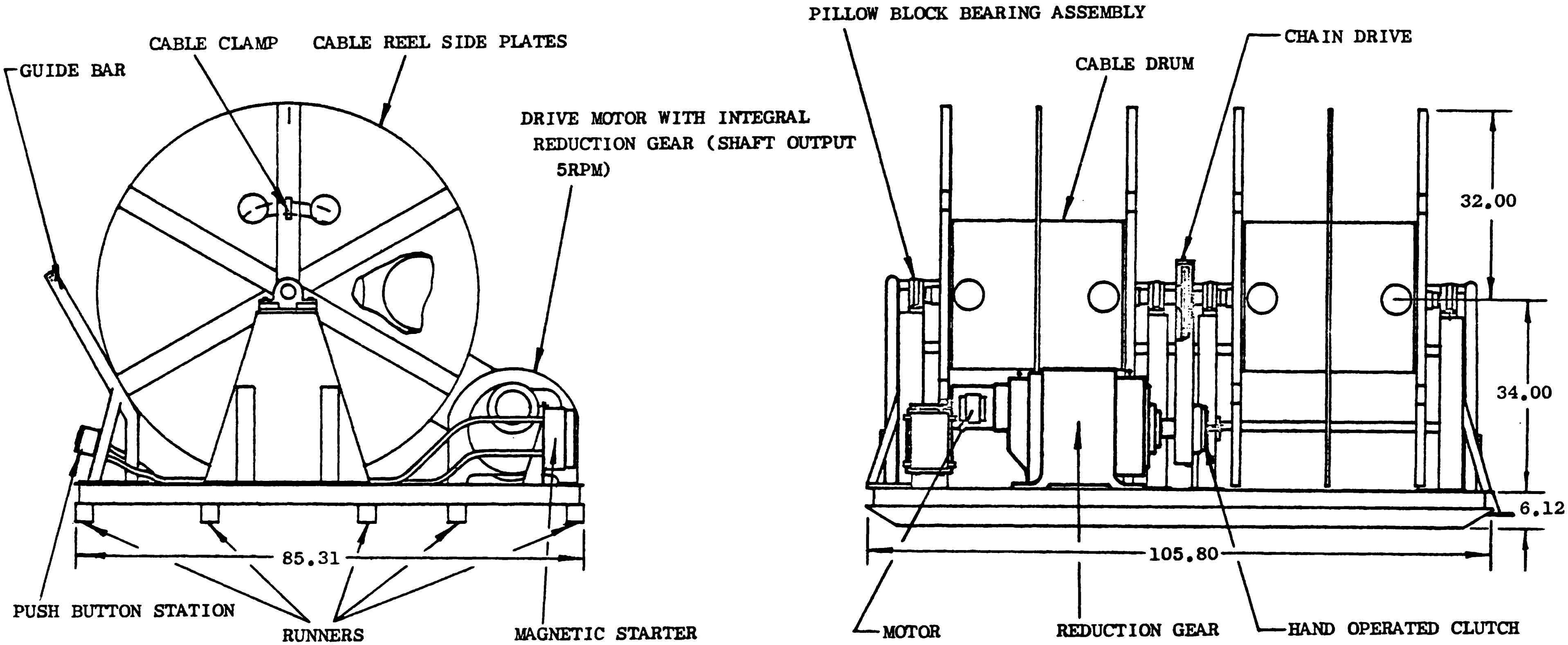


FIGURE 50

THE AUXILIARY SKID FOR THE REACTOR DRYING EQUIPMENT

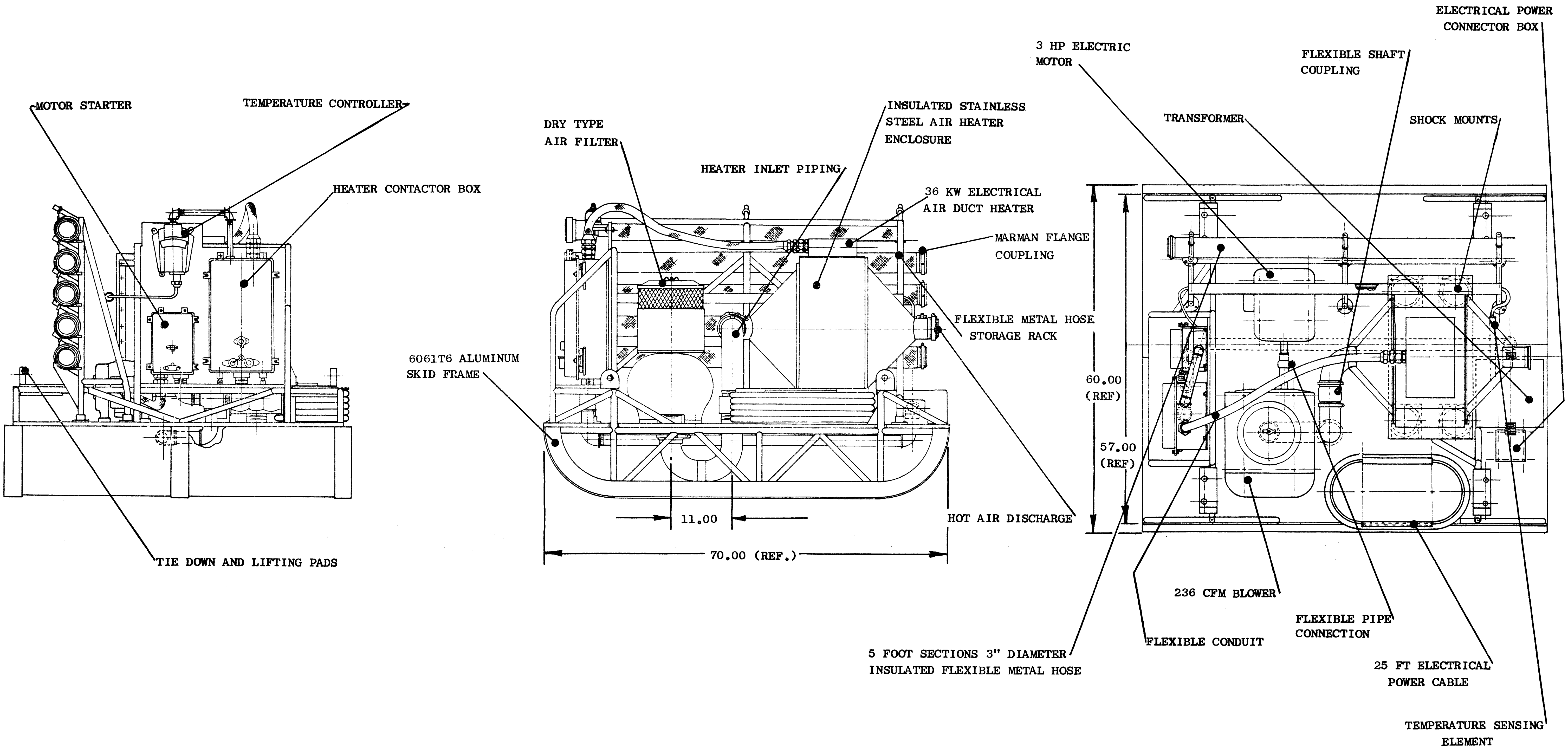


FIGURE 51

VII ML-1 OPERATION

VII ML-1 POWER PLANT OPERATION

A. GENERAL

The ML-1 power plant has been designed to serve as an operating prototype of plants to furnish electrical power at remote military installations. It incorporates many features to insure satisfactory performance under extreme conditions. The operation of the plant is described as it would be in military use. However, as the prototype will be operated at the NRTS, the test facility is also described.

B. TRANSPORT

1. General

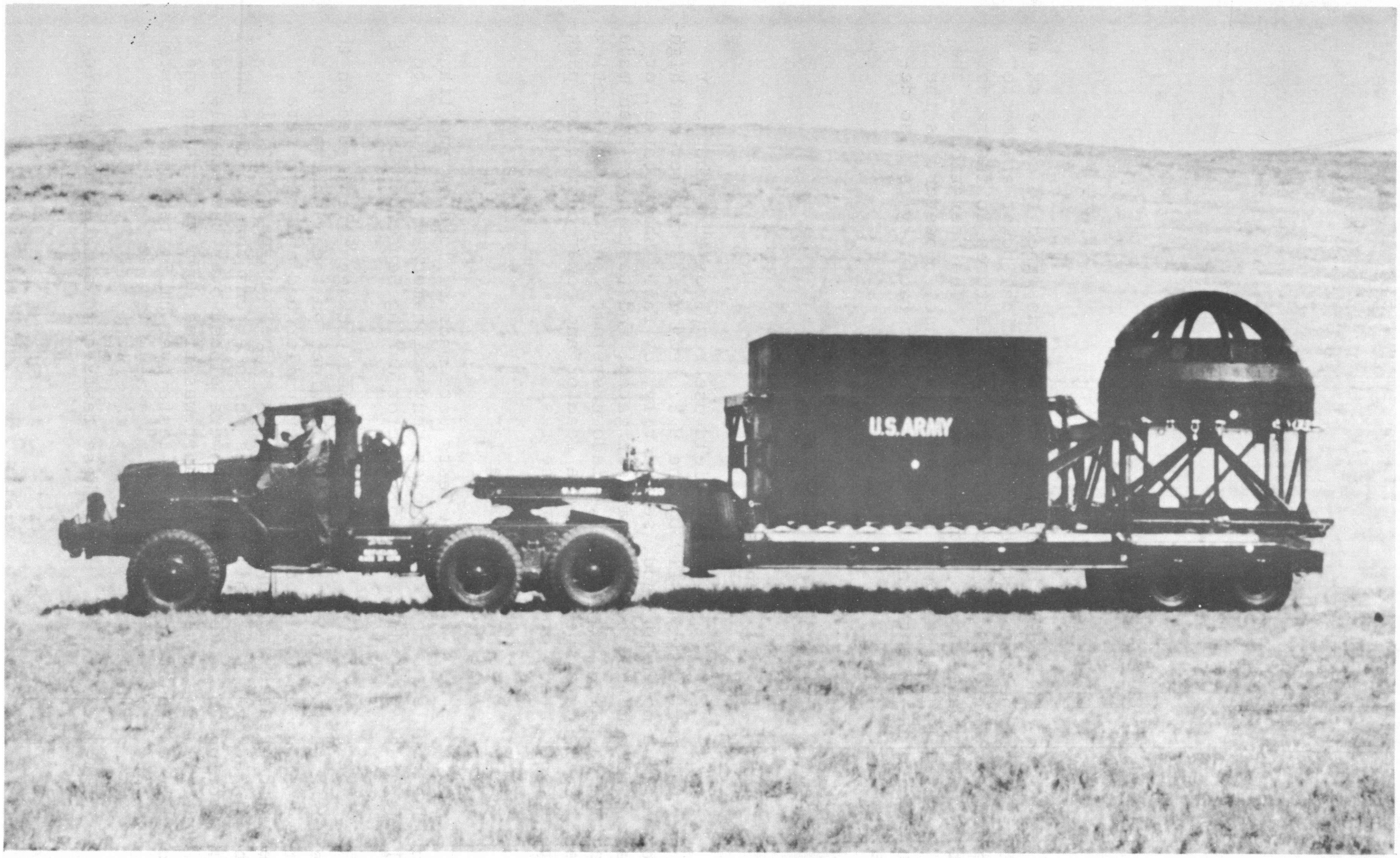
Military field use requires that the power plant be transported primarily by the U.S. Army M-172 trailer for highway or overland movement, and, secondarily, by rail, ship, barge, or aircraft. Each method has been investigated, and tests have been made of loading and unloading methods, tiedown systems, and shock reduction devices. Full-scale mock-ups of the reactor and power conversion packages were fabricated for use in these tests.

a. Trailer

Tests were made of loading and transporting the coupled reactor and power conversion mock-up packages on an M-172 trailer pulled by an M-52 tractor during September 1959.

The coupled packages are loaded on the trailer as a unit by using the 20,000 lb winch on the M-52 tractor to pull the unit up an inclined ramp. The trailer bed and ramp were covered with greased shoring, 3-in. thick. The package is so big it must be placed over the trailer wheels which extend through open wheel wells. Sections of inverted channel were placed over these wells to allow vertical axle movement. The unit was tied down with chain and subjected to extensive cross-country tests over hilly terrain (Figure 52).

These tests demonstrate that loading



CROSS COUNTRY TEST OF THE ML-1 MOCK UPS MOUNTED
ON AN M-172 TRAILER

FIGURE 52

and transporting the ML-1 on an M-172 trailer is feasible, although there are several problems. When the coupled unit is mounted with the reactor to the rear, the rear double-axle bogie is loaded to 57,000 lb. This is 11,000 lb over the allowable highway load limits in California. When the unit is loaded so that the reactor is to the front, the loading on the rear is reduced to 55,700 lb, still more than 10,000 lb over the California maximum allowable axle loading. (California is used as an example because it has nearly the highest maximum of all the states: Thus the problem is more severe in other locations.)

The overhead clearance limitation for military vehicles overseas restricts the overall height of the unit, including trailer and shoring to 132-in. from the road. The 93-in. reactor package height plus 3 in. of shoring subtracted from 132 in. leaves 36-in. for the trailer bed. Static load tests on an M-172 trailer indicate that the loaded bed height is 36-in. with recommended tire pressure (80 psi). The M-172A trailer has a nominal bed height of 39-in. Its height must be reduced 3-in. to meet the minimum overhead clearance requirements. This can be done by reducing the tire pressure to 50 psi before passing under restricted overheads. (A tire pressure of 40 to 50 psi will lower the bed 3-in. and is not considered detrimental for short runs.) Figures 53 and 54 show the M-172 trailer and a proposed trailer loaded with the coupled packages.

b. Aircraft

Tiedown restraint for all aircraft loads must conform to MIL-8421A (General Specification for Air Transportability Requirements). It specifies the following static tiedown restraint.

Forward	8 g
Aft	3 g
Vertical (up)	3 g
Vertical (down)	4.5 g
Lateral	1.5 g

(Forward and vertical - down - loadings are emergency landing conditions; others are in-flight loads.)

The ML-1 can be secured with standard Air Force tiedown chains and procedures, but the ML-1 would not necessarily be operable after an 8 g emergency landing. In addition, it is difficult to equally distribute tiedown restraint throughout the many tiedown fittings on the aircraft. Improper load distribution could result in the package tearing loose during high shock loads.

An alternate method was investigated using an elastic tiedown system with nylon ropes. This method assures system operability following an 8 g emergency landing. (This method is illustrated in tiedown diagrams referred to in later sections.) Each rope is 1-1/8-in. diameter and 5-ft long with a minimum breaking strength of 30,000 lb. Tiedowns for lateral and vertical restraint use 2-ft sections of nylon rope to allow freedom for fore and aft tiedowns. Each rope is in series with appropriate aircraft chain tiedown devices (D-1, MB-2, C-2, or MB-1). When the load must split to smaller capacity deck fittings, it is done through a whiffletree load distribution system.

In addition to nylon rope and whiffletrees, the tiedown hardware includes clevises at each package to receive individual ropes, and hand jacks having a 24-in. take up to pre-tension (1000 lb) the rope before securing it to the aircraft. The jack is released and removed after tiedown is complete.

A comprehensive analysis of an aircraft emergency landing shock was made, using data from the nylon rope dynamic shock tests. The analysis was based on an emergency landing speed of 100 mph imposing a de-acceleration pulse of 8 g for a minimum of 0.1 sec on the aircraft. These conditions represent a realistic situation for an emergency landing and result in a "worst case" analysis from the standpoint of input energy.

It is concluded that twelve 5-ft lengths of nylon rope will isolate an 8 g emergency landing shock to less than 5 g with rope temperatures down to $0^{o}F$ (Figure 55). (Since the cargo compartments of all of the transport aircraft are heated, rope temperatures will not fall below $0^{o}F$.)

The shoring beneath the packages is greased to allow loading and to put the bulk of shock absorption on the nylon rope in an emergency landing. Grease permits the package to return nearly to its initial position after a shock.

The tiedown system will be used in all aircraft. The following paragraphs briefly describe situations peculiar to each aircraft.

The Lockheed C-130A has a nominal cargo capacity of 30,000 lb. It can carry a single 30,000 lb ML-1 package about 2900 statute miles. Hence, three aircraft are required to transport the entire system. Figures 56 and 57 show the reactor and power conversion packages in place in the C-130 aircraft. In the C-130, a clearance of 18-in. is desirable to allow the crew to pass in the event of an emergency bail-out. This clearance is not available with the power conversion package. The Department of the Air Force has stated, however, that existing equipment (proven air transportable, but not in conformance with clearance criteria) will be transported. A passage 18 in. wide and 45 in. high is available with the reactor package in the C-130.

ELEVATION OF THE ML-1 POWER PLANT
ON THE M-172 TRAILER

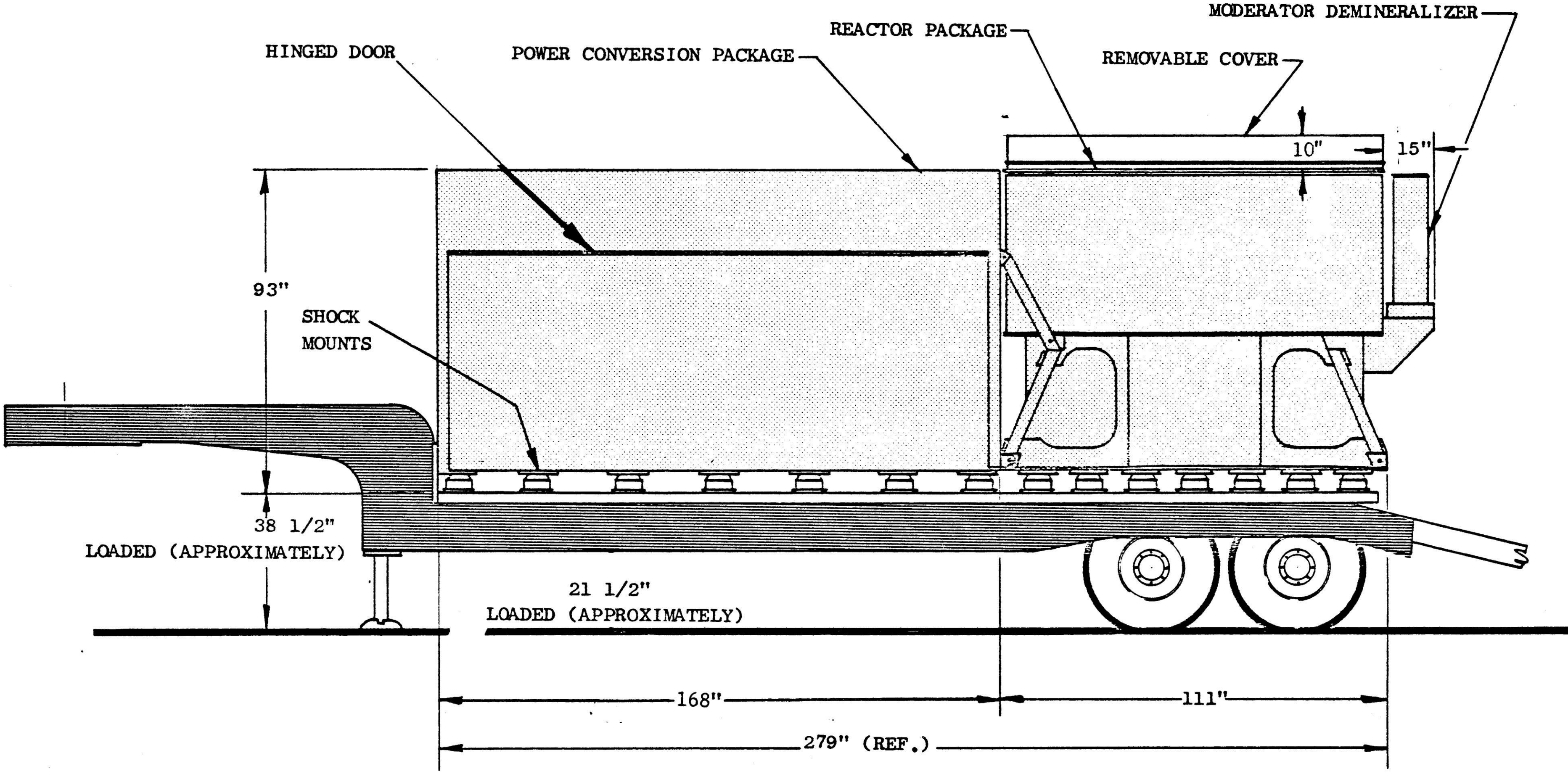


FIGURE 53

REPORT NO. IDO - 28550

ELEVATION VIEW OF THE ML-1 POWER PLANT ON PROPOSED U. S. ARMY TRAILER

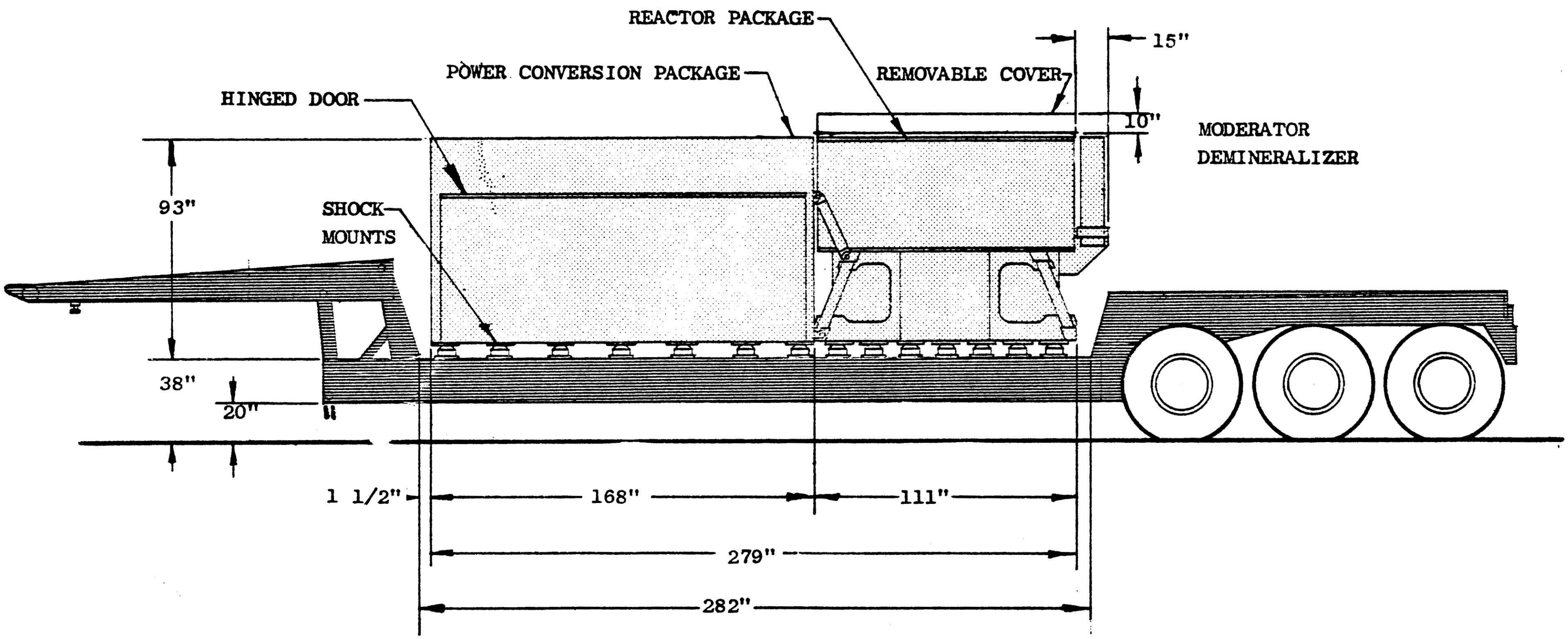


FIGURE 54

SHOCK LOAD FOR AIRCRAFT & ML-1 PACKAGE:
HORIZONTAL ACCELLERATION
Vs.
TIME
AIRCRAFT EMERGENCY LANDING

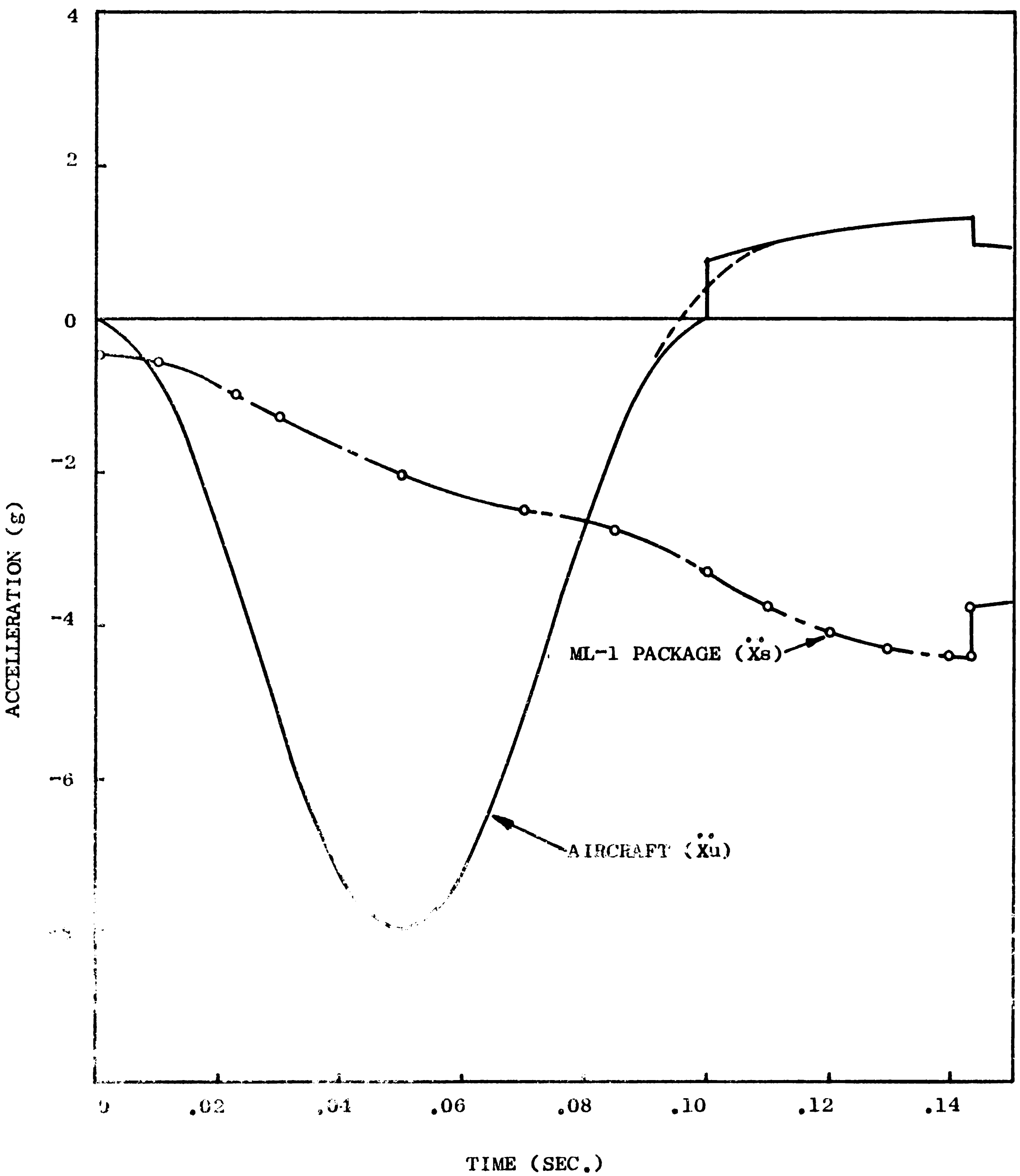


FIGURE 55

The packages are loaded and unloaded directly from the M-172 trailer by backing the trailer to the lowered ramp and resting the ramp toes on the trailer. Greased 2- x 12-in. shoring is placed over the ramp and aircraft floor and the package pulled aboard using the tractor winch. The C-130 treadway area can support a static unit load 20 lb/sq-in., and a running load of 4000 lb/sq-ft. The treadway extends from 15- to 50-in. on either side of the aircraft centerline. The power conversion package elastomer width is 50 in. (package centerline to elastomer centerline). Since either package may be placed several inches off center within the aircraft, the package undercarriage is designed to meet the deck dead load limit of 1080 lb/sq-ft when the package is resting on two inches of shoring.

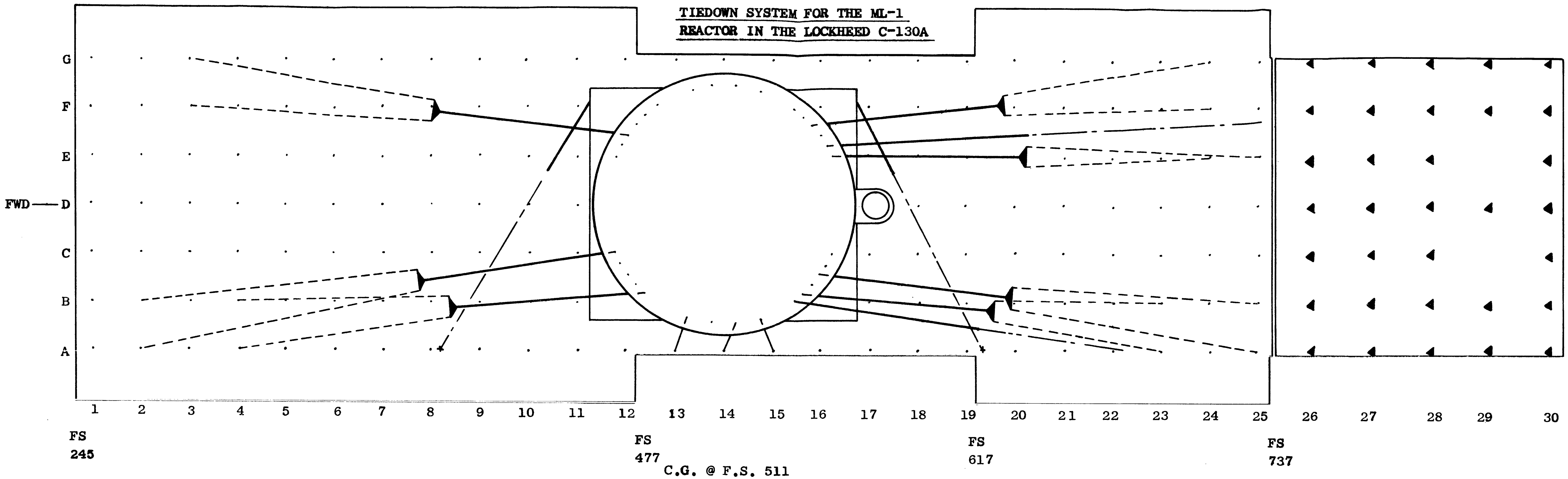
The Douglas C-133A has a cargo capacity of 120,000-lb and can carry the entire 82,000-lb ML-1 system about 2150 statute miles. Figure 58 shows the system tied down within the aircraft using an alternative procedure in which the packages are coupled. The packages can be loaded and unloaded directly from the M-172 trailer by backing the trailer up to the aircraft ramp, partially raised to mate with the trailer bed. The ramp is supported by wood blocks. Greased 2- x 12-in. shoring is laid on the ramp and aircraft deck. The unit is pulled aboard by the tractor winch.

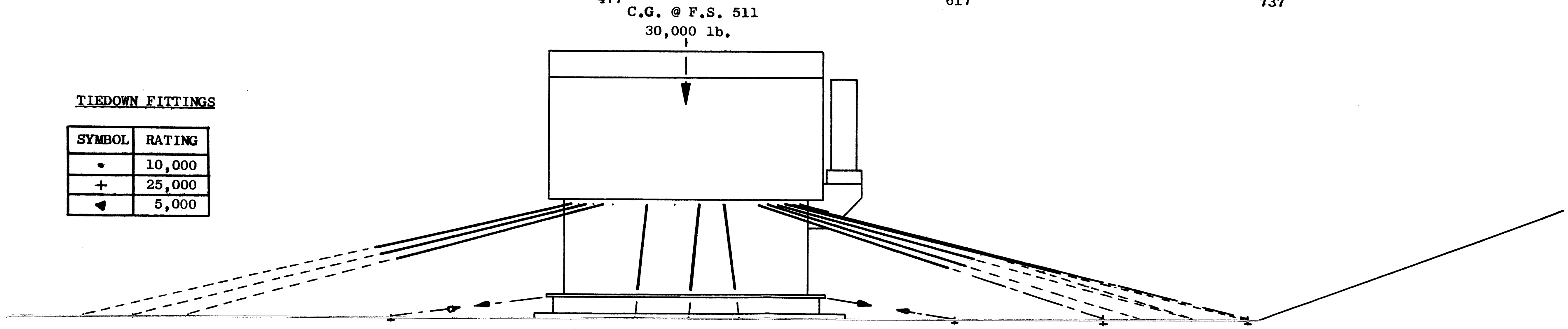
The C-133 treadway area can support a dead load of 50 lb/sq-in. The treadway extends from 19-1/2- to 60-in. on each side of the aircraft center line. The off-treadway area can support a dead load of 30 lb/sq-in. Compartment load limitations are met for the ML-1 system by the use of the standard shoring.

The Douglas C-124 has a cargo capacity of 50,000-lb for the C-124A series, and 55,000-lb for the C-124C series. Operating necessities, however, have reduced this to about 35,000-lb. Thus the ML-1 system will be carried in 3 separate lifts.

It is not practical to load the package directly from the M-172 trailer. The package must be unloaded from the trailer onto shoring on the runway and then winched on greased shoring up the 17° nose ramp and into the aircraft. The clearances on the incline and within the aircraft are limited, so extreme care must be used to keep the packages aligned during the loading operation. Off loading requires restraining the package with a winch while it is sliding down the ramp.

The C-124 treadway areas have a dynamic (3 g) load limit of 50 lb/sq-in. and extend from 25- to 54-1/2 in. on each side of the aircraft centerline. Outside the treadway area the allowable dynamic loading is 30 lb/sq-in. These conditions are met by the use of standard shoring.





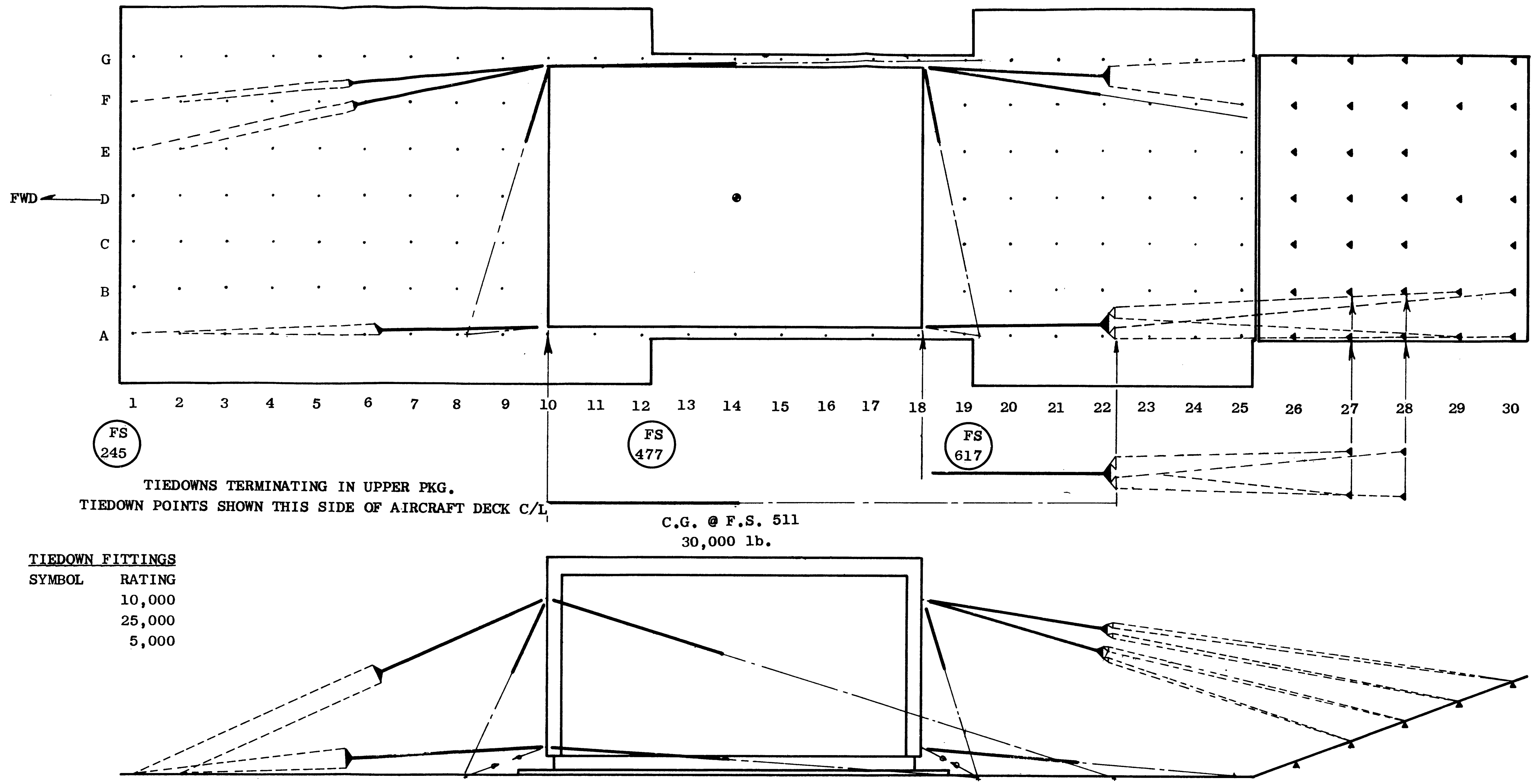
TIEDOWN FITTINGS

SYMBOL	RATING
•	10,000
+	25,000
◀	5,000

3. TIEDOWN SYSTEM SYMMETRICAL ABOUT DECK C.
2. AIRCRAFT LOADING IN ACCORDANCE WITH T. O. 1C-130A-9.
1. TIEDOWN RESTRAINT PER MIL-A-8421A (USAF).

SYMBOL	ITEM	SIZE OR PART NO.	RATING	SUPPLIER	NO. REQ'D
— — —	TIEDOWN DEVICE	D-1	25,000	USAF	8
- - - - -	TIEDOWN DEVICE	C-2 or MB-1	10,000	USAF	28
—— ——	NYLON ROPE (1 1/8" DIA.)	5'	25,000	ML-1	18
├──────┤	NYLON ROPE (1 1/8" DIA.)	2'	25,000	ML-1	10
▲	DOUBLE TREE		25,000	ML-1	14
	PRETENSION JACK		3,000	ML-1	2

FIGURE 56

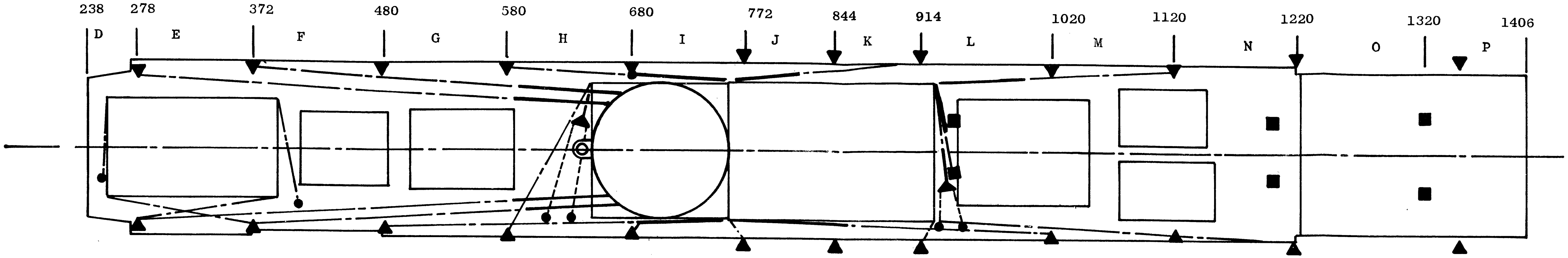


TIEDOWN HARDWARE

SYMBOL	ITEM	SIZE OR PART No.	RATING	SUPPLIER	No. REQ'D.
	TIEDOWN DEVICE	D-1	25,000	USAF	14
	TIEDOWN DEVICE	C-2 or MB-1	10,000	USAF	16
	TIEDOWN DEVICE	MC-1	5,000	USAF	16
	NYLON ROPE (1 1/8" DIA.)	5' (RELAXED)	25,000	ML-1	18
	NYLON ROPE (1 1/8" DIA.)	2' (RELAXED)	25,000	ML-1	8
	PRETENSION DEVICE		2,500	ML-1	2
	DOUBLE TREE		25,000	ML-1	16
	SINGLE TREE		10,000	ML-1	16

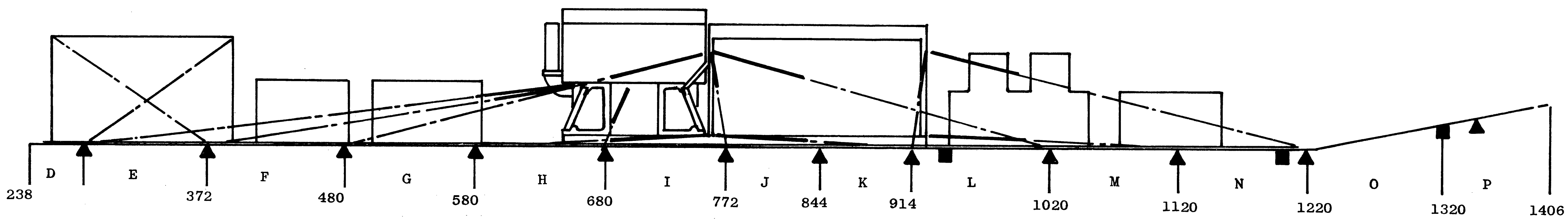
3. TIEDOWN SYSTEM SYMMETRICAL ABOUT DECK ℄.
2. AIRCRAFT LOADING IN ACCORDANCE WITH T.O. 1C-130A-9.
1. TIEDOWN RESTRAINT PER MIL-A-8421A (USAF)

FIGURE 57



CARGO C. G.
81;500 FS. 772

CONTROL CAB	MISC./CHEM.STORAGE	GAS STORAGE	REACTOR	POWER CONVERSION PKG.	CABLE REEL	GAS/WATER MAKEUP	ML-1 CREW	PACKAGE WEIGHT
5000	3000	1700	30,000	30,000	6000	3000	2800	C. G.
FS. 300	FS. 445	FS. 540	FS. 702	FS. 842	FS. 1000	FS. 1115	FS. 1300	



5. REACTOR & PWR. CNV. PKG. COUPLED FOLLOWING DIRECT LOADING FROM M-172 SEMI-TRAILER.
4. FOR PWR. CNV. PKG. & CONTROL CAB, TIEDOWNS TERMINATING IN LOWER PKG. TIEDOWN POINTS SHOWN ABOVE DECK C/L; TIEDOWNS TERMINATING IN UPPER PKG. TIEDOWN PTS. SHOWN BELOW DECK C/L.
3. ENTIRE TIEDOWN SYSTEM SYMMETRICAL ABOUT AIRCRAFT DECK C/L.
2. AIRCRAFT LOADING IN ACCORDANCE WITH TO. IC-133A-9.
1. TIEDOWN RESTRAINT PER TO. IC-133A-9.

TIEDOWN FITTINGS

SYMBOL	RATINGS
▲	35,000
■	25,000
●	10,000

TIEDOWN HARDWARE

SYMBOL	ITEM	SIZE OR PART NO.	RATING	SUPPLIER	NO. REQ'D
—·—·—	TIEDOWN DEVICE	D-1	25,000	USAF	
– – – –	TIEDOWN DEVICE	C-2 OR MB-1	10,000	USAF	
········	TIEDOWN DEVICE	MC-1	5,000	USAF	
─╲ ╲─	NYLON ROPE	1 1/8" DIA. X 5' LG.	25,000	ML-1	
━━━━	NYLON ROPE	1 1/8" DIA. X 2' LG.	25,000	ML-1	
▲	DOUBLETREE PRETENSION DEVICE		25,000 2500	ML-1 ML-1	

FIGURE 58

c. Rail

The ML-1 reactor and power conversion packages are coupled when transported on a standard rail flatcar. The standard rail flatcar is 53 ft long, has a capacity of 140,000 lbs, and a bed height of 42 in. This type of car was used in the rail loading tests conducted.

The coupled packages are loaded on the flatcar from the ground by backing the trailer to the rail car and bridging the gap with ramps and using winches, or by lifting the entire unit with a crane. When loaded on the flatcar the unit rests on greased shoring and is tied down with a nylon rope system to isolate shock during humping and switching operations. Four ropes per package are for longitudinal restraint (8 ropes per coupled unit). Lateral restraint is provided by one short (2 ft) rope per package per lateral direction, or a total of two ropes.

The tests showed that the units were shock isolated to a maximum of 2-1/2 g in longitudinal and 1 g vertically or laterally, under the severest of humping operations (Figure 59).

C. SITE PREPARATION

A minimum of site preparation is required to set up the power plant for operation on normal terrain and under any but extreme cold weather conditions.

1. Normal Provisions

Under normal weather conditions the erection of the power plant for operation requires a flat (within 5° of horizontal) smooth surface approximately 25- by 12-ft for the coupled power conversion and reactor packages. An additional area 14- by 10-ft is required for the control cab. The control cab may be as far as 500 ft from the power plant. An additional flat area about 10- by 20-ft adjacent to the power plant is required to accommodate auxiliary equipment, such as the gas handling and storage equipment and waste storage tank.

The cable reel and 45 kw auxiliary generator require a space about 10- by 15-ft near the control cab.

The mobile power plant is not required to distribute the electrical power from the local distribution panel on the power conversion skid to external load demands. All power distribution lines to power use locations will be supplied by the military user.

SHOCK LOAD FOR RAILROAD HANDLING

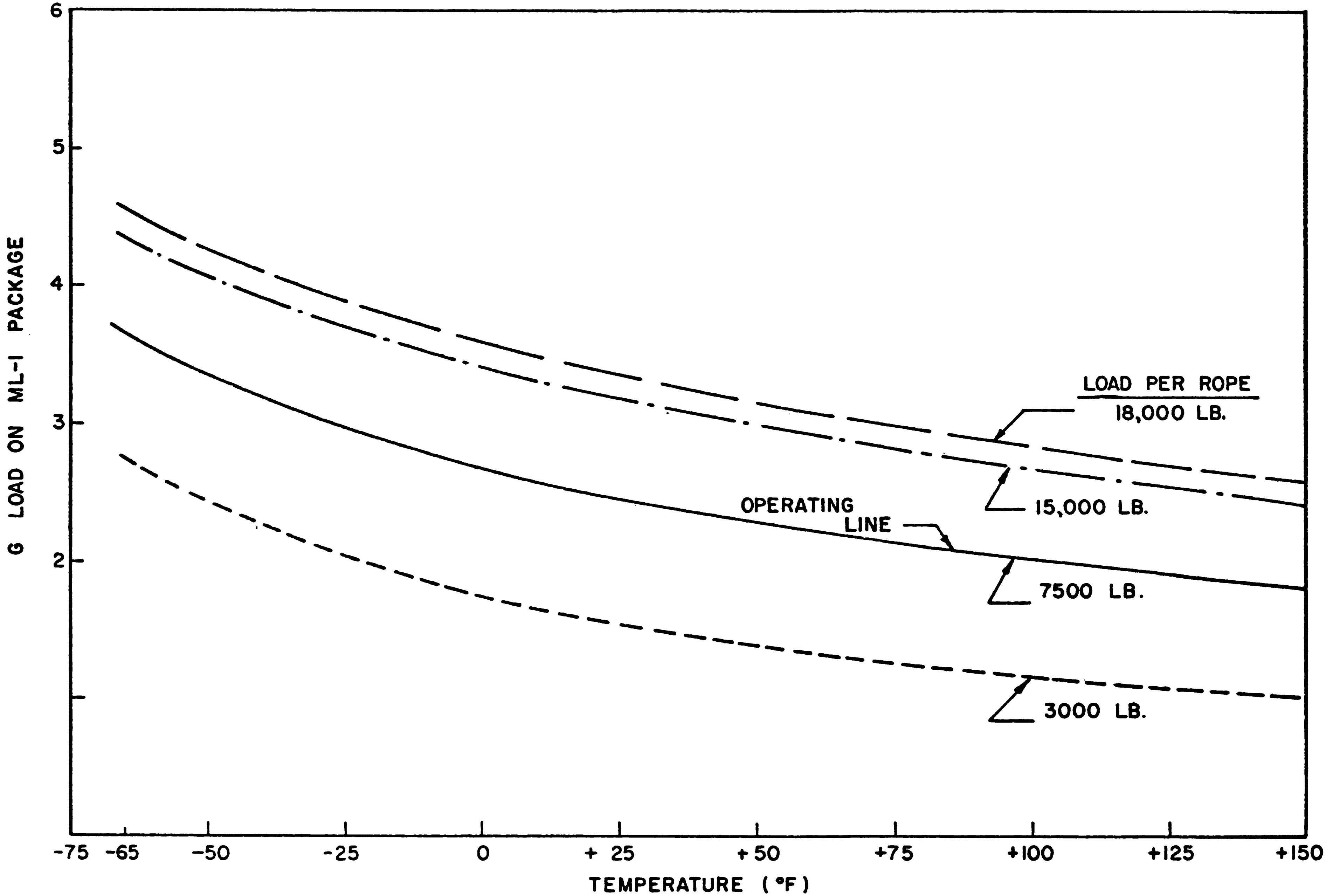


FIGURE 59

2. Cold Weather Provisions

a. Shelter

A heated shelter will be required for ML-1 start-up and maintenance under extreme environmental conditions. This is not normally provided as a plant auxiliary. It will also be necessary to pre-heat the reactor before operation. The shelter will be a portable frame and panels capable of being erected under arctic conditions. The frame will be lightweight spider-type, positive link and pin construction in sections to permit end-to-end construction. The roof may be assembled without shelter sides. Large positive link and pin connections will facilitate rapid erection by personnel wearing arctic-type clothing.

The panels will have a nominal thickness of 2-in. with a balsa-wood or honeycomb core. The panels will be provided with loosely interlocking edges to facilitate field erection.

A foundation will be necessary to adequately support the reactor over extended periods of time. This may be done one of two ways: Plant heat may be insulated from an ice or permafrost base to preclude plant settling or shelter temperatures may be kept near ambient by venting the shelter during reactor operation. The latter approach appears to be the most feasible for ML-1 operation.

The first step in erecting the shelter is to locate base frame members on prepared foundation bearing points. When the base frame is in place, the shelter frame is assembled, working from end to end. The roof and the shelter exhaust will be interlocked panel construction with positive mechanical indexing where required. It is expected it will take seven men about eight hours to erect the shelter in adverse weather without power equipment. It is possible to erect this shelter with semi-skilled labor.

b. Heating Shelter and Reactor

Shelter heat losses will total about 210,000 Btu/hr for 105°F difference between inside and outside of the shelter. Two heaters will be supplied with the shelter. One heater, rated at 216,000 Btu/hr, will be used for direct application to pre-heat the reactor to + 40°F. The other heater, rated at 366,000 Btu/hr, will be used as a space heater. The Air Force type skid-mounted heaters consist of a blower (gasoline engine driven) supplying uncontaminated air. These heaters will start at -65°F and operate at full output for eight hours on one re-fueling. Warm filtered air will be circulated through the moderator passages of the reactor until moderator water can be added.

c. Transporting and Sheltering the Heater

Shelter and heaters will comprise an arctic kit and can be transported by Army 2-1/2 ton trucks, C-133, C-130 or C-124 aircraft. The shelter weighs approximately 5,000 lb and two heaters about 2,600 lbs.

3. Mobile Configuration

The power plant can be operated for short periods without removing it from the M-172 trailer, but the trailer must be shored up during operation. Space for the control cab and auxiliary equipment must be prepared as for normal operating conditions.

D. FIELD INSTALLATIONS

The ML-1 power plant can be operated either on a leveled site or while tied down on the M-172 series trailer. Site will be leveled within five degrees (5^{o}) of horizontal, using a bulldozer if necessary. Trailer operation of the ML-1 affords the greatest degree of mobility. For extended periods of operation, the trailer will be lowered on shoring by adjusting the landing gear and reducing tire pressure. Tires and wheels may be removed if necessary. Only 4-in of vertical travel is necessary to lower the trailer on an 18-in. (3 layers of 6- by 6-in. shoring) foundation.

The procedures for trailer operation are:

1) Prepare the site.

2) Spot trailer at site and remove tractor.

3) Place shoring under trailer bed.

4) Lower trailer onto shoring.

5) Connect external and auxiliary power lines.

The above is estimated to take about one hour.

The ML-1 can be unloaded from the M-172 trailer in the field by using the winch on the M-52 tractor. The coupled packages can be winched onto shoring at the site in approximately 1-1/2 hours.

The main packages will be transported uncoupled in the aircraft. The packages will be unloaded separately at a landing strip, coupled together and loaded on the M-172 trailer for transport to the site.

Coupling the reactor package to the power conversion package will be done by pulling the packages together with a winch or load binders. Two bottom guide pins will facilitate coupling, and the packages coupled with ball-lock shear pins. Adjustable top coupling junctions will be provided to expedite the coupling operation. Precision placement of the packages is not required.

Auxiliary packages will be connected to the reactor and power conversion skids through flexible hoses and quick disconnect couplings.

E. FIELD OPERATION

1. Operating Manpower Requirements

The minimum crew required for routine field operation of ML-1 consists of a supervisor (commissioned or non-commissioned officer); four power plant operators, one each to cover a four shift operation (average 42 hour work week); an electrical-instrument technician; and a mechanical technician. All personnel assigned to operate the ML-1 will be trained in the various phases of ML-1 operation and maintenance. Additional specialists may be assigned during the initial operation at NRTS to assist in evaluating plant performance. Trainees will be assigned by the U.S. Army to the ML-1 site at NRTS.

2. Normal Power Plant Startup

The following system and component operations must be completed to start the ML-1. It is assumed that the work described previously has been completed.

1) Layout and connect all instrumentation and control cables.

2) Set up and operate the auxiliary generator unless another external power source is available.

3) Prepare borated shield water solution and circulate.

4) Fill moderator system and circulate.

5) Evacuate gas loop and pressurize with nitrogen.

6) Check out T-C set lubrication system, activate reservoir heaters and seal pressure bias system.

7) Complete all component and system check lists, correcting any malfunctions which may occur.

8) Complete the reactor check list and insure that all conditions are normal.

9) Bring the reactor to criticality using the standard rod withdrawal procedure under manual control.

10) Increase reactor power manually to approximately 5 kw.

11) Turn on the auxiliary lubricating oil pump and 3 precooler fans (group one) to one half speed. Observe that pressures and flows are normal.

12) Turn on the starting motor and observe tachometer for normal speed.

13) Increase reactor power gradually until reactor outlet temperature reaches 600°F.

14) Adjust the temperature demand until the temperature error meter indicates zero error between the outlet temperature signal and the temperature demand setting. Turn the temperature control switch from "manual to "automatic".

15) Adjust the speed demand until the speed error meter indicates zero. Turn the speed control switch from "manual" to "automatic".

16) Increase the reactor outlet temperature set point slowly to 900°F. Self-sustaining conditions should exist within the plant at this time (i.e., high enough turbine inlet temperature and high enough cranking speed).

17) Observe that the by-pass valve has opened indicating that self-sustaining conditions have been reached. The automatic disconnection of the starting clutch indicates that the self-sufficiency point has been passed.

18) At approximately 6000 rpm on by-pass control with the reactor outlet temperature between 900 and 1000°F, increase compressor outlet pressure manually to 70 psia by admitting gas from the make-up gas system or waste gas storage system.

19) Alternately, increase the reactor outlet temperature set point in approximately 25°F steps and speed set point in approximately 1000 rpm steps until rated temperature and rated speed are reached.

20) Transfer the internal plant load to the generator load bus.

21) When the no load condition of the plant is reached, the parameters will read: (Approximate values at 100°F)

Turbine inlet temperature	1200°F
Compressor outlet pressure	300 psig
Speed	18000 rpm or 22000 rpm

By-pass valve position	60% open (20% mass flow)
Electrical load	zero

The plant now is operating automatically and is ready for an external electrical load.

3. Normal Shutdown Procedure

The tentative normal shutdown procedure is as follows:

1) The external load is removed and the by-pass valve automatically opens.

2) The internal electrical load is then transferred to the external power supply.

3) The reactor outlet temperature is gradually reduced to about 950°F (50°F above the estimated self-sustaining temperature) while the T-C set is maintained at rated speed. At this point, the T-C set speed is reduced from rated speed to about 30% speed, at which point the system is barely self-sustaining.

4) The starting motor is turned on to maintain flow.

5) Control is transferred to manual and the reactor power is reduced slowly to a power level less than 10 kw at which point the reactor is scrammed. After the starting motor is turned on, the waste gas transfer compressor may be turned on to transfer the reactor coolant to the waste gas system.

4. Emergency Shutdown Procedure (without auxiliary power)

Rapid shutdown may be required to protect the reactor or because of component failure. The reactor is scrammed and simultaneously the generator is open-circuited to remove all turbine load. With this operation, the pre-cooler fans are stopped. To effect a reactor scram, all of the shim-scram blades are rapidly inserted. The reactor heat generation is reduced to about 25% of the steady state value in the first second. Thereafter the heat generation decays to about 5% of steady state value in about 60 seconds. During this transient the inertia of the system allows the rotating system to gradually coast down. Full gas flow is maintained for the first 20 seconds after scram and then the flow is decreased to about 1% in 3 minutes. At the time of scram, both pre-cooler fans and moderator cooler fans are stopped. Natural convection cooling occurs in the pre-cooler (at an estimated 18,000 lb/hr air flow) as the principal means of discharging reactor after-heat during the initial 3 minute post-scram period.

Following the 3 minute flow decay of the reactor gas coolant, the moderator system becomes the principal heat sink. The reactor after-heat, although continuing to decay, causes the moderator water to boil with subsequent release of steam through a pressure controlled vent valve. The moderator water surge tank supplies water for cooling for 24 hours.

F. RE-FUELING

Because maximum fuel element lifetime is less than the lifetime of the entire plant, the reactor must be shut down to replace fuel elements. This operation is performed in the field by using special equipment such as an extension for the neutron shield tank (shown schematically in Figure 60), a work platform, a hoist, and remote handling tools. It is assumed that no operations will be performed near the reactor until 24 hours after shutdown.

The field removal of fuel elements consists of the following steps:

1) Disconnect and separate the reactor and power conversion skids.

2) Drain the borated shield water from the shield tank to prevent borated water from entering the gas side of the pressure vessel when the upper plenum cap is removed, and to prevent the crystallization of boric acid from solution as the shield water continues to cool during fuel element changing.

3) Drain moderator water from the reactor core.

4) Connect moderator section to the auxiliary water pump and water tank. Prepare 2 wt% boric acid solution in tank and re-circulate the solution through the moderator section. Filling the remaining moderator volume with borated water prevents a nuclear excursion in case a pressure vessel tube leaks.

5) Block off the gas ducts outside the shield tank with blind flanges.

6) Fill the shield tank with fresh demineralized water.

7) Fill the gas side of the pressure vessel with fresh demineralized water through the fill and drain valve.

8) Remove the tank cover.

FUEL ELEMENT FIELD REPLACEMENT TANK AND STRUCTURE

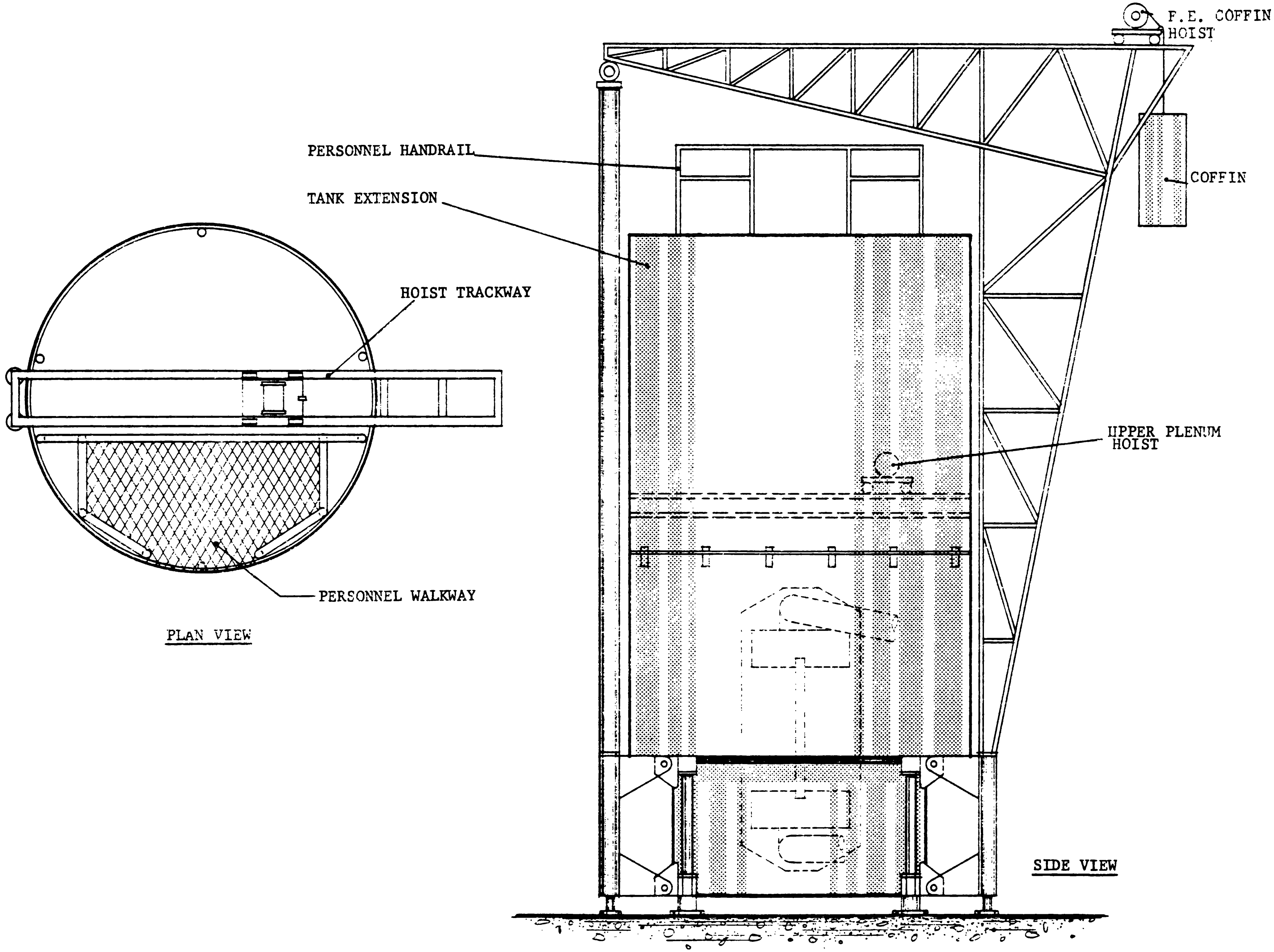


FIGURE 60

9) Install the 10-ft tank extension and the work platform above the reactor tank.

10) Fill the 10-ft tank with fresh demineralized water.

11) Loosen the pressure vessel closure clamp with remote handling tool.

12) Loosen the inlet gas duct coupling with the remote tool.

13) Remove the upper plenum cap with submerged hoist.

14) Remove the fuel element in the following steps:

a. Lower transfer coffin into extension tank.

b. Remove upper and lower caps of transfer coffin.

c. Load three fuel elements into coffin using remote handling tools.

d. Replace upper and lower caps.

e. Withdraw coffin from extension tank and load into transporter.

15) Repeat this procedure with additional transfer coffins until the entire core has been removed.

The installation of new elements is performed above water to shield personnel from activated reactor structural components. The transfer coffin is not required for this operation.

G. MAINTENANCE

The ML-1 plant has been designed for 10,000 hours operation between fuel changes and for a 50,000 hour overall plant life. The gas loop is essentially all welded except for the joints that must be broken to separate the skids or to remove major components. With the conservative operating conditions employed, major component failures are not anticipated. Spare parts will be provided for smaller components such as valves, relays, switches, instruments, etc.

Preventive maintenance will consist mostly of changing lubricating oil, lubricating oil filter cartridges, gas filter elements, demineralizer resin, etc. Prototype operation will determine the required frequency for replacement of parts and normal servicing.

Performance records of individual components will be kept. From these records it should be possible to predict the maintenance required for future plants.

H. INSTRUCTION MANUALS

The instruction manuals to be written for the ML-1 will consist of the material needed to check out, operate and completely evaluate the over-all power plant and associated equipment. The specific documents are described below. These instruction or operating manuals will be written for the prototype power plant at NRTS and will not necessarily indicate the manuals applicable for field use.

1. ML-1 Facility Manual

This manual will describe the ML-1 facility and the installed utilities and equipment. It will include instructions for operating the equipment, including fire control and evaluation procedures, radiological health and safety procedures, and protection and accountability during normal operation as well as during postulated emergency conditions.

2. ML-1 Power Plant Operating Manuals

These manuals will provide sufficient information to check out and operate the ML-1 power plant. The power plant will be described in detail, using system drawings and schematics. The ML-1 operating manual will be divided into three basic sections:

1) Reactor

2) Power Conversion Equipment

3) Auxiliary Systems

The documents will contain a system description, checkout and calibration procedures, standard operating procedures, operating limitations, and maintenance requirements.

3. ML-1 Test Program and Procedures

In addition to the above instructions, it will be necessary to establish certain tests with specific procedures outside the scope of standard power plant operation. These tests are necessary to evaluate the design of individual components as well as to evaluate the power plant as a whole. These procedures are the only ones required in addition, or in place of, the standard procedures.

The general categories included are:

1) Initial proof and functional tests of the system;

2) Initial criticality, control blade calibration, and reactivity coefficient measurements;

3) Power calibration with catcher foils and nuclear instruments;

4) Miscellaneous performance tests of auxiliary systems;

5) Radiation shielding test measurements (operating and shutdown);

6) Special turbo-machinery startup and shutdown tests including self-run;

7) Thermodynamic power calibration and performance evaluation including heat exchanger performance measurements;

8) Automatic control system tests;

9) Endurance tests; and,

10) Handling and logistic tests.

This document will cover each test in detail and will specify the data to be collected from each test.

I. HEALTH HAZARDS CONTROL

The radiological safety of ML-1 operating personnel and persons in the surrounding area has been assured by careful design, strict fabrication practices, and thorough radiological procedures. Operation at NRTS will prove the adequacy of the radiological safety provisions and waste disposal techniques, and will point out any simplification or modification needed for field operation. The operating manuals for ML-1 will cover the following procedures:

1) Personnel control, protection, and accountability for maintenance in a radiation field;

2) Personnel control and accountability before reactor startup;

3) Operational area surveys for direct radiation and airborne activity and daily log;

4) Area and power plant shutdown dose surveys and daily log;

5) Individual operating personnel radiation exposure log;

6) Plant effluent activity log;

7) Decontamination procedures for equipment and personnel;

8) Emergency procedure after a major power plant failure or accident;

9) Radioactive waste control and disposal procedures;

10) Clean and hot fuel control, handling and accountability procedures; and,

11) Fuel loading and unloading procedures, using field replacement equipment and techniques.

The radiation hazards associated with operating the ML-1 in the field appear to be reasonably low. Shielding calculations indicate an operational dose of approximately 30 mr/hr will exist 500 feet from the power plant when the reactor is being operated at full power. Self-shielding of the power plant by the power conversion equipment is expected to attenuate the operational dose by a factor between two and ten. The amount of expedient shielding required can only be determined after operating the ML-1 at NRTS.

Shutdown dose levels in the preferential shielded direction with the shield tank drained are expected to be 30 mr/hr 25 feet from the reactor after one year operation. Doses are approximately 10 times higher in the opposite direction. The power conversion equipment is expected to provide additional shielding by a factor of at least two, bringing the dose below the acceptable level of 15 mr/hr. With shield water present, the dose level will be about 1 mr/hr in the preferential direction. These shutdown radiation levels are for the system without fission products release through defective fuel element cladding. During normal operation, neutron activation of the gas coolant and its impurities will produce certain radioisotopes. The principal radioisotopes are argon-41 and carbon-14. Approximately 1 curie of carbon-14 will be produced per year but this isotope does not constitute an external radiation hazard since it is only a beta emitter. Personnel disconnecting parts of the coolant system will wear fresh air masks to prevent inhalation of the carbon-14 and other isotopes. The argon-41 isotope is a gamma emitter but will be produced in such a small quantity (less than 0.1 curie per year) that it will have little effect on plant radiation levels.

Precautions will be taken to prevent fission product contamination of the gas loop. Cleaning procedures will control outer surface contamination of the fuel cladding material by uranium dioxide. In addition, the pin tubing and pin welds will undergo intensive inspection for pinhole leaks. However, in-service leaks must be anticipated and calculations, using experimental diffusion data, have shown that release of fission product gases from UO_2 pellets at typical ML-1 operating temperatures is not excessive. (See Page 32 et. seq.)

Leakage into the plant of the loop gas does not appear to present significant radiological problems. All but two piping connections are located on the power conversion equipment skid so that the major leakage is expected to be sucked up into the pre-cooler fans, diluted with the pre-cooler air mass, and dispersed to the atmosphere. If gross leakage did occur at the two main piping connecttions between the reactor and power conversion packages, under the most unfavorable weather conditions the resultant gaseous fission product activity concentration in the air at the cab would be 0.2 μc/cc/sec, assuming complete release of all the fission products from a leaky pin into the atmosphere. This number is under the recommended maximum permissible values of 10 μc/cc/sec for emergency conditions[(2)] by a factor of 50.

The ML-1 plant is equipped with radiation detectors located at strategic locations on the power conversion skid. During operation, these detectors will indicate an increase in background radiation due to fission product release in the reactor coolant system. Experience gained in operating ML-1 at NRTS will indicate what percentage increase in radiation dictates plant shutdown. Removal of gaseous fission products can be effected by slowly releasing the gas coolant to the pre-cooler fan inlet and allowing the pre-cooler air mass to disperse the radioactivity. This is the desired disposal technique and will be done at the discretion of the plant supervisor. The ML-1 plant will contain a waste gas storage system. One evacuation cycle into this system, or to atmosphere, will reduce gaseous activity by a factor of about 900. The dispersion characteristics of the ML-1 pre-cooler fan effluent will be checked under various atmospheric conditions by using a smoke generator or similar device.

Approach to the ML-1 plant immediately after shutdown will be directed by the plant supervisor. The local radiation detectors (RAM System) will display the progress of radioactive decay. The system will be evacuated as required (to storage or to the atmosphere) before personnel approach the plant. All disconnects of the plant piping circuits will be made by personnel wearing air masks. Radiation surveys will be made before making any disconnects to determine the allowable maintenance time. During any plant maintenance, protective overalls, shoecovers, gloves and air masks will be worn by the personnel working on the equipment. Surveys will be made of all personnel after the maintenance procedure. Standard operating procedures for ML-1 operation will guide the plant supervisor.

The pre-cooler air will be monitored during operation at NRTS to determine the level of gaseous and particulate radioactivity escaping into the environment. In addition, periodic area surveys will be made by personnel using fast neutron and beta-gamma emitters

[(2)] A/conf. 15/p/430 "Exposure Criteria for Estimating the Consequences of a Catastrophe in a Nuclear Plant."

to augment the information supplied by the pre-cooler monitor. Activation of impurities in the neutron shield and moderator water will be minimized by using only demineralized water. Calculations indicate that the neutron shield water can be dumped without treatment. Moderator water is expected to be over maximum permissible concentrations by a factor of 1000 from sodium-24 production. This concentration requires storage and/or dilution before ground disposal. Concentrations of corrosion products from stainless steel and aluminum appear to fall below tolerances but can only be determined by NRTS experience. Water samples will be taken at NRTS to analyze the radioisotopes produced as a function of time. This information will influence disposal techniques ultimately used in the field.

J. FACILITY

The ML-1 facility is located about one-half mile north of the GCRE-I facility at the National Reactor Testing Station. The facility consists of the minimum accommodations necessary to provide shelter for operating personnel, support equipment and analysis instrumentation. The facility (Figure 61) consists of three main buildings: A test building, about 40- by 63-ft; a change room, about 26- by 55-ft, near the test building; and an auxiliary control building, about 18- by 50-ft, located about 500-ft south of the test building.

The test building primarily is provided for shelter from the weather during the initial development and evaluation tests of the power plant. It also will act as a "warm shop" to accommodate component maintenance on the power plant. A concrete pad is immediately in front of the test building to provide an approach to the test cell and to act as an outdoor platform for certain environmental tests.

The change building provides a means of controlling low level contamination inside the test building. Access of personnel to the test building will be through the change building. It will house lockers, benches and health physics equipment. Counting equipment in this building will be used to check personnel for contamination.

The auxiliary control building houses the analysis instruments used for the initial evaluation of the power plant systems and components. It will also provide space for office equipment sufficient for data and performance analysis. The control cab will be adjacent to the auxiliary control building to provide direct communication between the power plant operator and the observers monitoring the analysis instrumentation and performing initial analysis of data.

It is assumed that the AREA and GCRE-I facilities will be available to aid in maintaining the ML-1 power plant. The ANP hot shop capability, if required, will also be available to support the ML-1 power plant operations.

SITE PLAN FOR THE ML-1 FACILITY

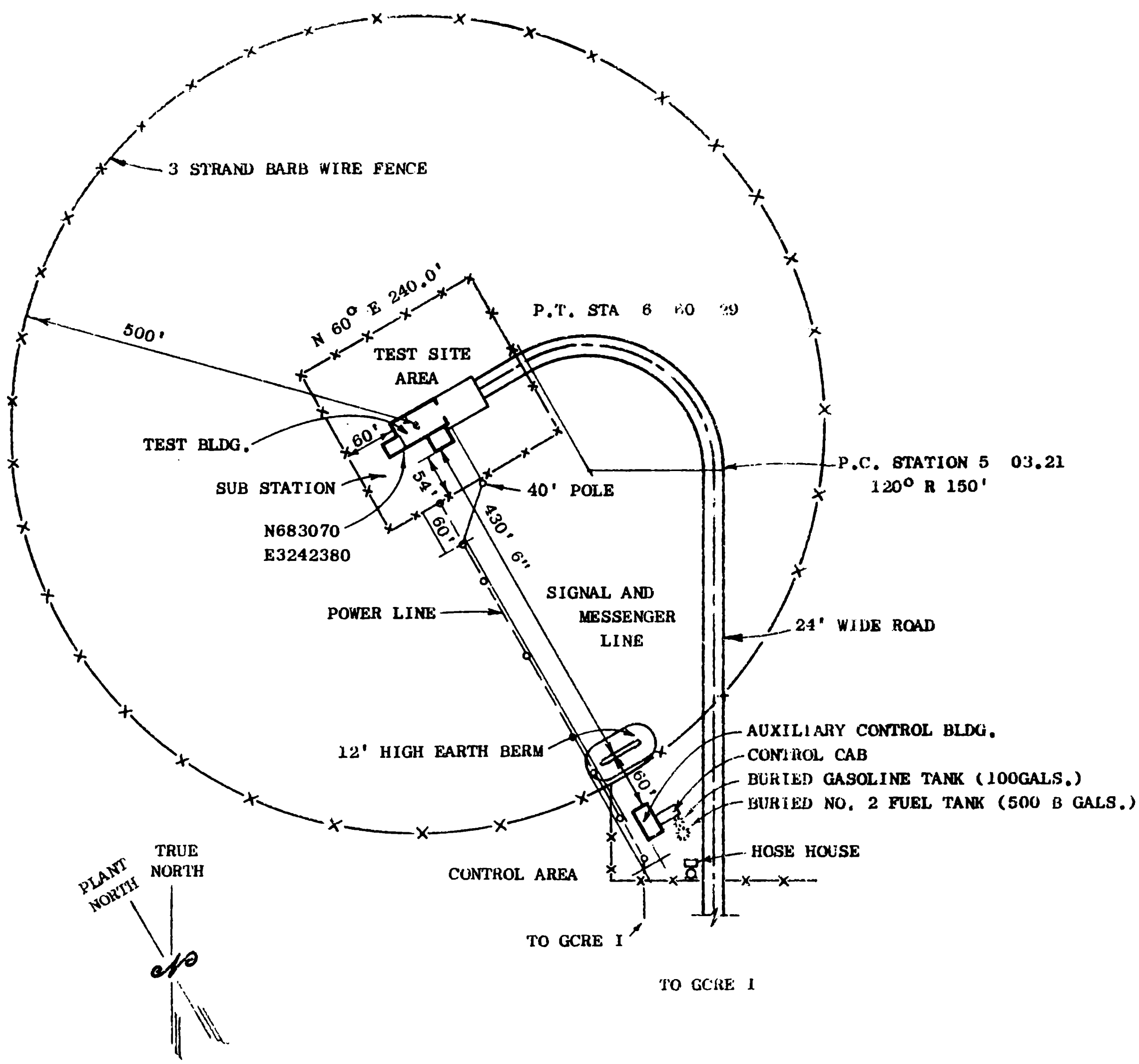


Figure 61

APPENDIX A - MILITARY CHARACTERISTICS

APPENDIX A

MILITARY CHARACTERISTICS

MOBILE NUCLEAR POWER PLANT, ML-1

November 30, 1959

I. Title: Mobile Nuclear Power Plant, 300-500 KW, ML-1

II. Security Classification:

A. Existence of Project: Unclassified

B. Military Characteristics: Unclassified

C. Reactor Design and Performance: Unclassified

III. Proposed Use: There are requirements within the military services for general purpose portable nuclear power plants with electric power outputs in the range from 300 to 500 KW. The ML-1 is the prototype of field units which will be procured to meet these requirements. Examples of military operations requiring a power source without dependence on continuous fuel or cooling water supply are: support of tactical missile systems, air head operations including field hospitals, remote locations, etc.

IV. Environmental Characteristics: The plant shall have the inherent capability for acceptable performance under the Basic Operating Conditions, Extreme Cold Weather Operating Conditions, and Extreme Hot Weather Operating Conditions as established in paragraphs 7a, 7b, and 7c of AR 705-15; and shall be capable of safe storage and transportation under conditions as established in paragraph 7d of AR 705-15.

V. Power Characteristics:

A. Nominal Output at "Design Conditions" (Ambient temperature -65°F to 100°F)

(1) Electrical power output in the range of 300-500 KW, .8 Power Factor

(2) 2400/4160 volts, 3 phase, 60 cycles per second

B. Output at "Off Design Conditions"

(1) Net output of the system in the event of hot weather (> 100°F or high altitude operation) shall be limited only by precooler performance and/or moderator coolant heat exchanger performance.

(2) Operation shall be possible up to 500 KW net output except as limited by precooler performance.

C. Power Quality

(1) Objective: Steady state and transient frequency and voltage control characteristics as specified by MIL-G-14609 (CE).

(2) Minimum requirement: Steady state and transient frequency and voltage control characteristics as specified by MIL G-10328A (CE).

D. Other Requirements:

(1) Automatic power level control is required.

(2) The power plant shall operate satisfactorily in parallel with other units of similar rating.

(3) The power plant shall be capable of 50 cycle operation.

(4) The power plant shall be treated for the elimination of interference with radio communication in accordance with applicable Signal Corps specifications.

VI. Field Operating Characteristics:

A. The plant shall be assembled on a standard military semi-trailer (M-172 or M-172A1) and all preparations completed for relocation to an operating site within six (6) hours after unloading from any aircraft.

B. The plant shall be capable of being installed and delivering rated power within twelve (12) hours after arrival at an operating site.

C. The plant shall be capable of relocation to a new site beginning twenty-four (24) hours after reactor shut down following operation for extended periods at full power

D. Nuclear Radiation allowed:

(1) Allowable radiation, twenty-four (24) hours after shutdown at twenty-five (25) ft from the reactor in the direction of the cab (without water shield), is fifteen (15) mr/hr

(2) No personnel shall receive greater than 3 rem/quarter.

E. Equipment may be operated in any plane within five degrees (5^{o}) from level

F Control of the power plant will be from a separate shelter which shall be transportable as a unit on a standard 2½ ton truck (M-35) which, during plant operation, shall be connected to the power plant by quick disconnect electrical cables of sufficient length (up to 500 ft) to permit flexibility in the relative locations of the power plant and control shelter.

G Plant design shall include necessary safety features for protection of personnel in the immediate area from results of reasonably conceivable mechanical, electrical, or nuclear malfunctions

H. During plant operation, radiation shielding integral to the plant may be supplemented by field expedient materials (earth, gravel, wood, water) sufficient to reduce radiation levels outside the combined shield to within dosage levels prescribed by the Surgeon General, D/A. The integral plant shield (excluding supplemental expedient shielding) shall be adequate to reduce the residual radiation level following full power operation for extended periods to safe levels in time to permit relocation twenty-four (24) hours after reactor shutdown

I. The operating crew for three-shift operation of the field unit shall consist of no more than seven (7) men (one operator per shift plus mechanic-electrician, radiological safety technician and officer or NCO in charge). The crew will be specially trained for operation, maintenance, and plant installation at the site

VII. Transportability Characteristics:

A. Objective: Capability of being transported overland (highway and cross-country), by rail, by water, and by aircraft in accordance with AR 705-8, Transportability

B. Requirements: The ML-1 plant shall be consistent with the following transportation requirements:

(1) General: The "power plant unit" is defined for transportability as the complete integral power plant including reactor, shutdown shielding, power conversion equipment and skid mounting. Control unit, auxiliary power unit, auxiliary equipment package and trailer are not included in this definition. Required modes of transport are indicated below.

(2) Primary mode of transportation:

(a) The primary mode of transport of the power plant unit shall be overland on standard military semi-trailer. Power plant unit integrity is required.

(b) The control unit shall be one package which can be transported intact and which is suitable for both operation and transport on a standard military 2½ ton truck.

(3) Secondary modes of transportation: (power plant unit integrity required).

(a) Secondary modes of transport for the power plant unit where unit integrity is required include:

1. Normal railway freight service U.S. and foreign.

2. Water freight by ship or barge.

(b) In addition, when necessary and where satisfactory clearances can be arranged, the power plant unit shall be transportable trailer-mounted on the above transit types.

(c) Similarly, when truck-mounted, the truck and control unit shall be transportable as one package when necessary and where satisfactory clearances can be arranged for the above transit types.

(4) Secondary modes of transportation: (power plant unit integrity not required).

(a) The power plant unit may be separated into two packages for transport by:

1. USAF C-130.

2. USAF C-124C.

3. Sled.

(b) Trailer mounting is not required for (a) above.

(c) The control unit shall be transportable intact. Truck mounting is not required for (a) above.

(d) The complete power plant including the control unit and auxiliary equipment shall be transportable in one USAF C-133.

(5) Other Requirements:

(a) The power plant shall be transportable in Phase III of airborne operations.

(b) Design for air transport shall conform to requirements of USAF Specification MIL A-8421A for transportation of material in military cargo aircraft.

(c) Provisions shall be made to permit rapid loading and unloading of each unit by standard weight handling techniques.

(d) Shock and vibration protection shall be provided integral with the plant consistent with each transport type as indicated below:

1. Shock loading in transit by rail, semi-trailer, or ship without loss of serviceability:

Direction	Load Factor, g	Duration of versed sine pulse, sec.
Fore & Aft	15	.030
Lateral	2	.030
Vertical	4	.030

The maximum shock load transmitted to components in either direction will be reduced to 8g, fore and aft, by shock mounts provided on the skid.

2. Emergency landing shock loads during transit by air, with questionable plant serviceability:

Horizontal	--	8g for .1 sec.
Vertical	--	4.5g for .1 sec.
Lateral	--	1.5g for .1 sec.

3. Emergency landing shock loads during transit by air, without loss of plant serviceability:

Horizontal	--	5g for .1 sec.
Vertical	--	4.5g for .1 sec.
Lateral	--	1.5g for .1 sec.

4. Steady vibrations in transit, without loss of serviceability:

Source	Peak Amplitude, Inches	Frequency, cps
Railroad Flatcar	.12	20-30
Semi-trailer	.05	> 20
Ship	.05	15-20
Aircraft	.05	> 20

(e) Weight:

1. Heaviest package for air transport is 15T.

2. Trailer load (M-172 or M-172A1) is 30T.

3. Control Shelter is 2.5T.

(f) Size:

1. Largest package shall be transportable on C-124, C-130, and C-133 aircraft; and on railroad with limits as prescribed by the Berne International Clearance Diagrams.

2. Reactor and power conversion skids shall be transportable as a unit on the M-172 or M-172A1 semi-trailer.

3. Maximum height when trailer-mounted is 150 inches. Power plant height when trailer-mounted may be reduced to 132 inches for the purpose of passing low clearance obstacles outside CONUS.

4. Length and width shall be compatible with a standard military semi-trailer (M-172 to M-172A1).

(g) When trailer-mounted and in transit, the plant shall have the capability of shallow fording in fresh or salt water, as defined in SR 705-125-10. Extreme caution must be taken to avoid a nuclear accident due to core flooding.

VIII. Logistical Characteristics:

A. The plant shall operate with no more than periodic field maintenance service for 10,000 hr between major overhaul.

B. The plant shall have 50,000 hr total life.

C. The plant shall be capable of full power operation for 10,000 hours between refueling operations. Refueling may be accomplished in the field.

D. The plant shall be capable of operation without a continuous water supply. Any initial quantity of water (for shielding or reactor moderator) will be kept to a minimum and of a quality which can be supplied by standard military purification equipment capable of delivering 600 GPH.

E. Radioactive waste from the plant will be kept to a minimum. Disposal of radioactive waste will be in accordance with field procedures approved by the Chief Chemical Officer. (NOTE: Disposal will be subject to AEC approved procedures at NRTS).

F. The plant will be completely self-sufficient to permit steady state operation without the need for auxiliary equipment. For startup and shutdown operations, the plant should require no more than a 45 KW diesel generator and necessary construction equipment for erection of the supplemental expedient shield. Equipment for expedient shield construction shall not be part of overall plant equipment.

G. The power plant shall be equipped with all special purpose tools required for normal maintenance and startup, but not for refueling. Special equipment and procedures required for field refueling shall be specified. The plant shall be equipped with complete operating manuals (AR 310-3) defining detailed operating, maintenance, installation, and relocation procedures.