

APPENDIX B

ML-1 PLANT CHARACTERISTICS

1. GENERAL

Design performance at 100°F

Gross electrical output	420 kw
Net electrical output	350 kw
Reactor thermal power	2.98 Mw to gas; 3.41 Mw total
Cycle efficiency $\left(\frac{\text{Thermal output}}{\text{Power to gas}}\right)$	17.2%
Plant thermal efficiency $\left(\frac{\text{Gross elect. pwr}}{\text{Total reactor pwr}}\right)$	13.2%
Net plant efficiency $\left(\frac{\text{Net elect. output}}{\text{Total reactor pwr}}\right)$	10.3%
Coolant flow (compressor inlet)	92,500
Dose rate at control cab @ 500-ft during full power operation	5 mr/hr (with expedient shielding as needed)
Dose rate at 25 ft, 24 hr after shutdown (direction of transport vehicle driver with P/C skid in place)	15 mr/hr
Overall plant dimensions	279 x 113 x 93 in. high
Overall plant weight and dimensions	Weight Dimensions (in.)
Reactor package	30,000 lb 111 x 110 x 93 high (plus ion exchange column on end)
Power conversion package	30,000 lb 168 x 113 x 93 high
Control cab	6,500 lb 145 x 82 x 81 high
Auxiliary equipment	15,000 lb - - - - -

Operating supplies (startup and 90 day operation):

Demineralized water	2900 gal
Nitrogen (with 0.5 vol% oxygen)	2400 scf
Oxygen	200 scf
Anhydrous boric acid (B_2O_3)	1200 lb
Mixed bed ion exchange resin	900 lb max.
Lubricating oil	60 gal
Filter elements	7
Plant startup time	12 hr
Auxiliary power requirements	
Pre-startup	30 kw max.
Normal startup	75 kw max.
Normal shutdown	45 kw max., 3 kw ave
Emergency shutdown	None
Reactor drying	36 kw max.

2. REACTOR THERMAL CHARACTERISTICS

Power density	700 kw/ft ²
Maximum heat flux	140,000 Btu/hr/ft ²
Average heat flux	78,200 Btu/hr/ft ²
Maximum to average heat flux ratio	
Axial	1.41
Radial	1.27
Maximum fuel center temperature (including hot spot factors)	2160 ^o F (BeO-UO ₂) 2650 ^o F (UO ₂) ²
Maximum moderator temperature	190 ^o F
Maximum surface temperature of fuel cladding (nominal, average)	1500 ^o F
Maximum surface temperature of fuel cladding (including hot spot factors), reference	1650 ^o F

3. REACTOR NUCLEAR CHARACTERISTICS

Average thermal neutron flux (fuel)	1.9×10^{12} neut/cm ² -sec
Average fast neutron flux (fuel)	1.7×10^{13} neut/cm ² -sec
Maximum to average thermal flux ratio	3.9
Hydrogen to U-235 atom ratio	40

Core buckling*	0.0047 cm ⁻²
Fermi age	60 cm ²
Square of thermal diffusion length, L ²	2.05 cm ²
Thermal utilization, f*	0.66
Infinite multiplication factor, k	
Without shims	1.54
With shims*	1.36
Neutron lifetime	1.9 x 10 ⁻⁵ sec
k _{eff} , cold, clean core; no shims or burnable poison	1.067
Operating k _{eff} , cold, clean core, with shims and burnable poison	1.018
Core life, full power	3000 hr min; 10,000 hr design
Burnup (U-235), average	3.5% in 10,000 hr
Maximum	6.5%
Prompt temperature coefficient, ΔK/K-°C	
at 0°C	+ 0.3 x 10 ⁻⁶
at 90°C	-0.5 x 10 ⁻⁶

4. REACTOR VESSEL

Materials

Tube sheet	Stainless Steel, Type 304, 2.94 in. thick
Pressure tubes	Stainless Steel, Type 321
Source tube	Stainless Steel, Type 321
Gas ducts, plenums	Stainless Steels, Types 304-L, 321 and 347
Baffle	Stainless Steel, Type 321; Tungsten; and Inconel X (springs)
Outside diameter	30.960 in. max. (exclusive of upper flanged connection)
Overall height	79.5 in.
Pressure tube length	24 in. between inside surfaces of tube sheets
Design pressure	345 psia (gas)
Design temperature	525°F (max.)

*Indicates item revised from previous tabulation.

Wall thicknesses	Tubes 0.020 in.; plenum 2.12 in. min
Source tube	0.020 in. wall thickness; 6.500 in. OD

5. REFLECTOR

Composition, top	2 in. H ₂ O; 4.5-5.0 in. stainless steel; 1.5 in. W
bottom	3-4 in. stainless steel; 3 in. W
radial	1.8 in. Pb; 2 in. W; 180° segment 4 in. Pb; 180° segment
Total heat generation	6 × 10 ⁵ Btu/hr
Maximum power density	360 Btu/hr-in. ³

6. BIOLOGICAL SHIELDING

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

Diameter*	21.54 in. equivalent
Height	22 in.
Number of fuel elements	61
Number of coolant passages	61
Number of coolant passes	1
Type of geometry of fuel elements	Cluster of 19 pins (18 fueled)
Cold, clean critical mass, U-235 no shims, no burnable poison	37 kg
U-235 loading	49 kg
Enrichment, inner 6 pins	93% U-235 as UO ₂
Outer 12 pins	31 vol% UO ₂ , 93% enriched U-235, 69 vol% BeO
Core composition	
Materials	<u>Volume %</u>
UO ₂	4.3
BeO	3.3
Stainless steel	3.6

*Indicates item revised from previous tabulation.

Materials (continued)	<u>Volume %</u>
Hastelloy X	7.0
H ₂ O	58.6
Insulation	7.0
Gas void	<u>16.2</u>
Total	100.0

8. FUEL ELEMENT

Dimensions	1.72 in. OD x 32 in.
Fuel material	BeO-UO ₂ (outer pins); UO ₂ (inner pins)
Number of pins per element*	19 (12 with 70 wt% UO ₂ in BeO; 6 with 100 wt% UO ₂ ; 1 empty)
Pin outside diameter	0.241 in.
Pin cladding material	Hastelloy X
Pin cladding wall thickness	0.030 in.
Pin spacer	0.040 in. OD Hastelloy wire
Heat transfer material (pin internal)	He
Pellet diameter	0.176 in. (nominal)
Type burnable poison	Cadmium
Reactivity worth of burnable poison	0.5% at startup

9. CONTROL ELEMENTS

Type	Tapered blades
Location	Moderator
Number: Shim blades	3 pairs (3 actuators)
Safety blades	2 pairs (2 actuators)
Regulating blades	1 pair (1 actuator)
Absorber material: Safety and shim blades	5 wt% Cadmium- 15 wt% Indium- 80 wt% Silver
Dimensions (each blade)	4 x 9 x 0.25 to 0.62 in.
Regulating blades	stainless steel
Dimensions (each blade)	4 x 9 x 0.25 to 0.62 in.
Cladding material	None

*Indicates item revised from previous tabulation.

Reactivity worth of control elements:

Safety and shim rods (each)*	1.58% $\Delta K/K$
Regulating rods*	0.45% $\Delta K/K$
Total (6 rods)*	7.4% $\Delta K/K$

Actuating time for regulating blade:

Drive	13.3 sec for full insertion or withdrawal
Scram	0.35 sec (max) for full insertion from signal

Safety and shim actuator:

Drive	4.0 min for full insertion or withdrawal
Scram	0.35 sec (max) for full insertion from scram signal

10. MODERATOR

Type	Water
Reactor inlet temperature	180 ^o F
Reactor outlet temperature	190 ^o F
Pressure	30 psi max.
Flow rate	300 gpm
Type of flow circulation	Forced
Purity:	
Total solids	1 ppm
Resistivity	10 ⁵ x 10 ⁶ Btu/hr

11. REACTOR WORKING FLUID FLOW

Working fluid	99.5 vol% N ₂ + 0.5 vol% O ₂
Reactor inlet temperature	800 ^o F nominal
Reactor mixed mean outlet temperature	1200 ^o 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

*Indicates item revised from previous tabulation.

12. POWER CYCLE

Type	Brayton cycle with regeneration
Total volume of working fluid system	120 ft ³
Total system working fluid inventory full load at 100°F	52 lb
Working fluid transit time	2.0 sec
Cycle characteristics (100°F ambient temp.)	
Net power, kw	350
Reactor inlet, °F	781
Turbine inlet, °F	1193
Compressor inlet, °F	133
Compressor inlet, psia	116
Compressor outlet, psia	321
Reactor inlet, psia	314

13. TURBINE-COMPRESSOR SET

	<u>Stratos T-C Set</u>	<u>Clark T-C Set</u>
Speed, rpm	18,338	22,000
Turbine stages	2	2
Turbine rotor material	Incoloy 901	A-286 (first stage) AISI 422 (second stage)
Turbine blade material	Inco 713	M-252
Turbine stator blade material	Inconel	N 155 or 19-9 DL
Expansion ratio	2.38	2.42
Compressor stages	2	11
Compressor material	AL 355 T71	403 stainless steel
Rotor shaft	SAE 4340	SAE 4340
Compressor ratio	2.72	2.765
Case material	304 stainless steel	304 stainless steel
Seals		
at journals	Buffered labyrinth	Buffered labyrinth
Interstage	Plain labyrinth	Plain labyrinth
Shaft	Buffered labyrinth	Double "L" ring seal oil buffered
Bearings		
Journal	Tilting pad	Plain babbitt

	<u>Stratos T-C Set</u>	<u>Clark T-C Set</u>
Thrust	Kingsbury type	Kingsbury type (in low pressure area)
Support	Overhung turbine	Turbine and compressor supported between bearings

14. ALTERNATOR

Output	
Rating	750 KVA 3 ϕ , 60 cycle
Voltage	2400/1600 V
Rotor shaft speed	1800
Diameter, maximum	36 in.
Length	54 in.
Weight	5000 lb

15. RECUPERATOR

Length (including insulation)	81 in.
Outside diameter (including insulation)	49.25 in.
Headers	
High pressure inlet	8 in.
High pressure outlet	8 in.
Low pressure inlet	20 in.
Low pressure outlet	14 in.
Effectiveness	78.4
Pressure loss	
High pressure $\Delta P/P$	2.1%
Low pressure $\Delta P/P$	1.25%
Type	Shell and tube regenerator
Tubes	4 passes X 840 tubes
Shell	1 pass
Surface	External fins
Materials	300 series stainless steel

16. PRECOOLER, MODERATOR COOLER AND OIL COOLER ASSEMBLY

Dimensions:	
Length, overall	166 15/16 in.
Precooler	122 5/16 in.

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Moderator cooler	32 1/8 in.
Oil cooler	11 5/16 in.
Width	113 in.
Thickness, overall	32 in.
Core	15 in.
Fans and plenums	17 in.
Material	
Tubes and fins	Series 1100 aluminum
Headers	Series 2219 aluminum
Weight	6500 lb
Precooler:	
Header, inlet	One, 14 in.
Header, outlet	One, 10 in.
Effectiveness	92.2%
Total $\Delta P/P$	1.69%
Air flow	247,500 lb/hr
Type	Fin fan air-to-gas exchanger
Tubes	1105 tubes, single pass
Surface	Internal and external fins
Moderator cooler:	
Headers, inlet and outlet	4 in.
Total ΔP	2.77 psi
Water temperature	
In	190 ^o F
Out	180 ^o F
Air flow	73,250 lb/hr
Type	Fin fan air-to-water exchanger
Tubes	88 tubes per pass, three passes
Surface	External fins
Oil cooler:	
Connections, inlet and outlet	1 1/2 in.
Total ΔP	9.38 psi
Oil temperature	
In	180 ^o F
Out	150 ^o F

Oil flow	18,900 lb/hr
Air flow	27,500 lb/hr
Type	Fin fan air-to-oil exchanger
Tubes	45 tubes, 2 passes
Surface	Internal and external fins