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APOLLO LOGISTICS SUPPORT SYSTEMS MOLAB STUDIES

TASK ORDER N-34

POWER SYSTEM CONCEPTUAL DESIGN

Prepared under Contract No. NAS8-11096 by

W. L. Breazeale and C. O. DeLong

NORTHROP SPACE LABORATORIES
Space Systems Section
6025 Technology Drive
Huntsville, Alabama

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NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

October 1964

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Advanced Studies Office
Astrionics Laboratory

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NOTICE

APOLLO LOGISTICS SUPPORT SYSTEMS
MOLAB STUDIES

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POWER SYSTEM CONCEPTUAL DESIGN

for a

LUNAR MOBILE LABORATORY

By

W. L. Breazeale
C. O. DeLong

ABSTRACT

10627

A conceptual design of the electric power system is evolved for the Lunar Mobile Laboratory. Functional block diagrams of appropriate subsystems are developed and pertinent design data is presented. Packaging concepts of the electric power system components on the MOLAB VII vehicle are investigated.

PREFACE

This document by Northrop Space Laboratories, Huntsville Department, is a report to Marshall Space Flight Center on work performed under Task Order N-34, Contract Number NAS8-11096.

The NASA Technical Liaison Representative for this Task Order was Mr. E. E. Dungan of Advanced Studies (R-ASTR-A).

A 30-man week effort beginning on July 1 and ending on September 30 was expended on this task.

The information contained in this document represents a conceptual design of the electric power system for a Lunar Mobile Laboratory.

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ABBREVIATIONS AND DEFINITIONS

ABBREVIATIONS

THEMS	Thermal Management Subsystem
RECS	Reactant Control System
RTG	Radio-isotope Thermoelectric Generator
SNAP	Systems for Nuclear Auxiliary Power
VT	Thermostatic Valve
VP	Pressure Operated Ball-Check Valve
VV	Vent Valve
VS	Solenoidal Valve

DEFINITIONS

Gamma	An energetic electro-magnetic wave of nuclear origin.
Alpha Particle	A helium nucleus.
Beta Particle	An electron
Half-Life	Time required for a given number of active nuclei to decay to half its initial value.
Radio-Isotope	Short for radioactive isotope, that is one which undergoes spontaneous decay by the emission of an alpha particle or a beta particle.

SECTION 1.0

SUMMARY

The conceptual design of the electric power system for the MOLAB consists of functional block diagrams for the reactant control subsystem, the thermal management subsystem, power source interfaces with system loads, and packaging arrangements of power system components on the MOLAB-VII vehicle. Pertinent design data is also included.

An analysis is performed on several radio-isotope thermoelectric generators to determine shield weights, isotope weights, and generator weights. Under the conditions investigated, a SNAP-19 type generator fueled with Pu-238 is considered the "best" choice for the auxiliary power source.

SECTION 2.0

INTRODUCTION

This document describes the evolution of the conceptual design of the electric power system for the MOLAB. The design consists of functional block diagrams and design data for the major electric power subsystems. A previous task order report (Reference 1) describes the fuel cells under consideration. A sketch of the fuel cell is shown in Figure 1. Each major subsystem has a section of the report devoted solely to that subsystem.

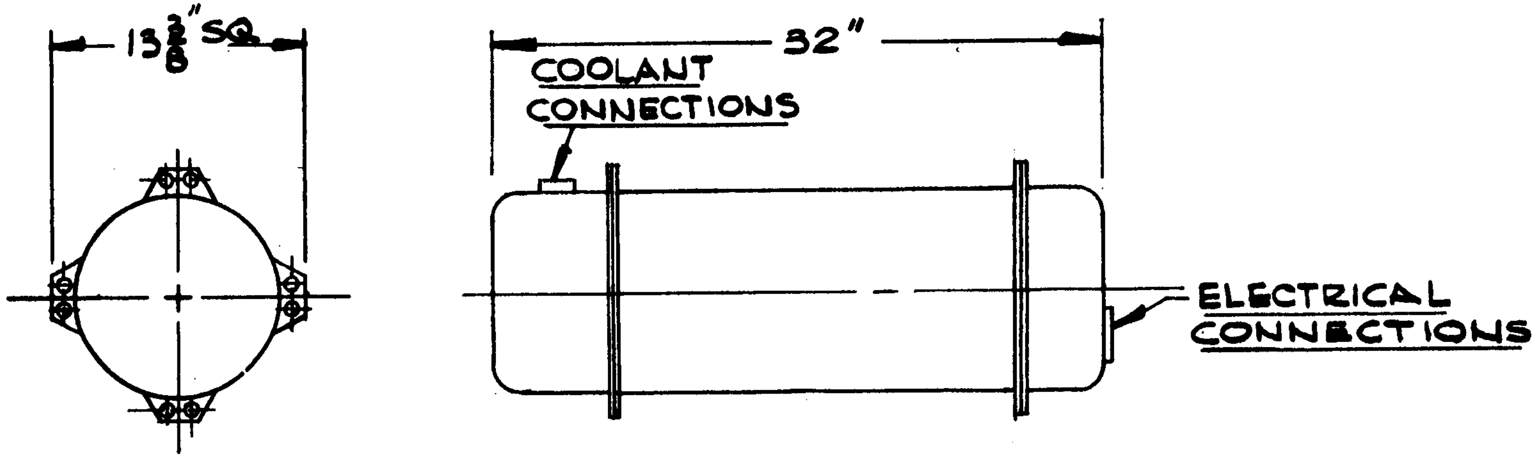

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FIGURE 1. FUEL CELL ASSEMBLY

SECTION 3.0

REACTANT CONTROL SYSTEM (RECS)

3.1 GENERAL

The Reactant Control System (RECS) is a system to control, monitor, and regulate the flow of reactants to the MOLAB fuel cell assemblies. A brief, simplified schematic is present in Figure 2.

The system, as presented, is redundant in all tanks and lines and is a reliable, flexible means of connecting reactant supplies to fuel cell assembly loads.

3.2 DEMAND REGULATOR SYSTEM

During the lunar storage phase the liquid hydrogen and oxygen tank pressures are maintained below a predetermined pressure by vent valves VVI, VV2, VV3, and VV4 as indicated in the referenced schematic. The boiloff rate through these vent valves is determined by the rate of influx of heat into the cryogenic tankage from exterior sources. During the active lunar phase, when electric power is being produced, heat from exterior sources is inadequate to maintain tank pressures at a level to sustain gas flow at the rates required. A simple means of introducing heat electrically is described in reference 2. Indicated heater power requirements are 119 watts average at a 6 KW generation level.

A "bang-bang" servo regulator is indicated in the referenced schematic to maintain line pressure, at regulator inputs, at the required level. The regulator consists of a pressure operated switch (HP), an activation relay (K1), and a heater load in the LH_2 #1 tank section. Each additional tank section contains a similar control system. The ratio of heater "on" to "off" time is determined by the flow demand and the heater dissipation.

Tank separator domes located in both LH_2 and LOX tanks permit thermodynamic feed-through such that failure of either tank section heater servo does not degrade system performance. Although not shown in the schematic, overpressure cutout switches may be provided as backup in case of heating circuit lock-up.

3.3 MEASUREMENTS

Transducers, not shown, are provided to supply electrical signals corresponding to flow rates from each tank section as well as to each fuel cell solenoid valve. An electrical signal corresponding to total LH_2 and LOX flow rate into each fuel cell is provided.

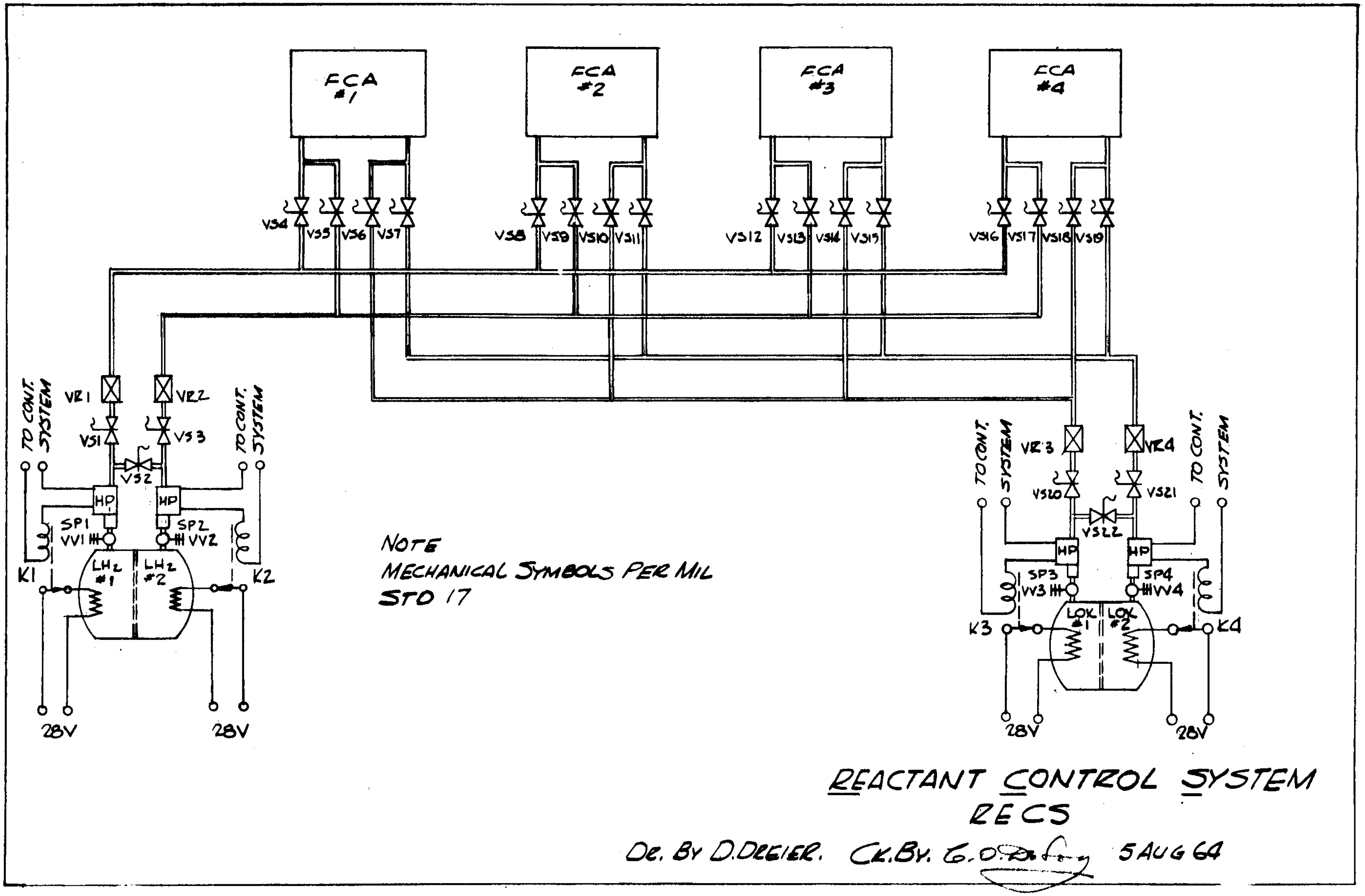


FIGURE 2. REACTANT CONTROL SYSTEM

Tank, regulator, and line pressure signals are available from each of four line sections.

Transducers are provided to supply electrical signals corresponding to remaining reactant in each tank section. Provision is made for monitoring heater current for each tank section.

A signal corresponding to total integrated flow-rate, either from a transducer or from adjacent equipment operating from flow-rate transducers is provided for each fuel cell reactant input.

A signal, which is independent of any voltage that might cause valve actuation, is provided to indicate the position of each valve.

SECTION 4. 0

ELECTRIC POWER SYSTEM THERMAL MANAGEMENT

4. 1 GENERAL

A large by-product fraction of MOLAB Electric Power System energy conversion is thermal. The kilowatt-hour requirement is significant for thermal control of electronic components and associated devices during the long six month dormant phase. Too, requirement exists for fuel cell temperature conditioning prior to utilization. Periodic telemetry, checkout, and locomotion requirements for electric power during dormancy demands readiness capability. Possible freezing or jelling of coolant necessitates heating of coolant lines prior to utilization. Judicious allotment of energy to meet these operational and dormant requirements bears careful consideration.

4. 2 HEAT SOURCES AND PROBLEM AREAS

In the process of generating a particular level of electric power, each fuel cell assembly produces heat as a by-product at a given rate. The rate of heat production depends upon the level of power produced and the operating efficiency associated with the particular power level. Utilization of electric power from this source, for heating, involves a weight penalty. As an illustration, assume a modest 500 watt thermal control requirement for one-half of the 14 day operational sequence. This increase in additional power creates an increase in tankage, reactants, cell capacity and radiator area. The weight penalty incurred is approximately 150 pounds. It is, therefore, easy to see that dependence upon electrical heating, during the operational mission, is undesirable. Heating by this means, for the six months dormant period, is also undesirable since the weight penalty is too excessive. Since an increase in fuel cell operating level decreases cell mean-time-to-failure, system reliability is also impaired.

The Radioisotope Thermoelectric Generator (RTG), as contrasted with fuel cells, produces heat continuously at a rate which decays exponentially with time from date of manufacture. Since the efficiency of conversion of heat to electric power is small, of order less than 10%, the effect of changes in electrical load on the RTG thermal output is second order. The weight penalty associated with utilization of this source of heat is negligible. Availability of heat is excellent in that heat is rejected in the range between 350 and 450°F. The RTG, therefore, becomes a prime candidate for selection of a heat generation source for MOLAB during the dormant and operational phases.

4.3 THERMAL MANAGEMENT SUBSYSTEM (THEMS) - A CONCEPTUAL DESIGN

4.3.1 General

The Thermal Management Subsystem (THEM)(see Figure 3), is synthesized as a means of supplying thermal management and temperature control for the MOLAB Electric Power System. The system, as presented in the referenced schematic, has the following attributes:

(1) Full 8.8 kilowatt electric power is immediately available upon demand and is fully operational at any time during the six month dormant phase or the 14 day operational phase.

(2) All fuel cell assemblies, pumps, piping, valves, radiator, attendant electronic devices, and cabin temperature are automatically kept above a minimum lower temperature as required.

(3) Total system heat requirements are furnished by the RTG units.

(4) A completely redundant system assures high reliability during all mission phases.

(5) Fully automatic system operation relieves the astronauts of manual functions.

4.3.2 System Description

THEMS, as generally described in the referenced schematic, contains four RTG units, each capable of an electrical output of approximately 40 watts and a by-product thermal output of approximately 800 watts. Each RTG is fitted with a fluid heat exchanger which conducts heat directly from the cold junction operating in the range of 350 to 450° F at no heat load. Fluid circulation through this exchanger affords heat transfer, by forced convection, to additional system elements. In the event that circulation fails, heat exchanger temperature approaches no-load values and heat is rejected by radiative

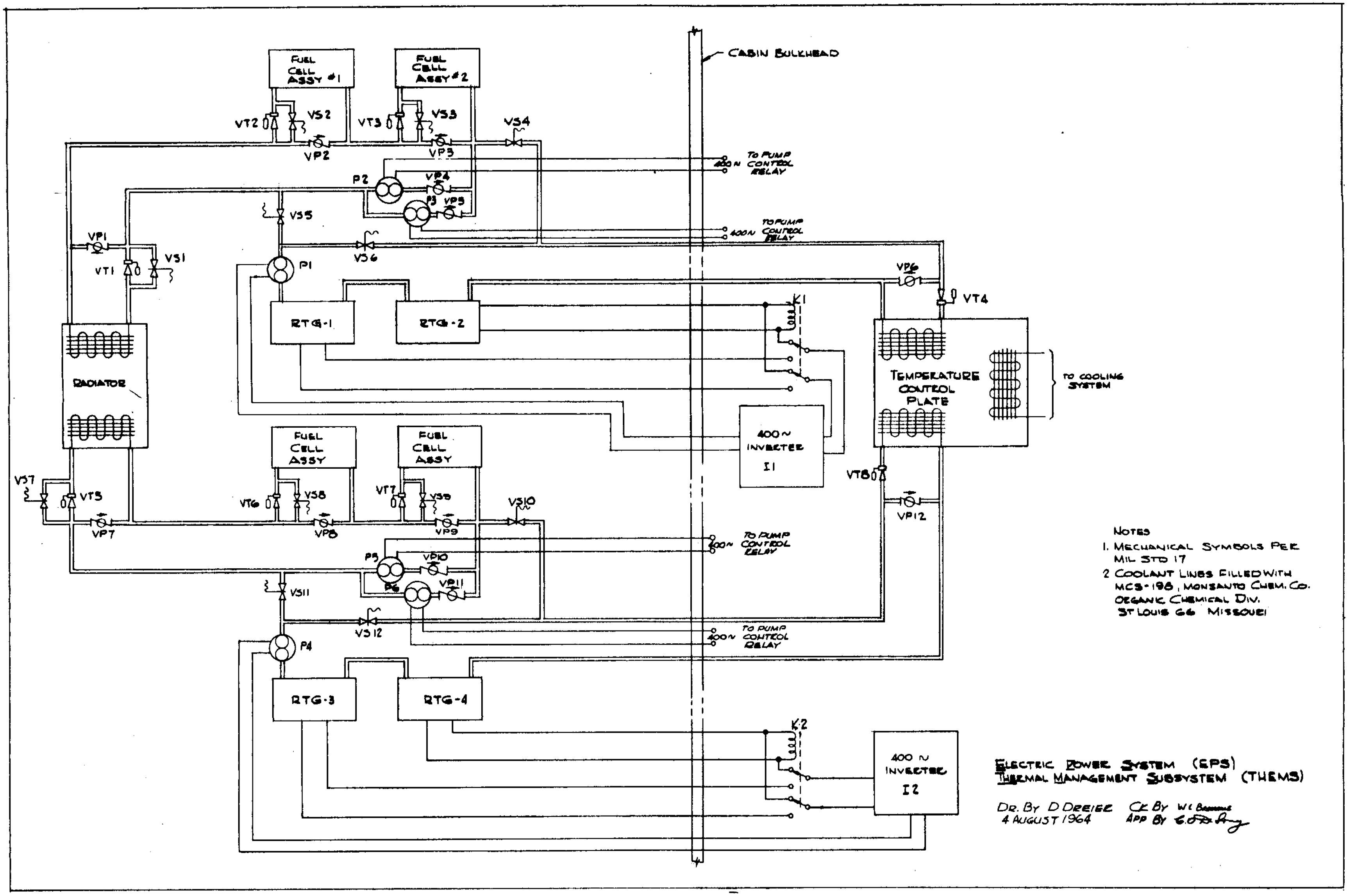


FIGURE 3. ELECTRICAL POWER SYSTEM THERMAL MANAGEMENT SUBSYSTEM

transfer from attached fins.

Pumps, piping, solenoidal and thermostatic valves are provided for the circulation, control, and regulation of the heat transfer fluid. Lines are filled with Monsanto Chemical Company MCS-198, a silicate ester based fluid, which has a pour point of -175°F and a vapor pressure of only 960 mm Hg at 475°F.

4.3.3 System Operation

All symbolism herein contained is related to the previously referenced schematic. Since the system is completely redundant, for ease of explanation only the upper half of the schematic is discussed. During the dormant phase pump P_1 is active, pumps P_2 and P_3 are inactive. Pump P_1 is a completely sealed weldment utilizing an immersed rotor and hydrostatic bearings. The pump is driven by a 400 cycle induction motor with field winding electrically accessible through glass-to-metal seals.

Circulation is out of P_1 into VS5, an open bistable solenoidal valve: VS6 is closed. A thermostatic valve, VT1, controls the flow into the radiator. Solenoidal valve VS1 is closed. Closing of VT1 shuts off vent to the radiator and flow is bypassed by VP1 a pressure operated ball-check valve. Radiator temperature is monitored by VT1 which maintains radiator temperature at a preset value during the night cycle. Fuel cell assemblies No. 1 and No. 2 are temperature controlled, in a similar manner as the radiator, by VT2, VT3, VS2, VS3, VP_2 and VP_3. VS4 is also open and conducting during dormant operation. The finned temperature control plate, whereupon electronic equipment is mounted and cabin air is exchanged, is controlled by VT4 and VP6 in a manner similar to that described for the radiator. During the 14 day active phase VS4 and VS5 are turned off and VS6 is turned on. Pump P_2 is turned on with pump P_3 off as redundant standby. Ball-check valves VP1, VP2 and VP3 are inactive due to reversed circulation. VT1, VT2 and VT3 are bypassed by VS1, VS2 and VS3.

A small solid-state 400 cycle inverter (IT) powers the low power sealed pump (P1). Power for the inverter is conducted through relay K1 from RTG-2. In event of failure of RTG-2 electrical output, K1 automatically switches the inverter to the alternate source (RTG-1).

Attention is drawn to the redundancy of the system. In the event of failure of any of the aforementioned items, a duplicate set is capable of performing the function of cabin heating. Each pair of RTG units provides heat at the maximum level of 1600 watts.

The system, as presented, is tentative and is not intended for design application. The electrical circuits associated with valves, pumps and transducers and the logic involved is presently beyond the level of detail of this report. An operational "truth" Table is enclosed for the half-system previously described (see Table 1).

TABLE 1

OPERATIONAL "TRUTH TABLE FOR THEMS

ITEM	SYMBOL	PHASE	
		DORMANT	ACTIVE
Bistable Solenoidal Valve	VS1	OFF	ON
Bistable Solenoidal Valve	VS2	OFF	ON
Bistable Solenoidal Valve	VS3	OFF	ON
Bistable Solenoidal Valve	VS4	ON	OFF
Bistable Solenoidal Valve	VS5	ON	OFF
Bistable Solenoidal Valve	VS6	OFF	ON
Pump	P1	ON	ON
Pump	P2	OFF	ON
Pump	P3	OFF	STANDBY

SECTION 5.0

ELECTRICAL POWER SOURCES INTERFACE WITH SYSTEM LOADS

5.1 GENERAL

The interconnection of sources of MOLAB electrical power with subsystem loads is provided by the power distribution system. The general philosophy of this arrangement is given in a previous report (see reference 1). Specifically the power distribution system provides a system of busses, circuit breakers, and shunts to distribute, control and monitor all sources of electrical power. A generalized schematic is provided in Figure 4.

5.2 DISTRIBUTION BUSSING AND GROUNDING

The MOLAB distribution bus system consists of the following primary busses:

1) Essential Buss
2) Locomotion Buss
3) Telemetry Buss

Under all conditions of source and load, the voltage, as delivered to these busses is (positive) 28 ± 2 volts. Each buss as named is provided with a separate ground return, which is not the MOLAB structure or supportive sheet metal. All ground returns are connected to the MOLAB structure at a common grounding point. All fuel cell and RTG negative output terminals are directly connected through conductors to the said common grounding point.

All ground and feed lines consist of non-braid, low-inductance conductors. Resistance and inductance of named conductors, under expected loads and in the absence of convective heat transfer, are sufficiently minimized to maintain equipment voltages within allowable tolerances and minimize inductive transients and heating effects. Secondary distribution busses also meet the above named requirements. Insulation of primary and secondary busses is adequate to provide isolation under any possible transient fault conditions. Insulation materials do not produce smoke, noxious odors or toxic gases under sustained fault conditions in a pure oxygen atmosphere and are capable of maintaining integrity and initial properties under all conditions and combinations of environment.

A secondary buss is provided for each individual subsystem as required. Further "fanning" of busses within the subsystem is to be provided as desired. Each secondary buss which terminates within or upon an individual electrical load is provided with a female connector, adquately keyed and coded to prevent undesired connection, and whose inter-terminal insulation and terminal conductivity meet the previously

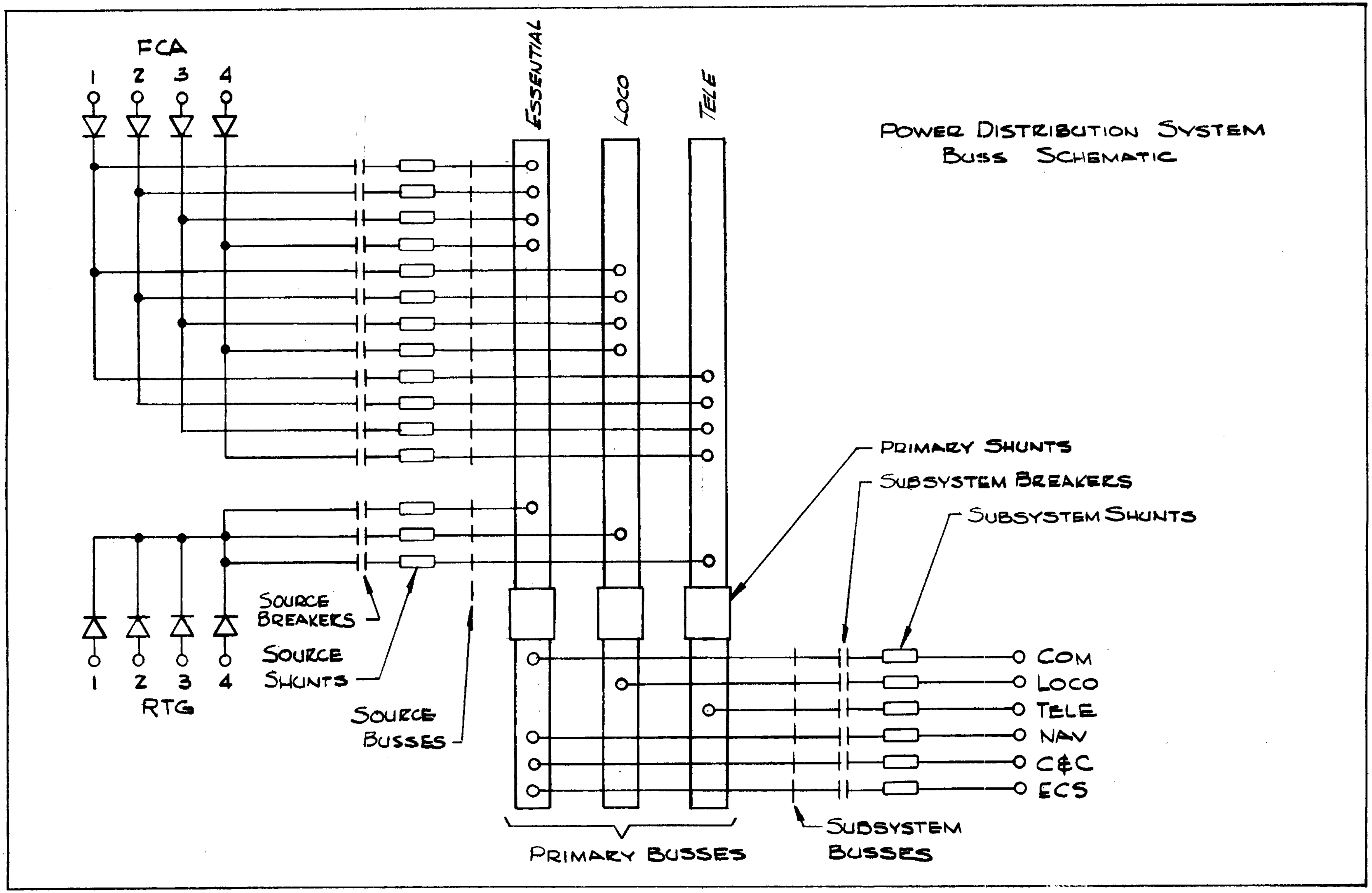


FIGURE 4. POWER DISTRIBUTION SYSTEM BUSS SCHEMATIC

named requirements.

5.3 POWER CONTROL

Control of electrical power is exerted in three general areas as follows:

1) Between each power source and each primary buss.
2) Between each primary buss and each secondary buss.
3) Between each primary buss.

A maximum of flexibility and protection is assured by providing means to individually connect all sources and loads. That is, failure of any source or a fault or failure in any secondary buss or subsystem does not degrade the remaining system performance as related through the electrical power system grid.

SECTION 6.0

AUXILIARY POWER SOURCE

6.1 GENERAL

During the dormant phase of the mission, the primary electrical power for the MOLAB is provided by four radio-isotope thermoelectric generator (RTG) units. These units also serve as an auxiliary power supply during the manned phase of the mission. In addition to the electrical power supplied by these units, a considerable amount of thermal energy is available for use in the thermal control of the MOLAB cabin and the power system. Thus the RTG units provide both electrical and thermal power.

6.2 POWER REQUIREMENTS

Since the primary purpose of the RTG units is to supply electrical power, the "size" of the RTG units is dictated by the electrical power requirements. Those subsystems normally requiring electrical power during the dormant phase are the telemetry subsystem, the thermal management system and the R. F. communications subsystem. There are periods during the dormant phase when large amounts of power are required such as the unloading of the MOLAB from the LEM truck, complete system chechout, etc. At these times, a sufficient number of fuel cells to meet the power demands are activated. However, these periods are infrequent and relatively short in duration.

The telemetry subsystem requires a maximum of 150 watts. Approximately 100 watts of this amount is required on a continuous basis while the other 50 watts may be required every hour for a duration of 1 to 2 seconds. The R. F. communications subsystem requires 50 watts every six hours for a period of about 12 minutes. During the operation of the R. F. communications subsystem, the telemetry power requirements are 100 watts or less. Hence, these two subsystems have a combined power requirement of 150 watts.

An allotment of ten watts electrical is made to the thermal management system for the operation of pumps, etc. Thus, the total electrical power required is 160 watts. If an RTG efficiency of 5% is assumed, then the maximum available thermal output of the RTG units is 3.2 kilowatts. The assumption is made that 1.5 kilowatts of this output is usable and available to the thermal management system, which maintains the temperatures of the electrical power system and the MOLAB cabin.

6.3 ANALYSIS

In order to perform an analysis of possible RTG units, a number of assumptions are made. These assumptions, necessary to insure consistent results, are as follows:

1. The RTG has an efficiency of 5%.
2. Sufficient shielding is provided to reduce the dose rate to 10 mrem/hr or less at 1 meter.
3. Generator weights and dimensions are based on SNAP-19 type characteristics (See Figure 5).
4. The useful generator life is one year or longer.

The list of isotope candidates for use as heat sources in the RTG units is rather small. The possible candiates are Plutonium-238, Polonium-210, Promethium-147, and Cerium-144. Table 2[3] lists the properties of these isotopes.

Three shielding materials are considered for gamma shielding, while lithium hydride (LiH) is used as the neutron shield. The gamma shields under consideration are lead, iron, and depleted uranium. Less frequently used materials, such as Mallory-1000 (a tungsten alloy) are not included in this study, but may warrant investigation in later studies. All the materials under study are readily available, and are easy to form into the required shield configuration.

Shielding weights are generated in the following manner. The electrical power level is multiplied by twenty to determine the thermal power level. From curves[4] of dose rates versus thermal power for different isotopes and for different thicknesses of shielding materials, the required shield thickness is determined. From these thicknesses the shield weights are calculated. The isotope weights are determined by dividing the thermal power by watts per gram for a particular isotope. Plutonium generator weights for various power levels are obtained by multiplying the ratio of the desired power level-to-30 watts times the generator weight for SNAP-19, which is a 30 watt generator. Generator weights for other isotopes at a given power level are calculated by obtaining the ratio of the specific power density (watt/cc) of plutonium to the specific power density of the isotope in question, and then multiplying this ratio time the plutonium generator weight. Figures 6 through 9 illustrate the results of these calculations. Several comments are in order regarding these figures. The power level indicated on the graphs is the initial power level of the generator and no allowance is made for the decay of the isotope with time. In order to account for this effect, the initial power is multiplied by the appropriate correction factor. For example, suppose a Pm-147 fueled RTG is desired which will furnish 150 watts-electrical for a period of one year. By looking at the Pm-147 curve on Figure 10, a correction factor of 1.47 is found to be necessary, i.e., an initial power of 150 times 1.47 or 220.5 watts is required to insure an output of 150 watts at the end of one year.

TABLE 2

ISOTOPE PROPERTIES

ISOTOPE	HALF - LIFE	MODE OF DECAY	POWER DENSITY
Pu -238	89.8 Yr.	Alpha*	9.3 Watts/cc
Po -210	0.38	Alpha**	1320
Pm -147	2.6	Beta	1.0
Ce -144	0.78	Beta	13.8

*Pu-238 also has a spontaneous fission half-life which gives rise to a neutron flux and a soft gamma flux. In addition to spontaneous fission, neutrons are generated by α, η reactions on light elements present.

**Although Po-210 is primarily an alpha emitter, the gamma activity is high enough to require shielding. Also, Po-210 is usually diluted in an inert metal matrix to achieve a specific power density of 75 watts/cc.

6.4 CONCLUSIONS

Based on total weight, shielding requirements, isotope availability, biological hazards, and power flatning, the Pu-238 fueled RTG is determined to be the most suitable for the MOLAB mission. Also the Pu-238 RTG is the only long-lived space power unit which is presently in use, being utilized in transit 4A and Transit 4B. However, other units undoubtedly will have been space tested before the launch period for the MOLAB mission. Although the present study is based on thermoelectric generators, the possibility of using more efficient thermionic generators cannot be eleminated as development programs on this type generator may produce tangible results before the scheduled launch period.

6.5 RECOMMENDATIONS

The shielding analysis in this study does not account for the location of the RTG on the MOLAB or for the inherent shielding provided by the MOLAB structure or apurtenances. These effects need investigation in a more detailed design of the power system layout. Also the shielding weights calculated are based on 4π shielding. By restricting the amount of time an astronaut spends near an unshielded side of an RTG, shadow shielding can be effectively employed.

It is assumed in this study that the RTG units remain on the MOLAB during the entire manned phase of the mission. However, if the units are removed from the MOLAB by the astronauts upon their arrival, then the sheilding requirements can be relaxed since the astronauts spend very little time in the vicinity of the RTG units. The weight savings and feasibility of this plan merit further attention.

The total expected dose from celestial sources such as solar flares, etc. needs to be estimated for the entire mission. In light of this dose and the mission operational plan, the relaxing of the allowable dose rate of 10 mrem/hr at one meter from the RTG is possible.

One area that deserves considerable attention is the disposition of the RTG units at the end of the MOLAB mission. Since the Pu-238 has such a long half-life (89 years) and the generator life is also lengthy, the RTG units provide 160 w (e) for a minimum of five years on the lunar surface. This amount of power is useful in numerous ways. One such possibility is the use of these RTG units as a subsequent power supply for a navigational homing beacon. Another possibility is to use the RTG units to power a scientific package that automatically collects, analyzes, and transmits data to the earth for extended time periods. Therefore, modular design should be employed with flexibility in useas a guideline in subsequent RTG studies.

SECTION 7.0

COMPONENT PACKAGING

7.1 GENERAL

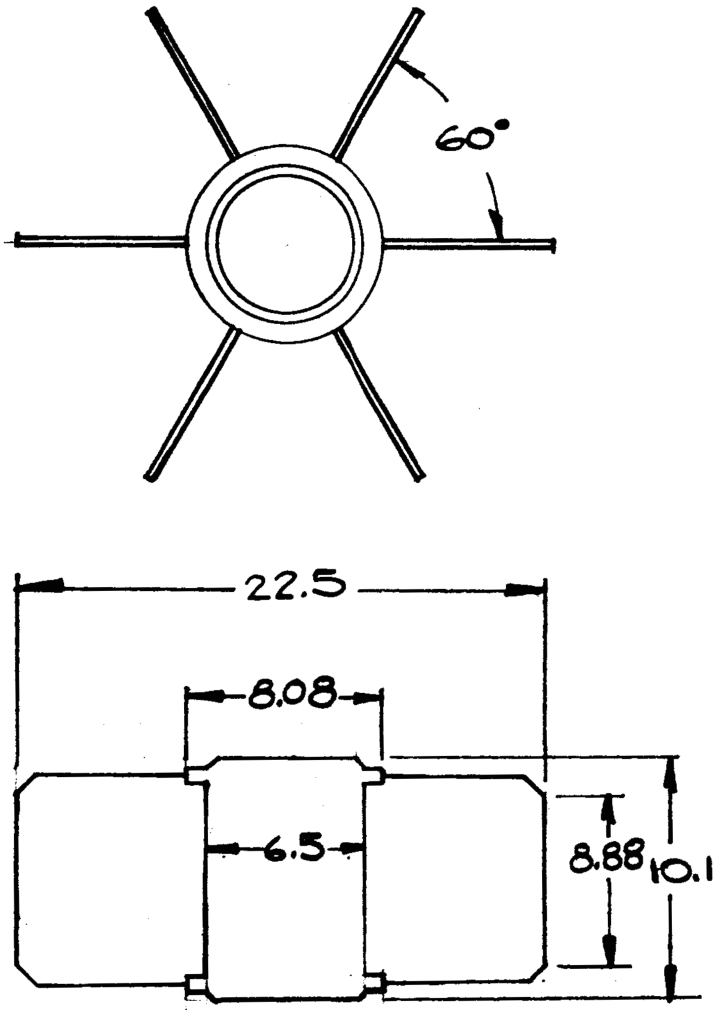
Three packaging arrangements of reactant tanks, RTG units, and fuel cells on MOLAB VII are evolved for the purpose of determining desirable power equipment configurations. Although each configuration developed has desirable features, these configurations have not been completely analyzed to determine if they are the "best" layouts. As an example, the RTG units are kept close to the fuel cells and the reactant tanks in order that coolant lines from the RTG units to the fuel cells are as short as possible. However, radiated thermal energy from the RTG units incident on the reactant tanks may greatly complicate the tankage insulation problems. Existence of such trade-offs is acknowledged, but complete studies of such problems are not part of this task.

7.2 MOD I

This concept (Figure 11) and the other two concepts have the hydrogen tank mounted above the oxygen tank. In all three concepts, these tanks are mounted contiguous to the cabin. This arrangement moves the cg's of these tanks as close as possible to the cg of the vehicle. The four fuel cells are mounted as two horizontal pairs on opposite sides of the reactant tanks. An RTG is mounted above and below each fuel cell pair. This arrangement utilizes the radiant heat from the RTG units for heating of the fuel cells. The RTG fuel cell combinations are mounted as far forward as possible without interferring with the airlock door operation. Table 3 lists weights and balances for this configuration.

7.3 MOD II

In this configuration (see Figure 12) the fuel cell pairs are mounted below the RTG units. The longitudinal axes of the fuel cells are parallel to the fore-aft axis of the MOLAB. This configuration lowers the vehicle cg since the heavier fuel cells are placed below the RTG units. This arrangement also allows for easier handling of the RTG units. Table 4 contains weight and balance data.



30 W(e) @ 2.4 VOLTS
SERIES - PARALLEL CIRCUITRY
WEIGHT - 27#

FIGURE 5. SNAP-19 THIRTY WATT GENERATOR

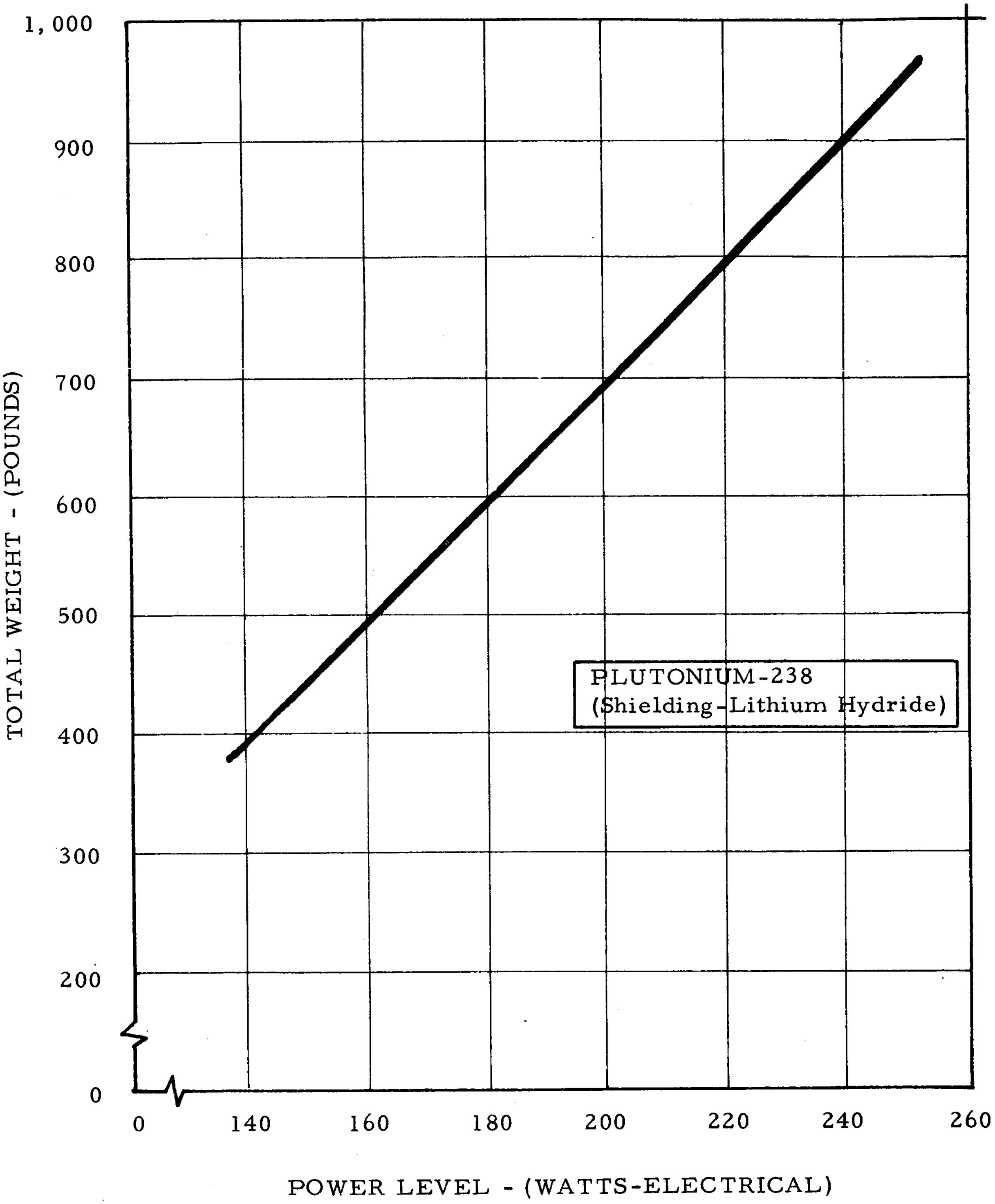


FIGURE 6. TOTAL GENERATOR WEIGHT AS A FUNCTION OF POWER LEVEL - PU-238

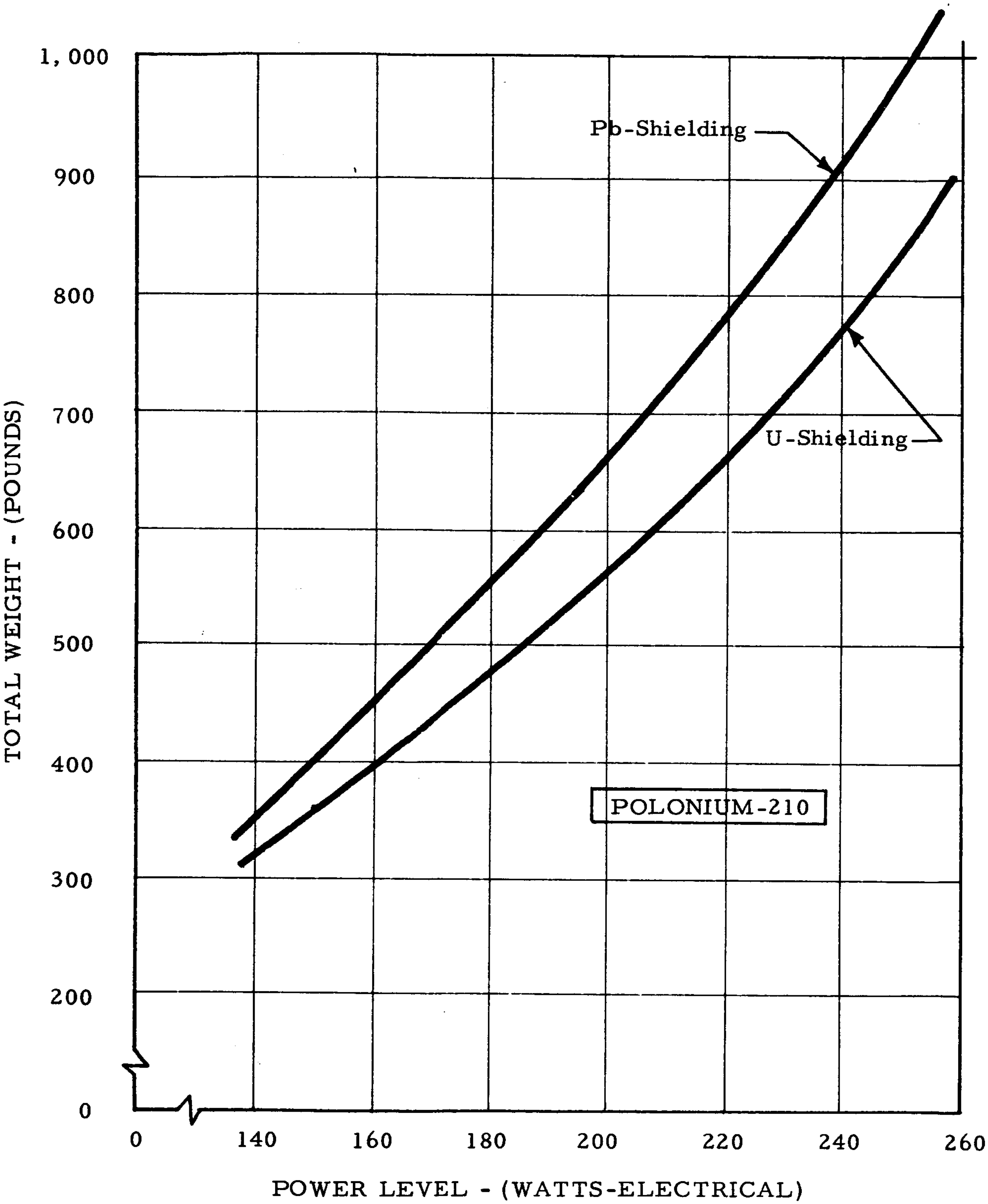


FIGURE 7. TOTAL GENERATOR WEIGHT AS A FUNCTION OF POWER LEVEL - PO-210

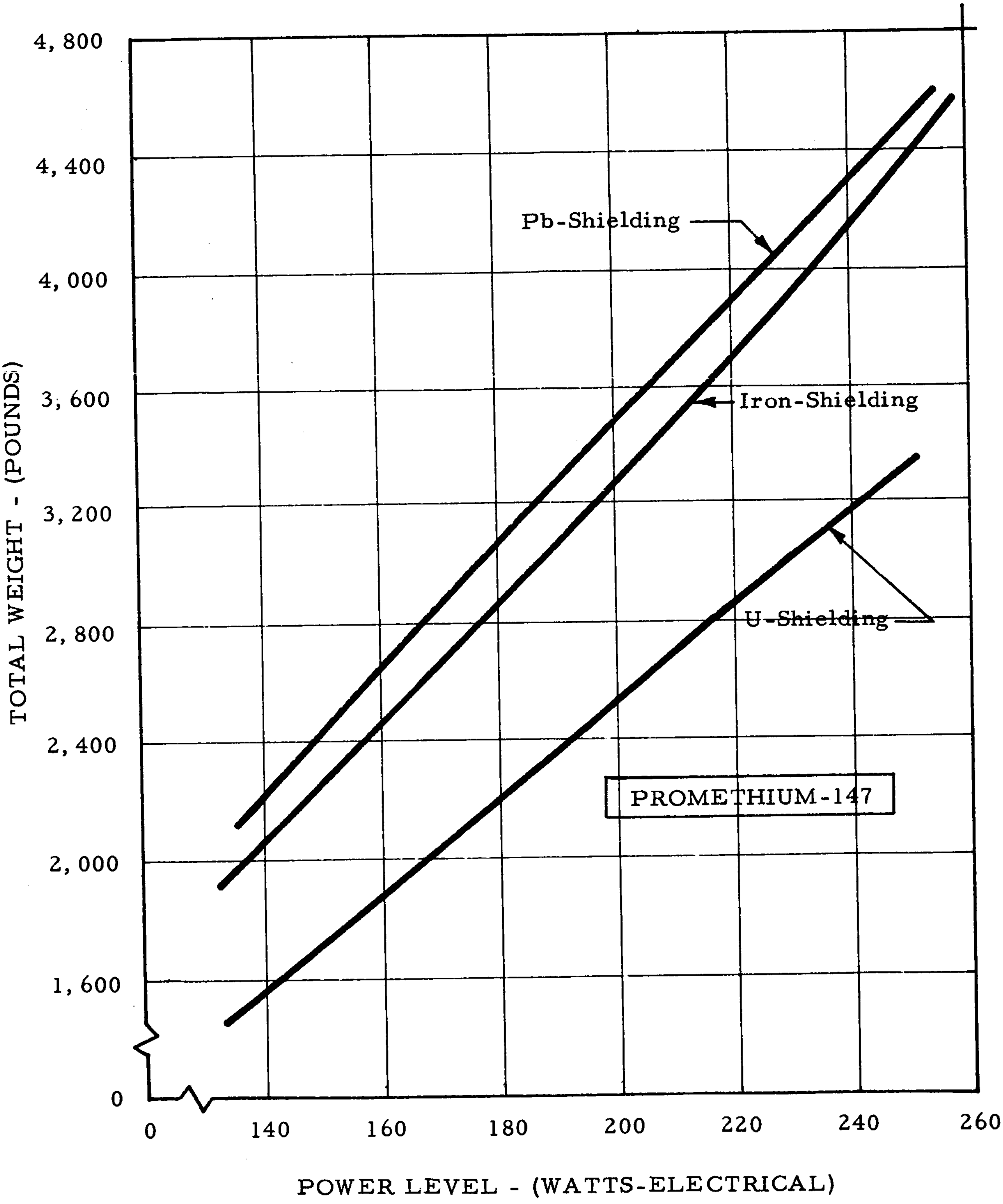


FIGURE 8. TOTAL GENERATOR WEIGHT AS A FUNCTION OF POWER LEVEL - PM-147

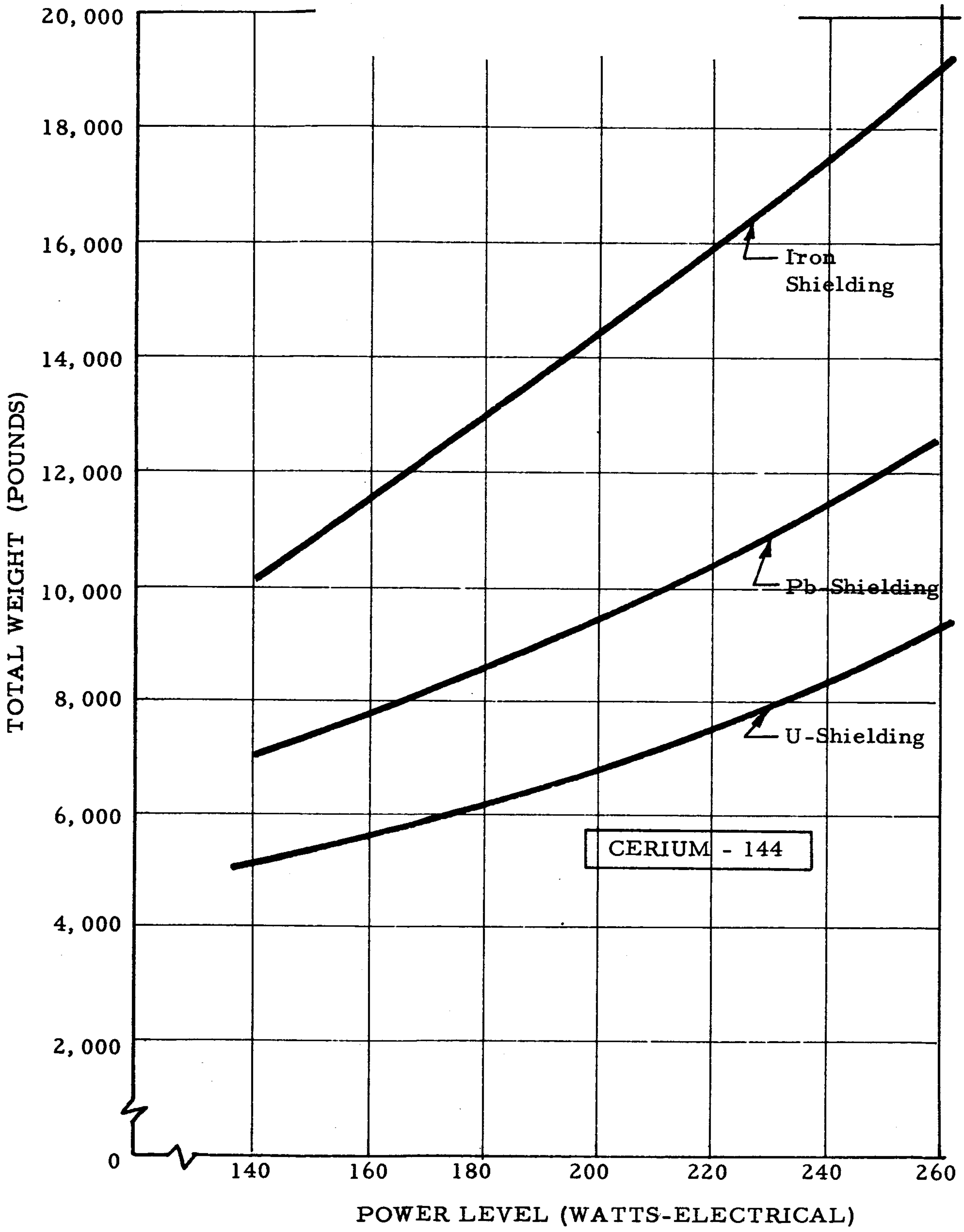


FIGURE 9. TOTAL GENERATOR WEIGHT AS A FUNCTION OF POWER LEVEL - CE-144

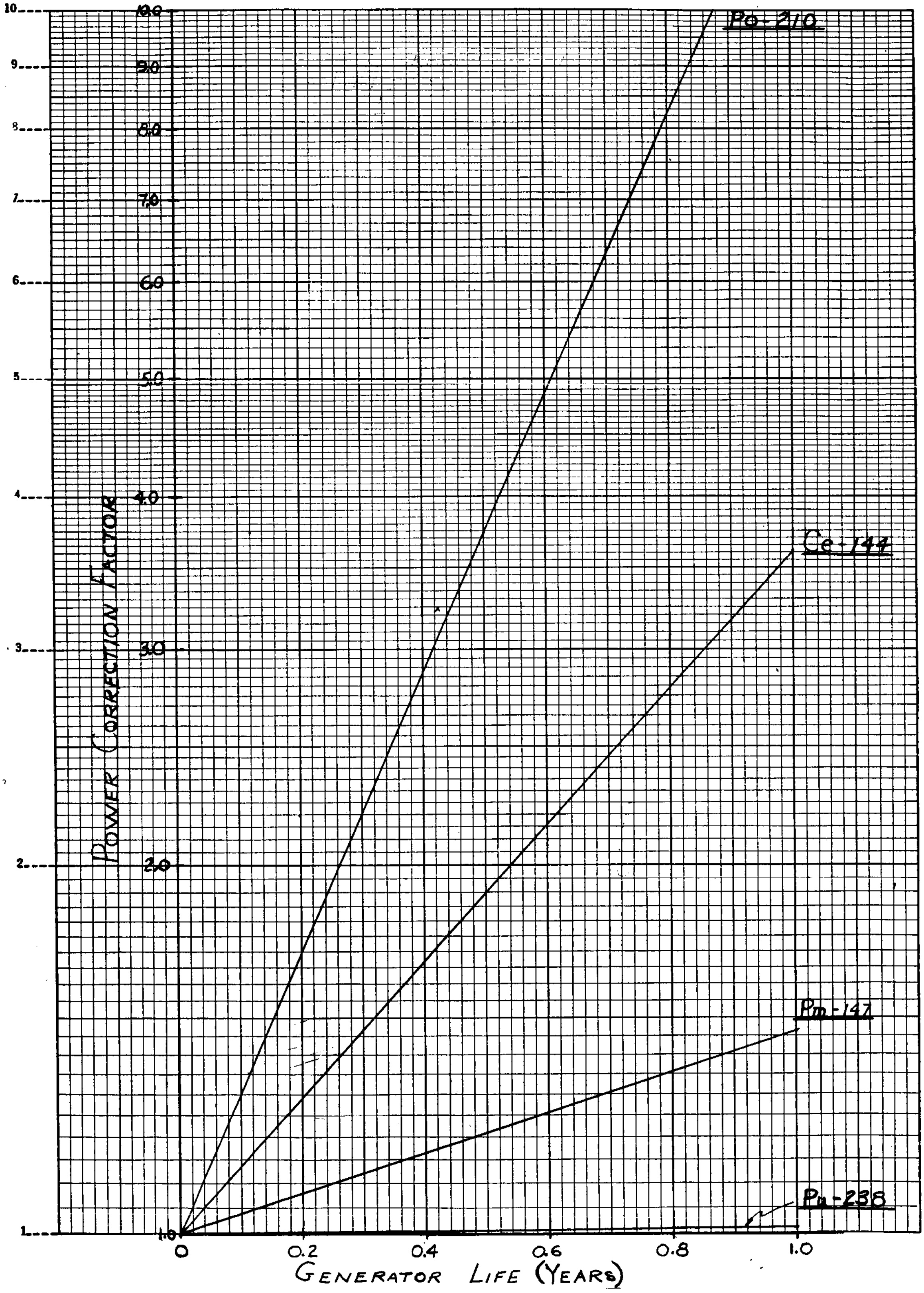


FIGURE 10. POWER CORRECTION FACTOR AS A FUNCTION OF GENERATOR LIFE

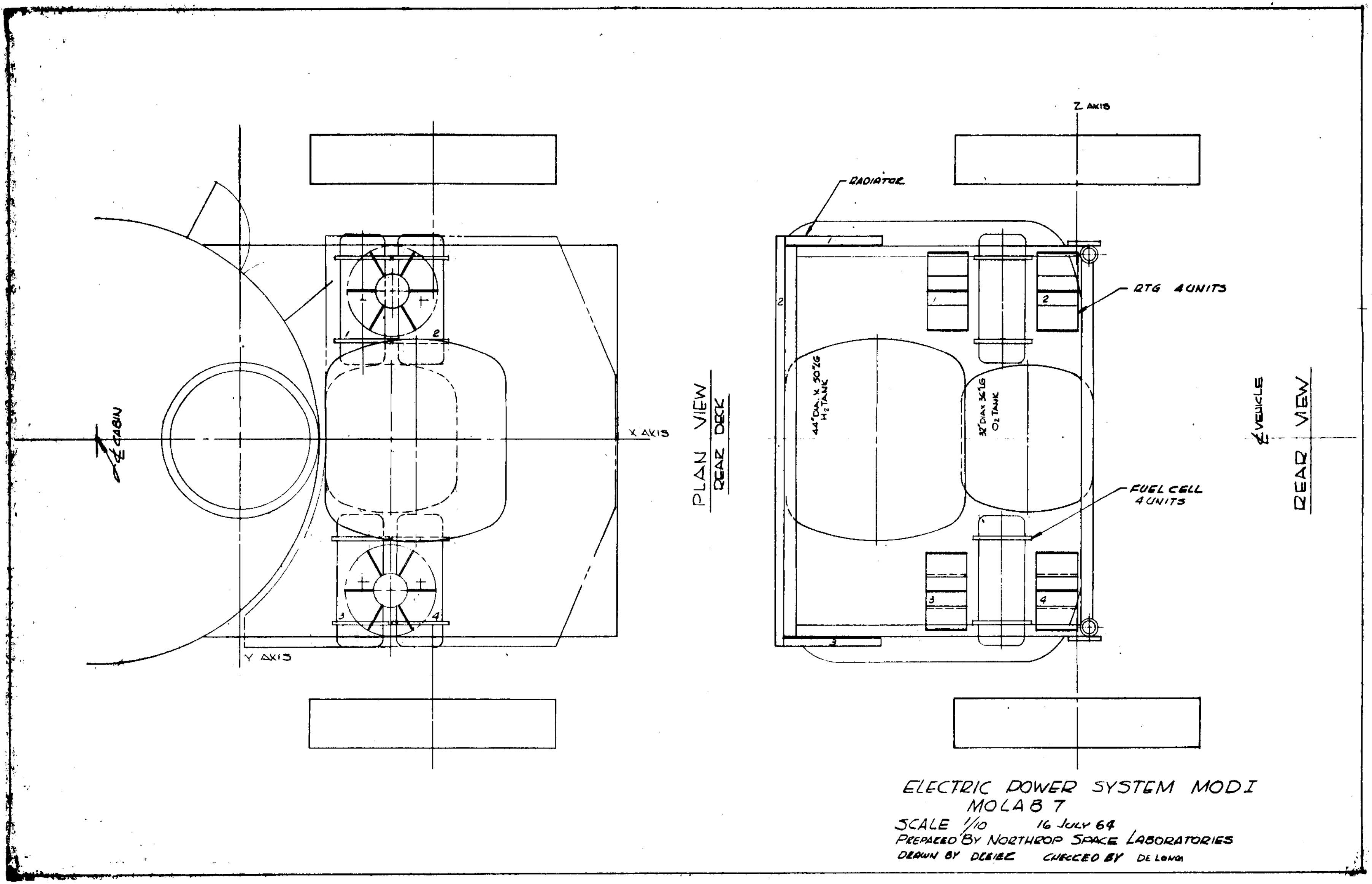


FIGURE 11. ELECTRIC POWER SYSTEM MOD I, MOLAB-VII

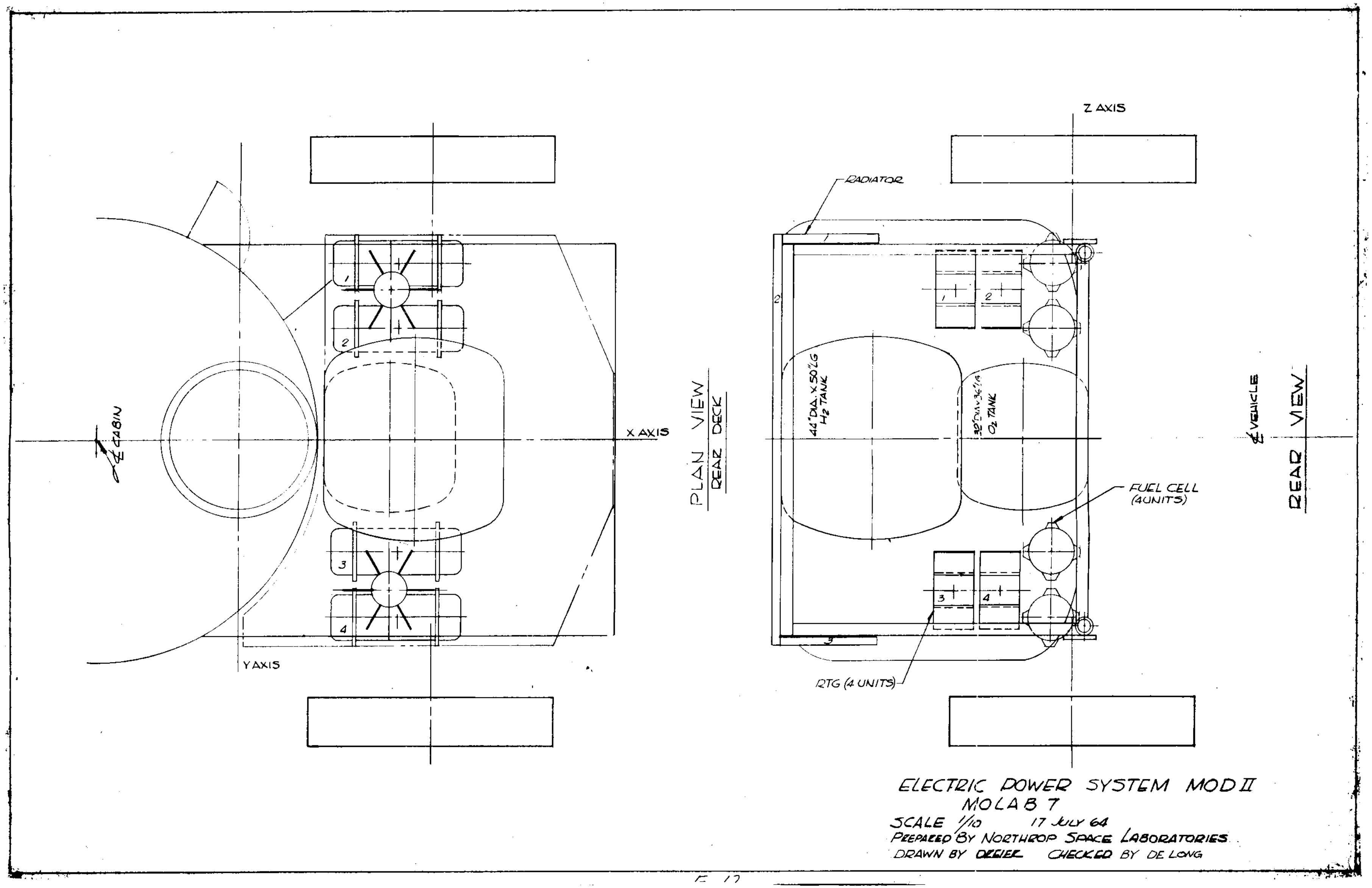


FIGURE 12. ELECTRIC POWER SYSTEM MOD II, MOLAB-VII

7.4 MOD III

For this configuration (see Figure 13) the fuel cell pairs are mounted with their longitudinal axes vertical. The fuel cells are mounted above the RTG units. The RTG-fuel cell assemblies are placed next to the MOLAB cabin. This configuration assumes that the airlock door is changed from its present location. This particular arrangement places the cg's of the fuel cells and RTG units as far forward as possible. Balance and weight information for this layout are given in Table 5.

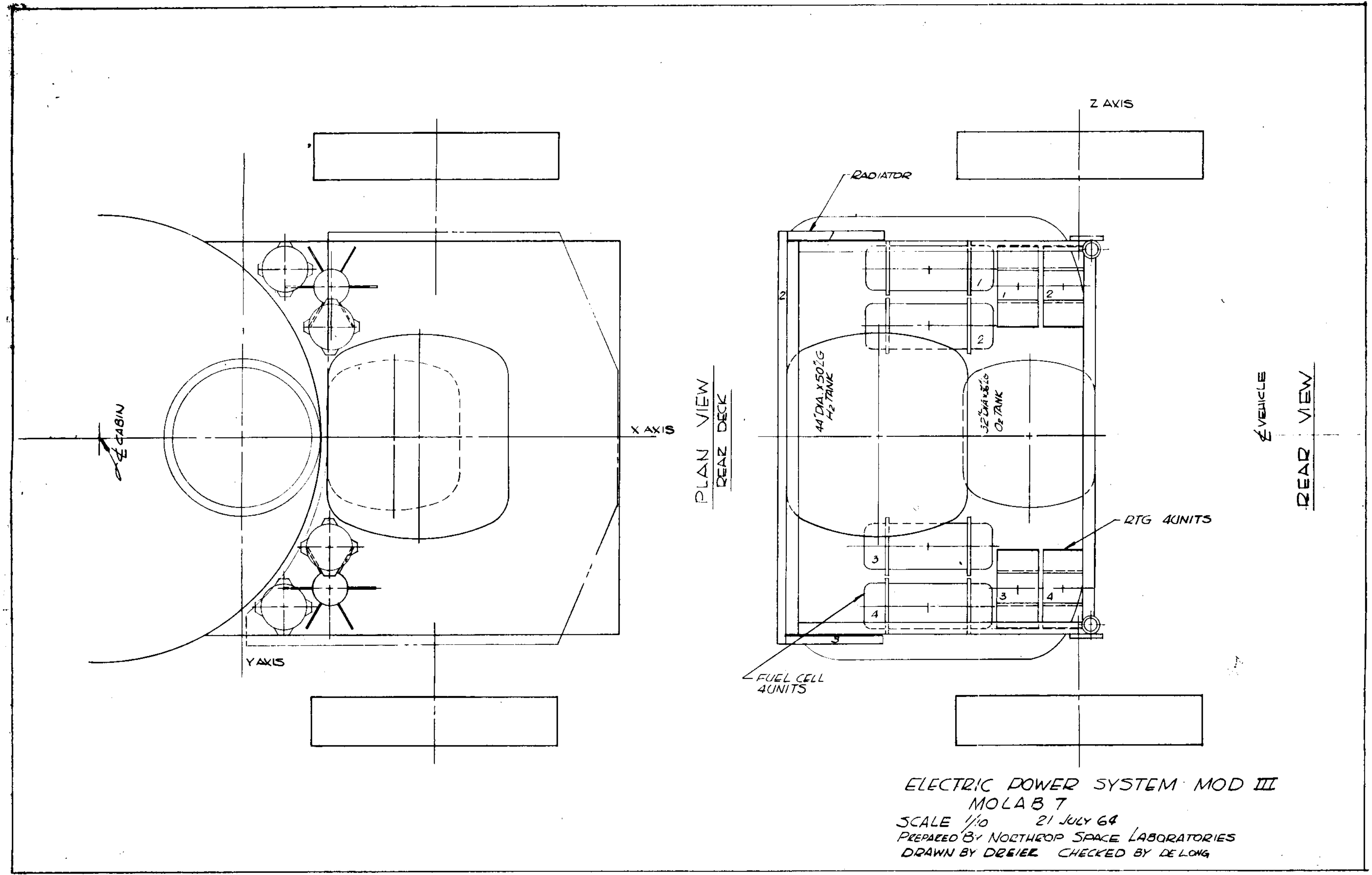


FIGURE 13. ELECTRIC POWER SYSTEM MOD III, MOLAB-VII

TABLE 3

WEIGHT & BALANCE CHART

MOD I

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH LBS. FULL	EMPTY	Δ
FUEL CELL 1	X	88	34.5	3036	NA	0
FUEL CELL 2		88	34.5	3036	NA	0
FUEL CELL 3		88	-34.5	-3036	NA	0
FUEL CELL 4		88	-34.5	-3036	NA	0
RTG 1		45	37	1665	NA	0
RTG 2		45	37	1665	NA	0
RTG 3		45	-37	-1665	NA	0
RTG 4		45	-37	-1665	NA	0
H_2 TANK		427/320	0	0	0	0
O_2 TANK		1013/160	0	0	0	0
RADIATOR 1		9	49	441	NA	0
RADIATOR 2		47	-3	-141	NA	0
RADIATOR 3	X	12	-49	-588	NA	0
			TOTAL	-288	NA	0

TABLE 3

WEIGHT & BALANCE CHART

MOD I

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH LBS.		
				FULL	EMPTY	Δ
FUEL CELL 1	Y	88	30	2640	NA	
FUEL CELL 2		88	44.5	3916	NA	
FUEL CELL 3		88	30	2640	NA	
FUEL CELL 4		88	44.5	3916	NA	
RTG 1		45	37.5	1687.5	NA	
RTG 2		45	37.5	1687.5	NA	
RTG 3		45	37.5	1687.5	NA	
RTG 4		45	37.5	1687.5	NA	
H_2 TANK		427/320	43	18361	13760	4601
O_2 TANK		1013/160	37	37481	5920	31561
RADIATOR 1		9	50	450	NA	
RADIATOR 2		47	52	2444	NA	
RADIATOR 3	Y	12	40	480	NA	
			TOTAL	79088	42926	36162

TABLE 3
WEIGHT & BALANCE CHART
MOD I

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH LBS.		
				FULL	EMPTY	Δ
FUEL CELL 1	Z	88	18.5	1628.0	NA	
FUEL CELL 2		88	18.5	1628.0	NA	
FUEL CELL 3		88	18.5	1628.0	NA	
FUEL CELL 4		88	18.5	1628.0	NA	
RTG 1		45	32	1440	NA	
RTG 2		45	5	225	NA	
RTG 3		45	32	1440	NA	
RTG 4		45	5	225	NA	
H_2 TANK		427/320	49.5	21136.5	15840	5296.5
O_2 TANK		1013/160	12.5	12662.5	2000	10662.5
RADIATOR 1		9	60	540	NA	
RADIATOR 2		47	73	3431	NA	
RADIATOR 3	Z	12	60	720	NA	
			TOTAL	48312.0	32353	15959

TABLE 4
WEIGHT & BALANCE CHART
MOD II

ITEM	AXIS	WGT. LBS	MOMENT ARM INCHES	MOMENT INCH-LBS. FULL	MOMENT INCH-LBS. EMPTY	MOMENT INCH-LBS. Δ
FUEL CELL 1	X	88	27.5	2420	NA	0
FUEL CELL 2	↓	88	43.5	3828	NA	↓
FUEL CELL 3		88	-27.5	-2420	NA	
FUEL CELL 4		88	-43.5	-3828	NA	
RTG 1		50	37	1850	NA	
RTG 2		50	37	1850	NA	
RTG 3		50	-37	-1850	NA	
RTG 4		50	-37	-1850	NA	
H_2 TANK		427/320	0	0	.0	
O_2 TANK		1013/160	0	0	0	
RADIATOR 1		9	49	441	NA	
RADIATOR 2		47	-3	- 141	NA	
RADIATOR 3	X	12	-49	- 588	NA	
			TOTAL	-288	NA	0

TABLE 4
WEIGHT & BALANCE CHART
MOD II

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH-LBS. FULL	MOMENT INCH-LBS. EMPTY	MOMENT INCH-LBS. Δ
FUEL CELL 1	Y	88	39.5	3476	NA	
FUEL CELL 2		88	39.5	3476	NA	
FUEL CELL 3		88	39.5	3476	NA	
FUEL CELL 4		88	39.5	3476	NA	
RTG 1		50	37	1850	NA	
RTG 2		50	37	1850	NA	
RTG 3		50	37	1850	NA	
RTG 4		50	37	1850	NA	
H_2 TANK		427/320	43	18361	13760	4601
O_2 TANK		1013/160	37	37481	5920	31561
RADIATOR 1		9	50	450	NA	
RADIATOR 2	↓	47	52	2444	NA	
RADIATOR 3	Y	12	40	480	NA	
			TOTAL	80,530	44,372	36,162

TABLE 4

WEIGHT & BALANCE CHART

MOD II

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH-LBS.		
				FULL	EMPTY	Δ
FUEL CELL 1	Z	88	5	440	NA	
FUEL CELL 2	↑	88	5	440	NA	
FUEL CELL 3	│	88	5	440	NA	
FUEL CELL 4	│	88	5	440	NA	
RTG 1	│	50	24	1200	NA	
RTG 2	│	50	12.5	625	NA	
RTG 3	│	50	24	1200	NA	
RTG 4	│	50	12.5	625	NA	
H_2 TANK	│	427/320	49.5	21136.5	15840	5296.5
O_2 TANK	│	1013/160	12.5	12662.5	2000	10662.5
RADIATOR 1	│	9	60	540	NA	
RADIATOR 2	↓	45	73	3285	NA	
RADIATOR 3	Z	12	60	720	NA	
			TOTAL	43,754	27,795	15,959

TABLE 5
WEIGHT & BALANCE CHART
MOD III

				MOMENT INCH LBS.		
ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	FULL	EMPTY	Δ
FUEL CELL 1	Y	88	10	880	NA	
FUEL CELL 2		88	22	1936	NA	
FUEL CELL 3		88	22	1936	NA	
FUEL CELL 4		88	10	880	NA	
RTG 1		50	22	1100	NA	
RTG 2		50	22	1100	NA	
RTG 3		50	22	1100	NA	
RTG 4		50	22	1100	NA	
H_2 TANK		427/320	43	18361	13760	4601
O_2 TANK		1013/160	37	37481	5920	31561
RADIATOR 1		9	50	450	NA	
RADIATOR 2		47	52	2444	NA	
RADIATOR 3	Y	12	40	480	NA	
			TOTAL	69238	33076	36162

TABLE 5
WEIGHT & BALANCE CHART
MOD III

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH LBS. FULL	MOMENT INCH LBS. EMPTY	MOMENT INCH LBS. Δ
FUEL CELL 1	Z	88	37	3256	NA	
FUEL CELL 2		88	37	3256	NA	
FUEL CELL 3		88	37	3256	NA	
FUEL CELL 4		88	37	3256	NA	
RTG 1		50	15	750	NA	
RTG 2		50	3.5	175	NA	
RTG 3		50	15	750	NA	
RTG 4		50	3.5	175	NA	
H_2 TANK		427/320	49.5	21 136.5	15840	5296.5
O_2 TANK		1013/160	12.5	12662.5	2000	10662.5
RADIATOR 1		9	60	540	NA	
RADIATOR 2		45	73	3285	NA	
RADIATOR 3	Z	12	60	720	NA	
			TOTAL	53 218	37259	15959

TABLE 5
WEIGHT & BALANCE CHART
MOD III

ITEM	AXIS	WGT LBS	MOMENT ARM INCHES	MOMENT INCH LBS.		
				FULL	EMPTY	Δ
FUEL CELL 1	X	88	41	3608	NA	0
FUEL CELL 2	↑	88	27	2376	NA	↑
FUEL CELL 3		88	-27	-2376	NA	
FUEL CELL 4		88	-41	-3608	NA	
RTG 1		50	37	1850	NA	
RTG 2		50	37	1850	NA	
RTG 3		50	-37	-1850	NA	
RTG 4		50	-37	-1850	NA	
H_2 TANK		427/320	0	0	0	
O_2 TANK		1013/160	0	0	0	
RADIATOR 1		9	49	441	NA	
RADIATOR 2	↓	47	-3	-141	NA	
RADIATOR 3	X	12	-49	-588	NA	↓
			TOTAL		NA	0

SECTION 8.0

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