POWER FOR THE MOON: IS MICROWAVE POWER BEAMING AN OPTION?

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PROBLEM:

SURFACE POWER APPROACHES SUFFER FROM:

SOLAR:

- HIGH MASS DUE TO 14 DAY ENERGY STORAGE REQUIREMENT

NUCLEAR:

- POLITICAL & ENVIRONMENTAL QUESTIONS OF PLACING A REACTOR ON THE MOON

POSSIBLE SOLUTION:

POWER BEAMING MAY ALLOW THE POWER SUPPLY (NUCLEAR OR SOLAR) TO BE PUT IN ORBIT AROUND THE MOON AND SUPPLY POWER TO MULTIPLE ASSETS

QUESTIONS NEEDING ANSWERS

① COST (MASS) COMPARISON TO SURFACE POWER TECHNOLOGY

② TECHNICAL FEASIBILITY OF OPTIONS

OBJECTIVE:

PERFORM 0th ORDER ANALYSIS OF ALTERNATE POWER SYSTEM ARCHITECTURES USING POWER BEAMING:

- SYSTEM MASS DRIVERS
- APPLICATIONS ISSUES
- TECHNOLOGY ISSUES
- IDENTIFY SYNERGISTIC OPTIONS

SCENARIOS POSTULATED

LUNAR BASE

SURFACE POWER
- **SOLAR**
- **NUCLEAR**

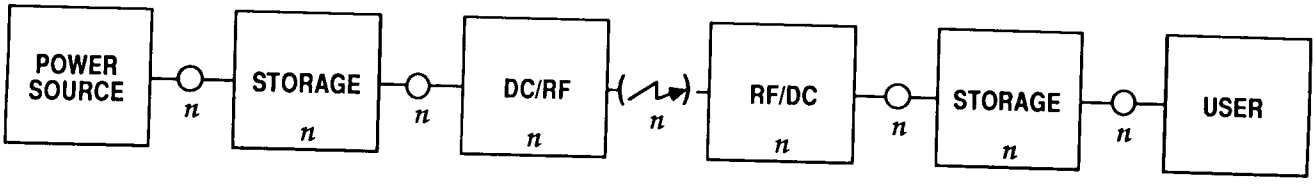
BEAMED POWER
- **LOW ORBIT (STORAGE)**
- **LOW ORBIT (MULTIPLE SAT.)**
- **STATIONARY ORBIT**

LEVELS OF TECHNOLOGY
- **SOA**
- **PATHFINDER**
- **ADVANCED**

MULTIPLE LUNAR LOCATIONS

BASES
OUTPOSTS
VEHICLES

POWER BEAMING SYSTEM
(UNIVERSAL DIAGRAM)



—O— PMAD

BEAMED POWER LINK

POWER BEAMING ANALYSIS APPROACH

ASSUMPTIONS:

- CIRCULAR, EQUATORIAL ORBITS
- VIEW ANGLE TO 10° ABOVE HORIZONS
- ENERGY FLOW
  - DIRECTLY FROM SOURCE TO LOAD WHILE IN VIEW
  - TRANSMITED TO SURFACE STORAGE WHILE IN VIEW FOR USE WHEN OUT OF VIEW
  - STORED ON SATELLITE WHILE OUT OF VIEW (PV ONLY, NUCLEAR CASE MORE MASS EFFICIENCT TO ELIMINATE SATELLITE STORAGE AND ENLARGE NUCLEAR SOURCE)

POWER BEAMING ANALYSIS APPROACH

ASSUMPTIONS (Cont.):

TOTAL MASS = POWER DEPENDENT MASS + POWER INDEPENDENT MASS

POWER DEPENDENT MASS:

- SOURCE
- PMAD
- STORAGE
- TUBE

POWER INDEPENDENT MASS:

- SPACECRAFT BUS
- TUBE SUPPORT EQUIP.
- ANTENNA
- RECTENNA

POWER DEPENDENT SYSTEM MASSES

(Kg/Kw CONTINUOUSLY TO LOAD)

POWER DEPENDENT SYSTEM MASS = EFFECTIVE SURFACE MASS + EFFECTIVE ORBITER MASS

ASSUME: $\frac{\text{MASS ON SURFACE}}{\text{MASS IN ORBIT}}$ = 1/2 - DUE TO PROPELLENT REQUIREMENTS

NORMALIZE TO SURFACE SYSTEM:

PDSM = SURFACE MASS + 1/2 (ORBITER MASS)

$$\text{PDSM} = \text{PMAD} + \text{STORAGE}*(T)*(1\text{-DC}) + \text{PMADs}*\left(\frac{1}{DC}-1\right) + \text{PMAD}$$
$$1/2\ [\text{TRANSMITTERs}*\left(\frac{1}{DC}-1\right) + \text{TRANSMITTER} + \text{PMADs}*\left(\frac{1}{DC}-1\right) +$$
$$\text{PMAD} + \text{STORAGE}*(T)*(1\text{-DC}) + \text{PMAD}*(1\text{-DC}) + \text{SOURCE}]$$

WHERE: DUTY CYCLE (DC) = f (ALTITUDE)
ORBIT TIME (T) = f (ALTITUDE)

S. O. A. TECHNOLOGY

(ORBITER)	EFF. (%)	MASS (Kg/Kw or Kg/Kw hr)	POWER MULTIPLIER STORAGE	POWER MULTIPLIER NO STOR.	MASS (Kg/Kw DELIVERED) STORAGE	MASS (Kg/Kw DELIVERED) NO STOR.
PV (OAST-1)	-	15	14.00	6.25	210.0	93.8
PMAD	98	10	13.72	-	137.2 (1-DC)	-
STORAGE (Ni H_2)	67	20	9.26	-	185.2 (T) (1-DC)	-
PMAD	98	10	9.07	6.12	90.7 $(\frac{1}{DC} - 1)$	61.2
TRANSMITTER	40	1	3.63	2.45	3.6 $(\frac{1}{DC} - 1)$	2.5
TRANSMISSION LINK	85					
(BASE)						
RECEIVER (RECTENNA)	50		1.54	1.04		
PMAD	98	10	1.51	1.02	15.1 $(\frac{1}{DC} - 1)$	10.2
STORAGE	67	20	1.02	-	20.4 (T) (1-DC)	-
PMAD (S.S.F.)	98	100	1.00	1.00	100.0	100.0

S.O.A. MICROWAVE LINK
PATHFINDER GENERATION/STORAGE TECHNOLOGY

(ORBITER)	EFF. (%)	MASS (Kg/Kw or Kg/Kw hr)	POWER MULTIPLIER STORAGE	POWER MULTIPLIER NO STOR.	MASS (Kg/Kw DELIVERED) STORAGE	MASS (Kg/Kw DELIVERED) NO STOR.
NUCLEAR (SP-100)	-	20.0	9.81	6.25	196.2	125.0
PV (AMORP. Si)	-	3.3	15.09	6.25	49.8	20.6
PMAD	98	1.0	14.80	-	14.8 (1-DC)	-
STORAGE (REG. FUEL CELL)	65	.8	9.61	-	7.7 (T) (1-DC)	-
PMAD	98	1.0	9.42	6.12	9.4 $(\frac{1}{DC} - 1)$	6.1
TRANSMITTER	40	1.0	3.77	2.45	3.8 $(\frac{1}{DC} - 1)$	2.5
TRANSMISSION LINK	85					
(BASE)						
RECEIVER (RECTENNA)	50		1.60	1.04		
PMAD	98	5.0	1.56	1.02	7.8 $(\frac{1}{DC} - 1)$	5.1
STORAGE	65	.8	1.02	-	.8 (T) (1-DC)	-
PMAD (S.S.F.)	98	45.0	1.00	1.00	45.0	45.0

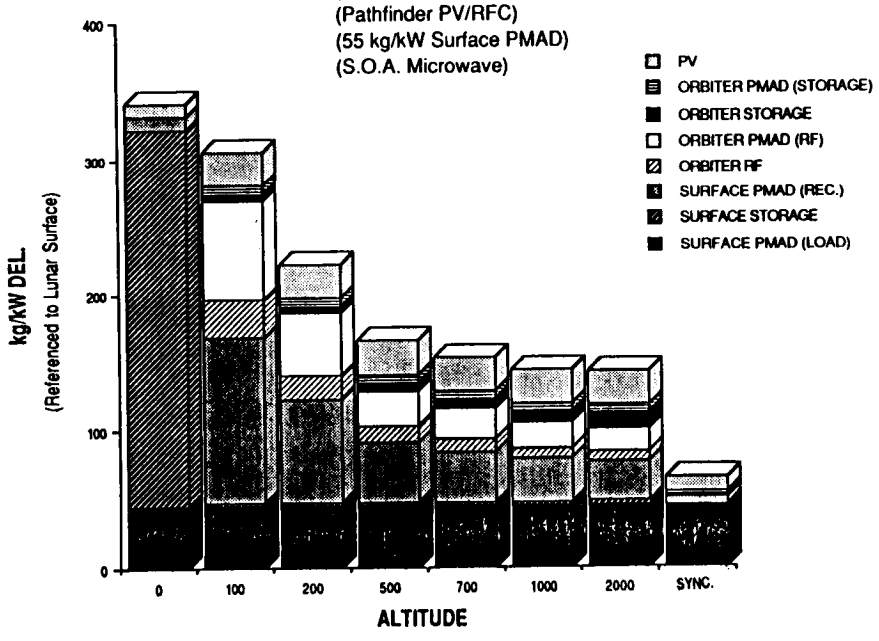
ADVANCED MICROWAVE TECHNOLOGY
PATHFINDER GENERATION/STORAGE TECHNOLOGY

(ORBITER)	EFF. (%)	MASS (Kg/Kw or Kg/Kw hr)	POWER MULTIPLIER STORAGE	POWER MULTIPLIER NO STOR.	MASS (Kg/Kw DELIVERED) STORAGE	MASS (Kg/Kw DELIVERED) NO STOR.
NUCLEAR (SP-100)	-	20.0	2.62	1.68	52.40	33.60
PV (AMORP. Si)	-	3.3	4.02	1.68	13.25	5.56
PMAD	99	1.0	3.98	-	3.98 (1-DC)	-
STORAGE (REG. FUEL CELL)	65	.8	2.59	-	2.07 (T) (1-DC)	-
PMAD	99	1.0	2.56	1.67	2.56 $(\frac{1}{DC} - 1)$	1.67
TRANSMITTER	80	1.0	2.05	1.33	2.05 $(\frac{1}{DC} - 1)$	1.33
TRANSMISSION LINK	85					
(BASE)						
RECEIVER (RECTENNA)	85		1.57	1.02		
PMAD	99	1.0	1.55	1.01	1.55 $(\frac{1}{DC} - 1)$	1.01
STORAGE	65	.8	1.01	-	.81 (T) (1-DC)	-
PMAD (S.S.F.)	99	45.0	1.00	1.00	45.00	45.00

SOLAR SOURCE BEAM POWER SYSTEM

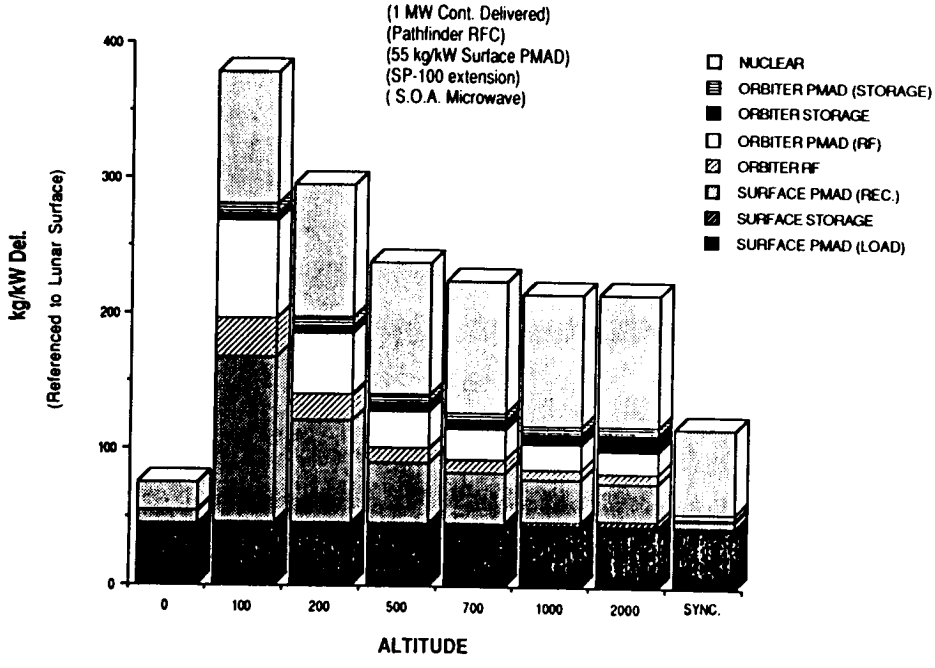
(Power Dependent System Masses Only)

(1MW Cont. Delivered)
(Pathfinder PV/RFC)
(55 kg/kW Surface PMAD)
(S.O.A. Microwave)



NUCLEAR SOURCE BEAM POWER SYSTEM

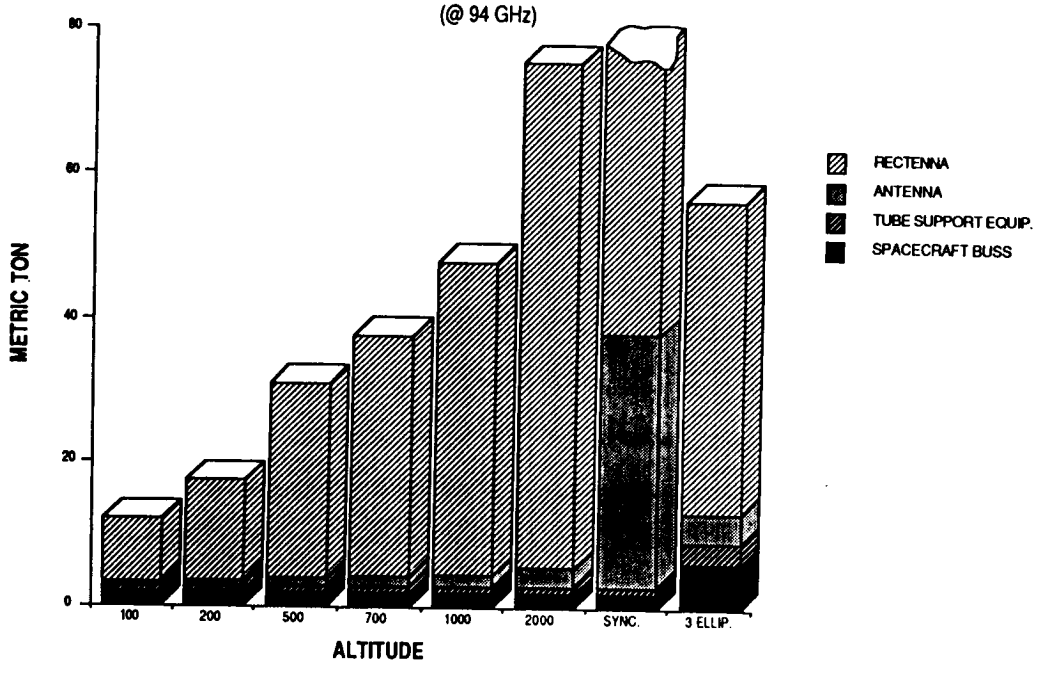
(Power Dependent System Masses Only)



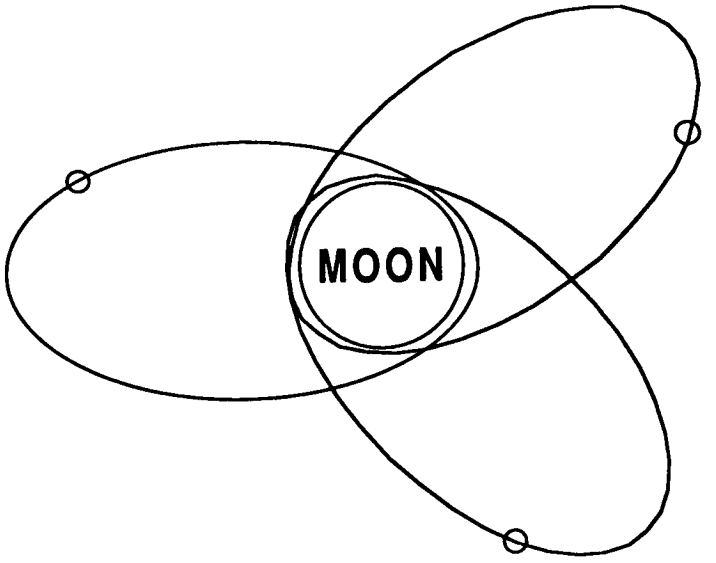
TRANSMISSION SYSTEM

MASS

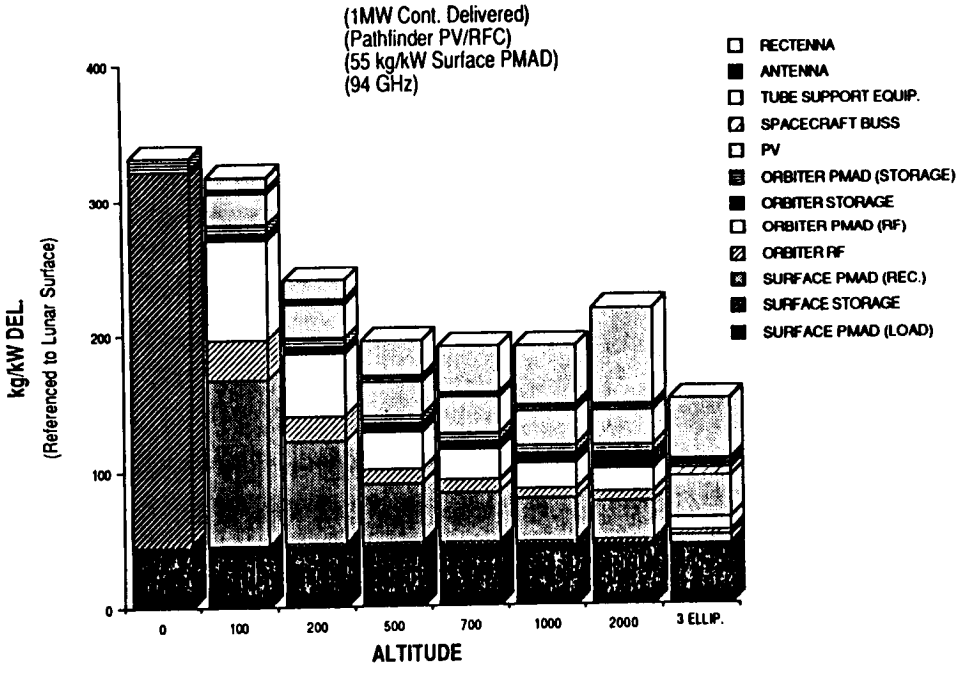
(@ 94 GHz)



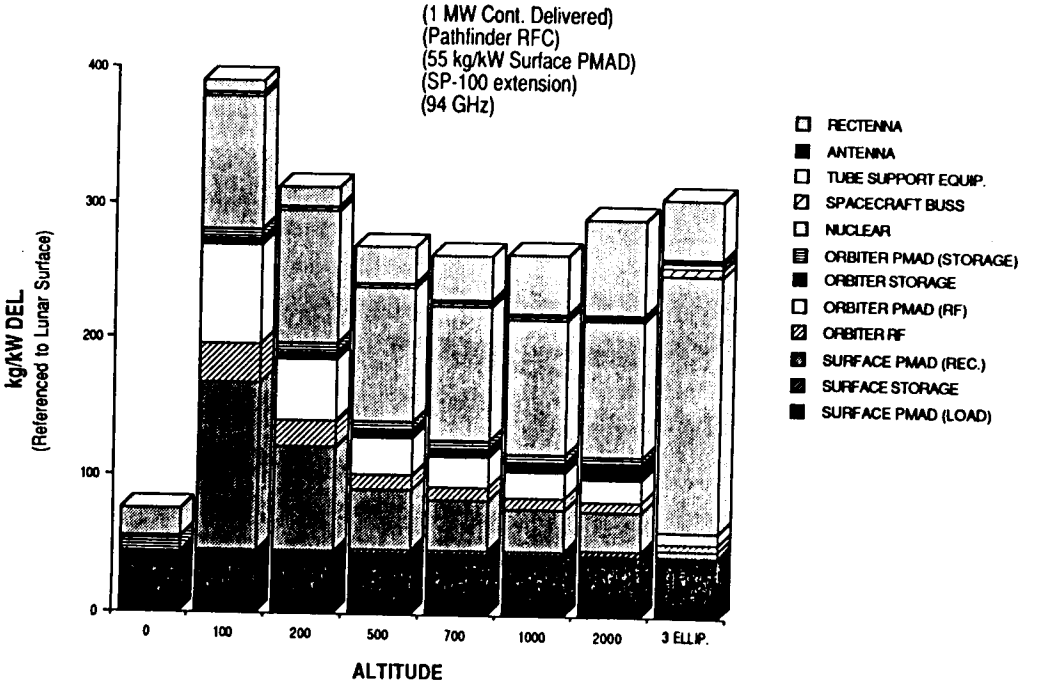
THREE SATELLITE BEAM POWER SYSTEM



SOLAR SOURCE BEAMED POWER SYSTEM



NUCLEAR SOURCE BEAMED POWER SYSTEM



LUNAR BASE POWER

METHOD	POWER TRANS.	TECHNOLOGY LEVEL S.O.A S.O.A	PATHFINDER S.O.A.	PATHFINDER ADVANCED
SURFACE				
SOLAR		9,984 (9,874) *	341 (286)	336 (286)
SOLAR (14 DAY ONLY)		155 (45)	63 (8)	58 (8)
NUCLEAR		--	75 (20)	70 (20)
BEAM				
SOLAR (500 km Circular)		889 (779)	194 (139)	189 (39)
NUCLEAR (500 km Circular)		--	267 (212)	109 (59)
SOLAR (3; elliptical orbits)		396 (286)	144 (89)	78 (28)
NUCLEAR (3; elliptical orbits)		--	301 (246)	120 (70)

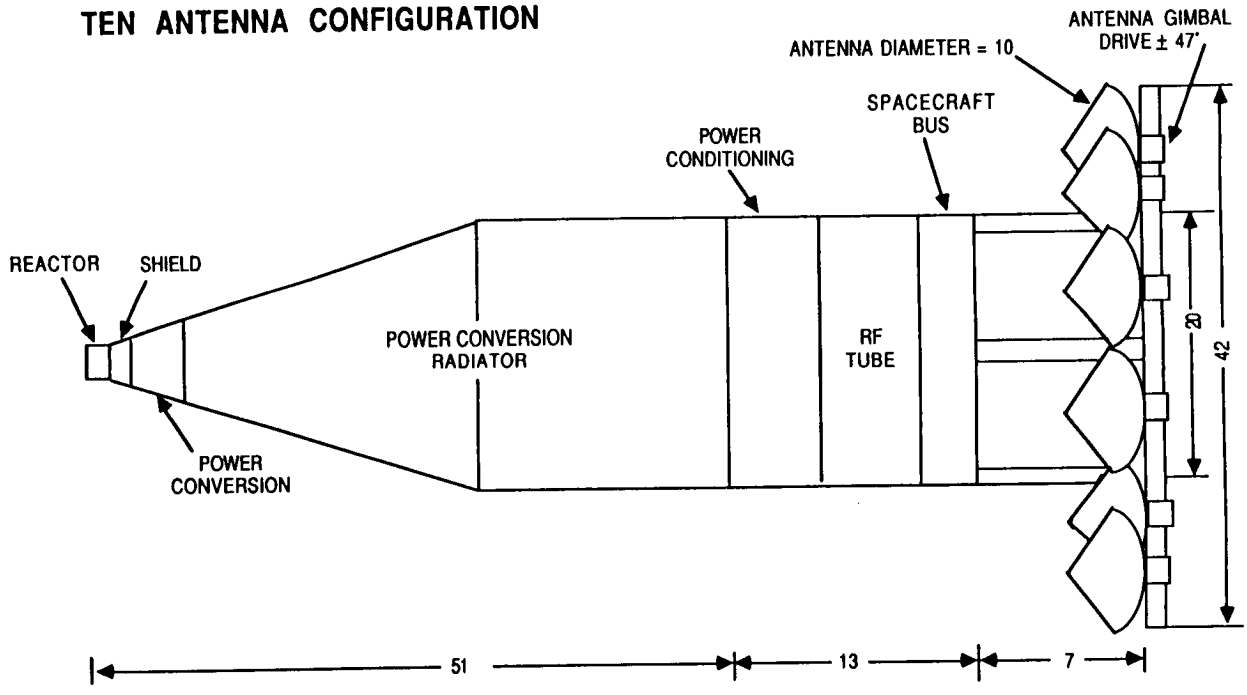
* WITH PMAD (WITHOUT PMAD)

ADDITIONAL LUNAR ASSETS POWER

METHOD	POWER TRANS.	TECHNOLOGY LEVEL S.O.A S.O.A		PATHFINDER S.O.A.		PATHFINDER ADVANCED	
SURFACE							
SOLAR		9,984	(9,874)*	341	(286)	336	(286)
SOLAR (14 DAY ONLY)		155	(45)	63	(8)	58	(8)
NUCLEAR		--		75 - 300	(20-245)	75 - 300	(20-245)
BEAM							
SOLAR (500 km Circular)		361 - 887	(251-777)	143 - 192	(88-137)	71 - 88	(21-38)
NUCLEAR (500 km Circular)		--		216 - 265	(161-210)	90 - 107	(40-57)
SOLAR (3; elliptical orbits)		154 - 390	(44-280)	94 - 137	(39-82)	60 - 72	(10-22)
NUCLEAR (3; elliptical orbits)		--		250 - 294	(195-239)	102 - 115	(52-65)

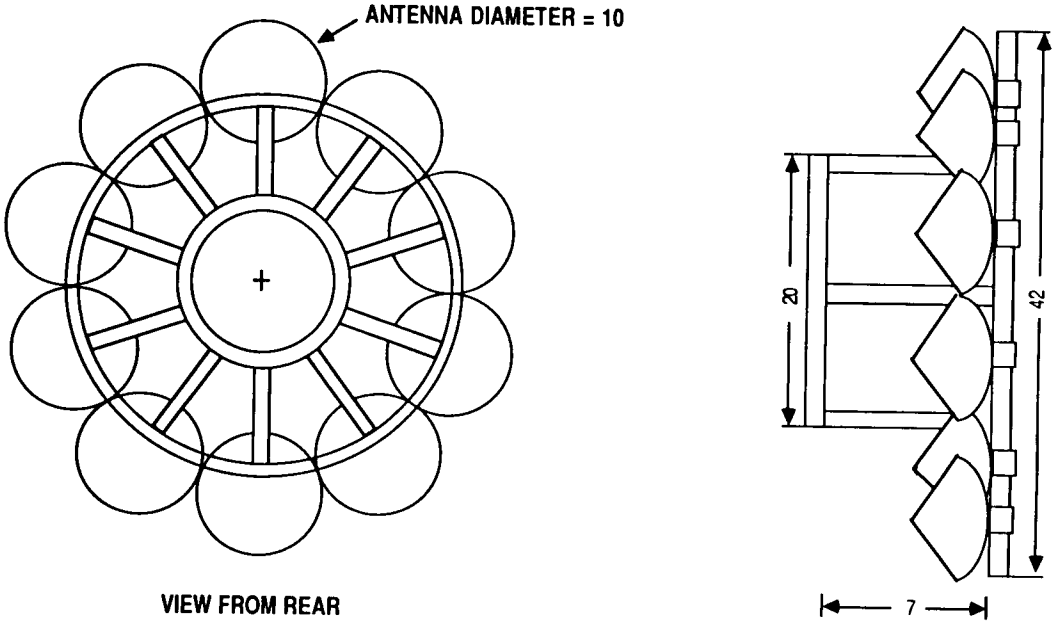
* WITH PMAD (WITHOUT PMAD)

TEN ANTENNA CONFIGURATION



DIMENSIONS IN METERS

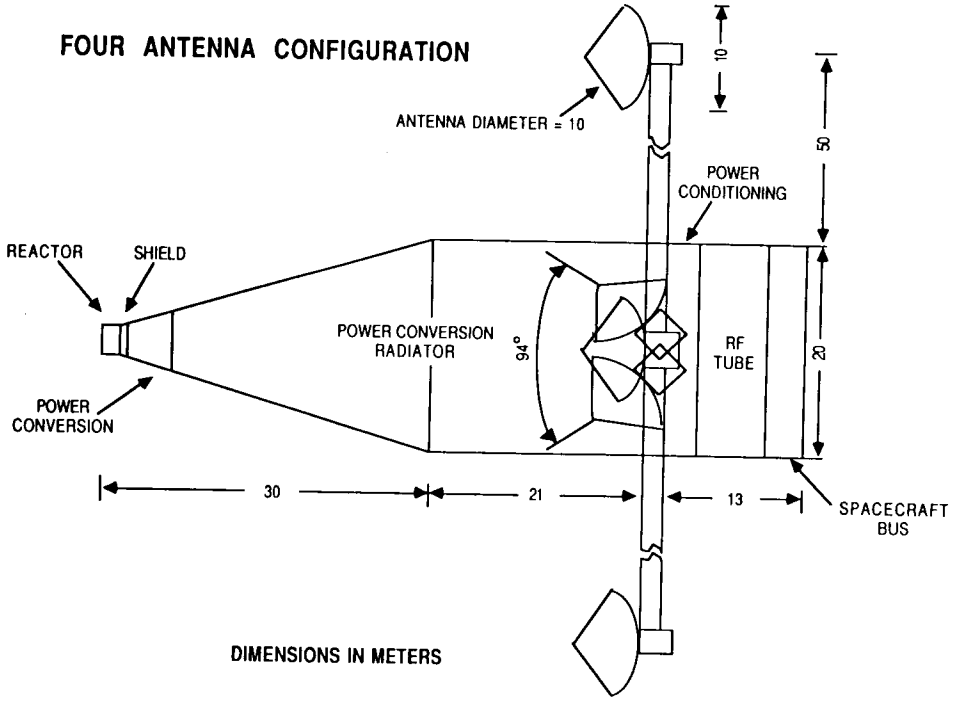
TEN ANTENNA CONFIGURATION



VIEW FROM REAR

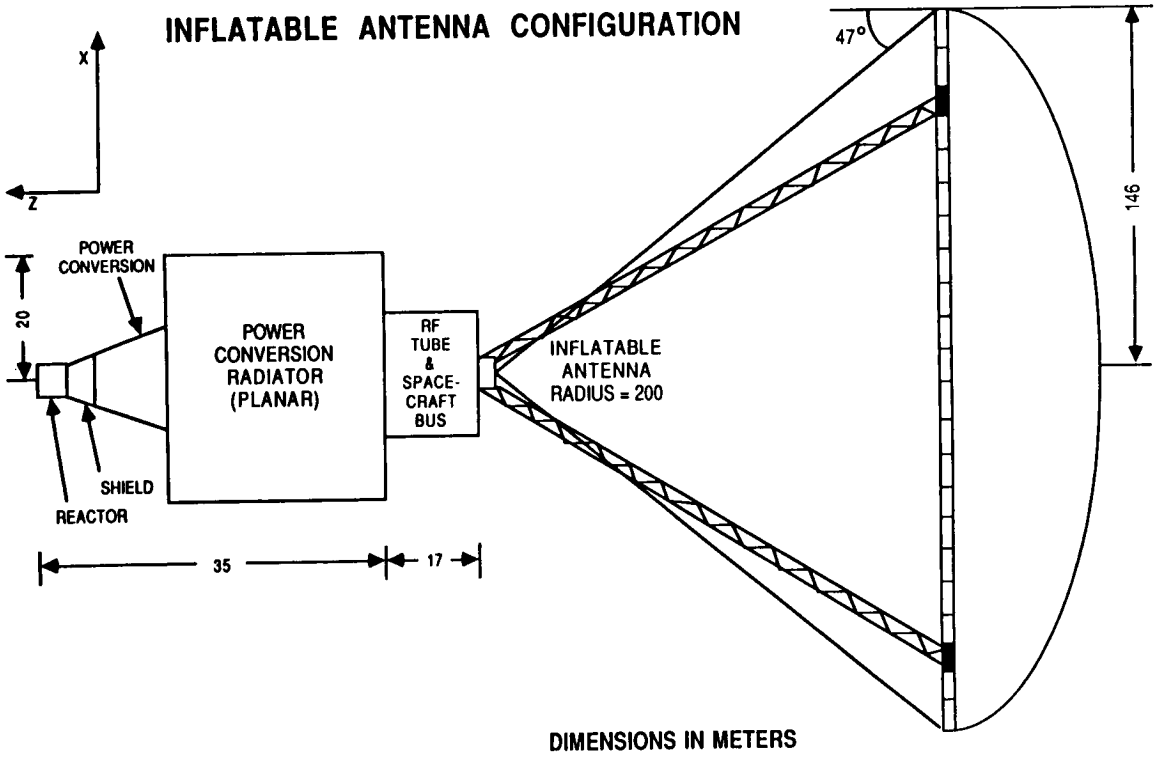
DIMENSIONS IN METERS

FOUR ANTENNA CONFIGURATION

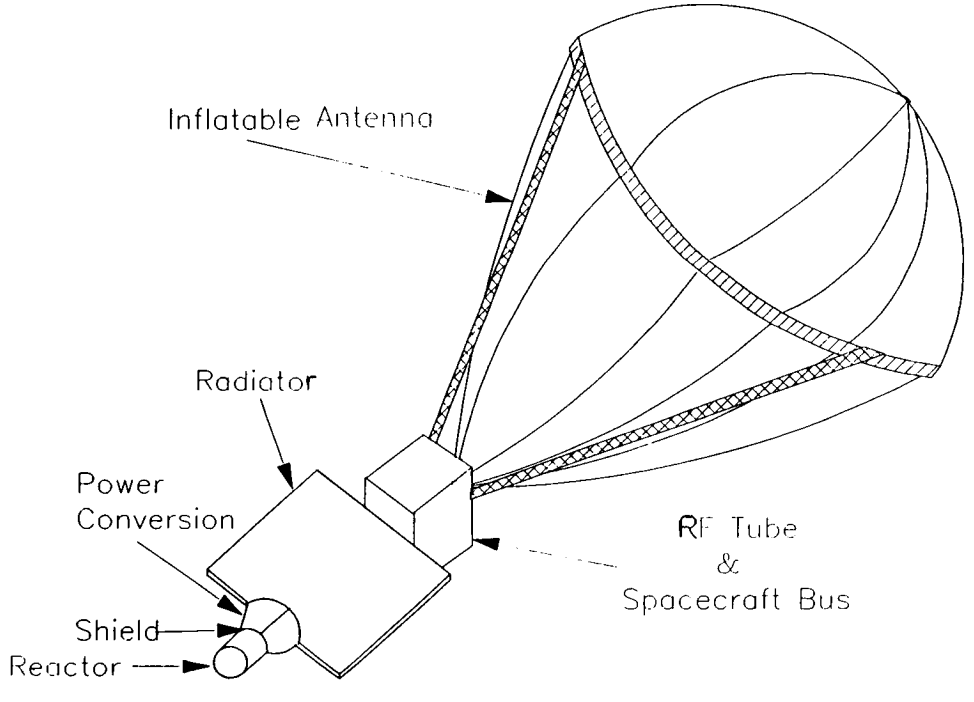


DIMENSIONS IN METERS

INFLATABLE ANTENNA CONFIGURATION



DIMENSIONS IN METERS



ISSUES & CONCERNS

ANTENNA SYSTEM

- POINTING ACCURACY
- SURFACE ACCURACY

RF SOURCE

- EFFICIENCY
- WEIGHT
- FREQUENCY
- COOLING
- CRYOGENICS

RECTENNA

- EFFICIENCY
- WEIGHT
- FREQUENCY

SUMMARY

- 0th ORDER ANALYSIS INDICATES MICROWAVE BEAM POWER SYSTEM MASS FALLS BETWEEN SOLAR AND NUCLEAR SURFACE POWER SYSTEMS
- MANY TRADES - MORE INTENSIVE STUDY NEEDS TO BE PERFORMED
- A NUMBER OF TECHNICAL & APPLICATIONS QUESTIONS NEED TO BE ANSWERED