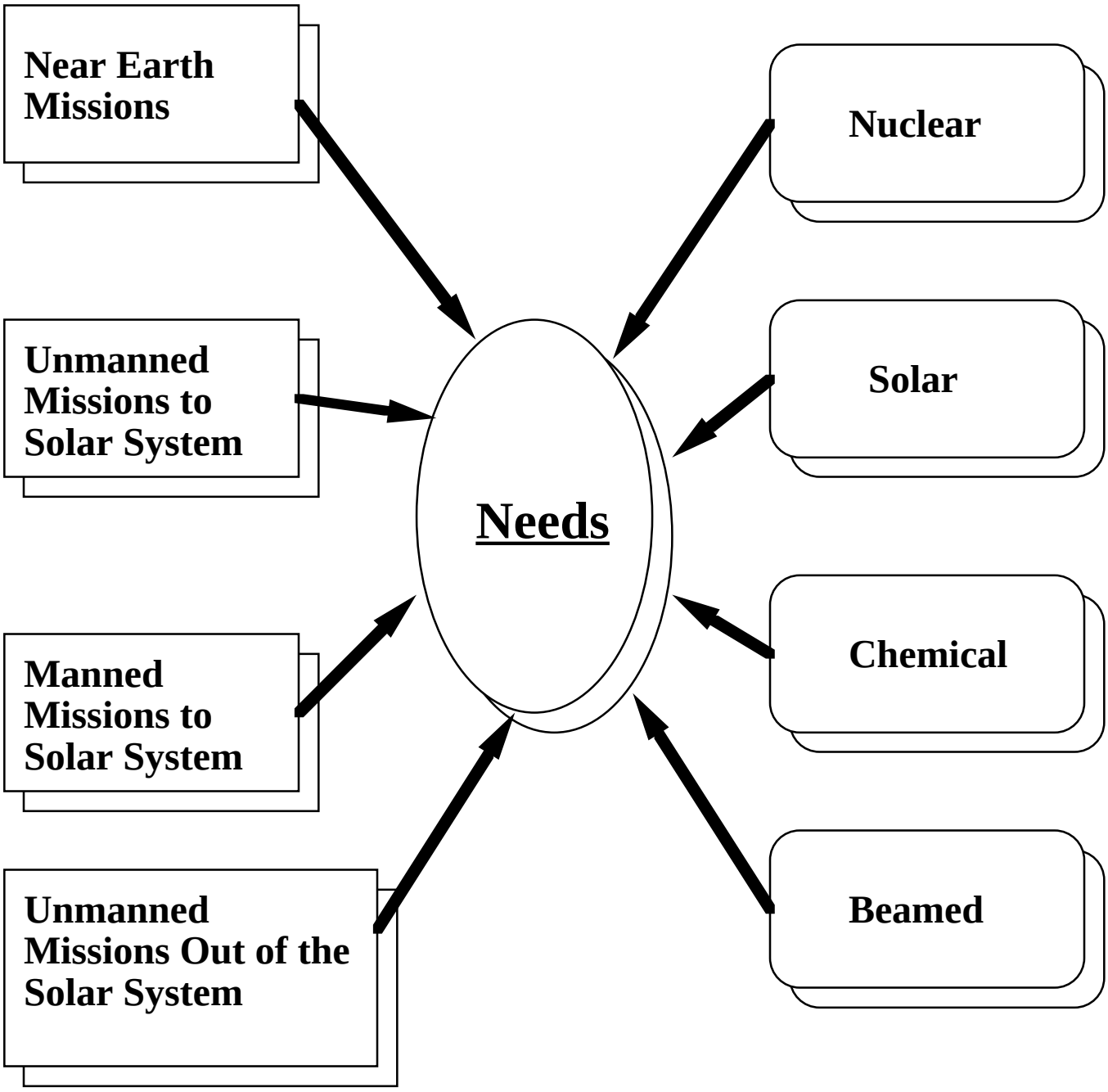
Requirements & Solutions to Power Needs in Space



Reasons That Solar Power May Not Be Appropriate For Specific Space Missions

1) Too far from the Sun to make use of solar power

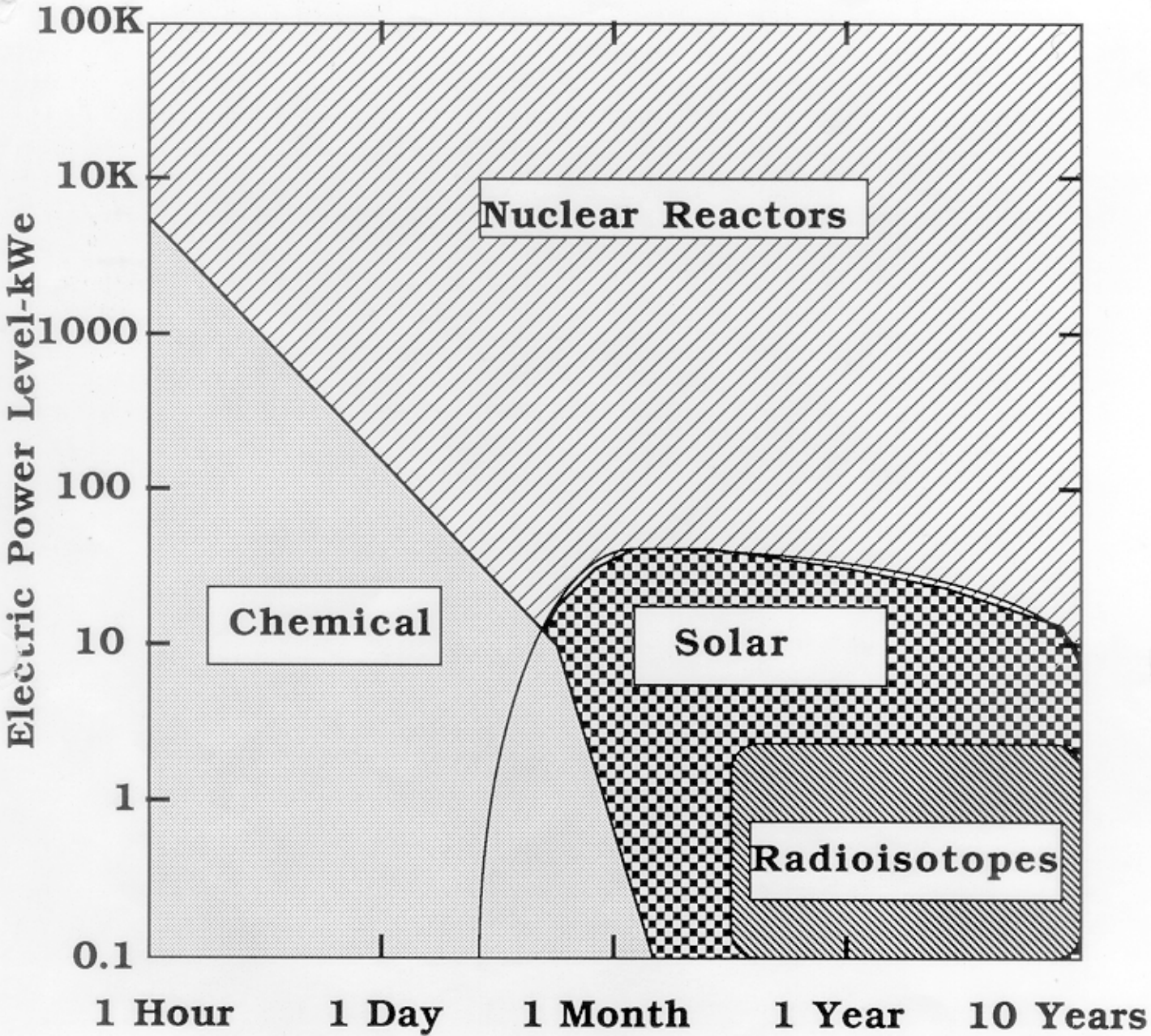
2) In a space radiation environment too harsh to allow sustained use of solar cells (e. g., very near to the Sun)

3) Landing near a planet's poles, where the illumination is insufficient

4) In night environments with time frames beyond practical battery capacity

5) On a dust- or cloud-enshrouded world, or in a subsurface application, where the use of solar power is impractical or impossible

Regimes of Possible Space Power Applicability



Near Earth Missions Requiring Space Power

Civilian

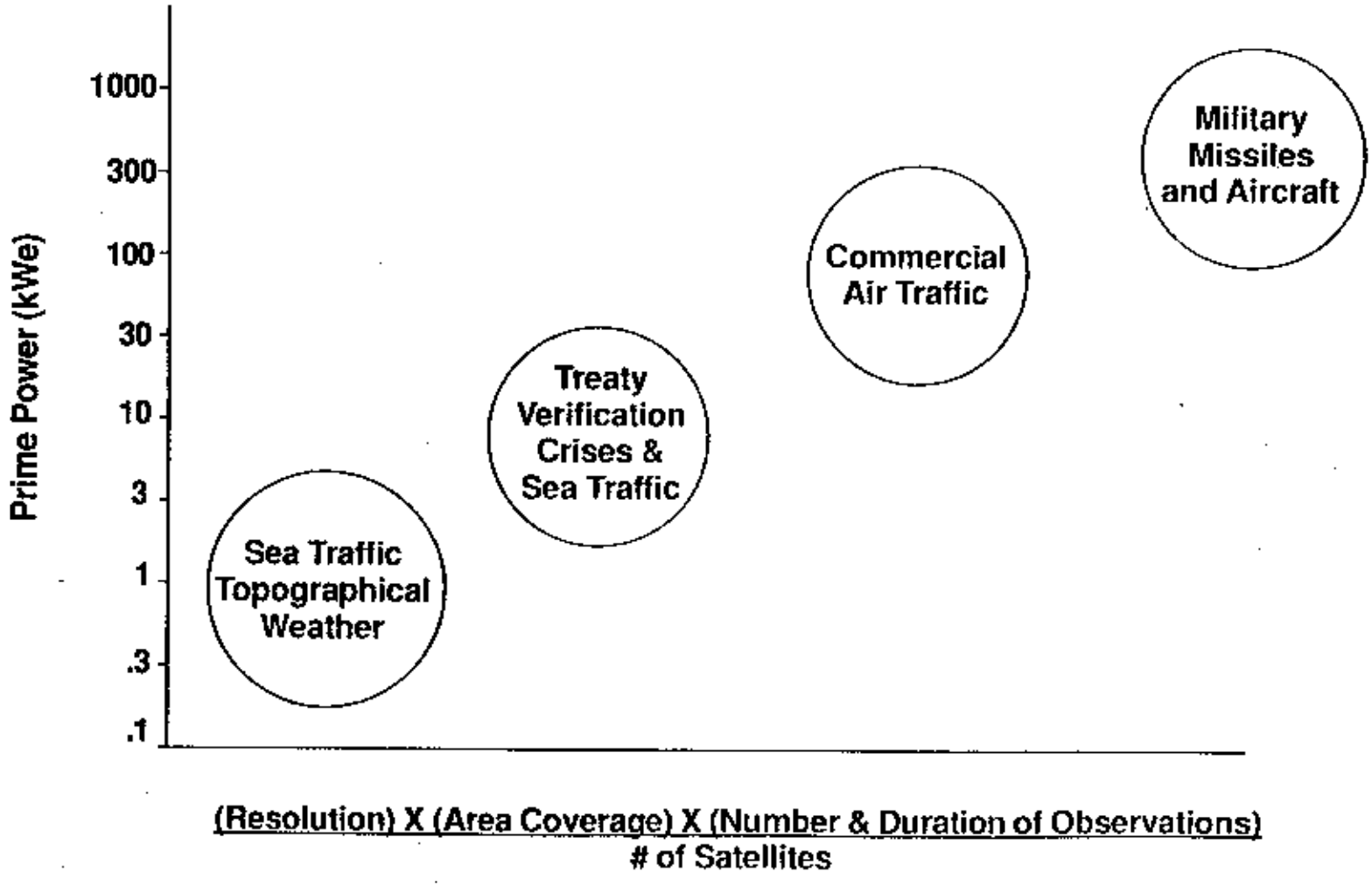
- **Broadcast Satellites**
- **Commercial Air Traffic Radar**
- **Space Shuttle**
- **Space Station**

Military

- **Monitoring, Control, and Tracking**
- **Strategic Defense Initiative**
    - **Station Keeping**
    - **Alert Mode**
    - **Burst Mode**

POWER REQUIREMENTS FOR SPACE BASED RADAR

Monitoring, Control and Tracking



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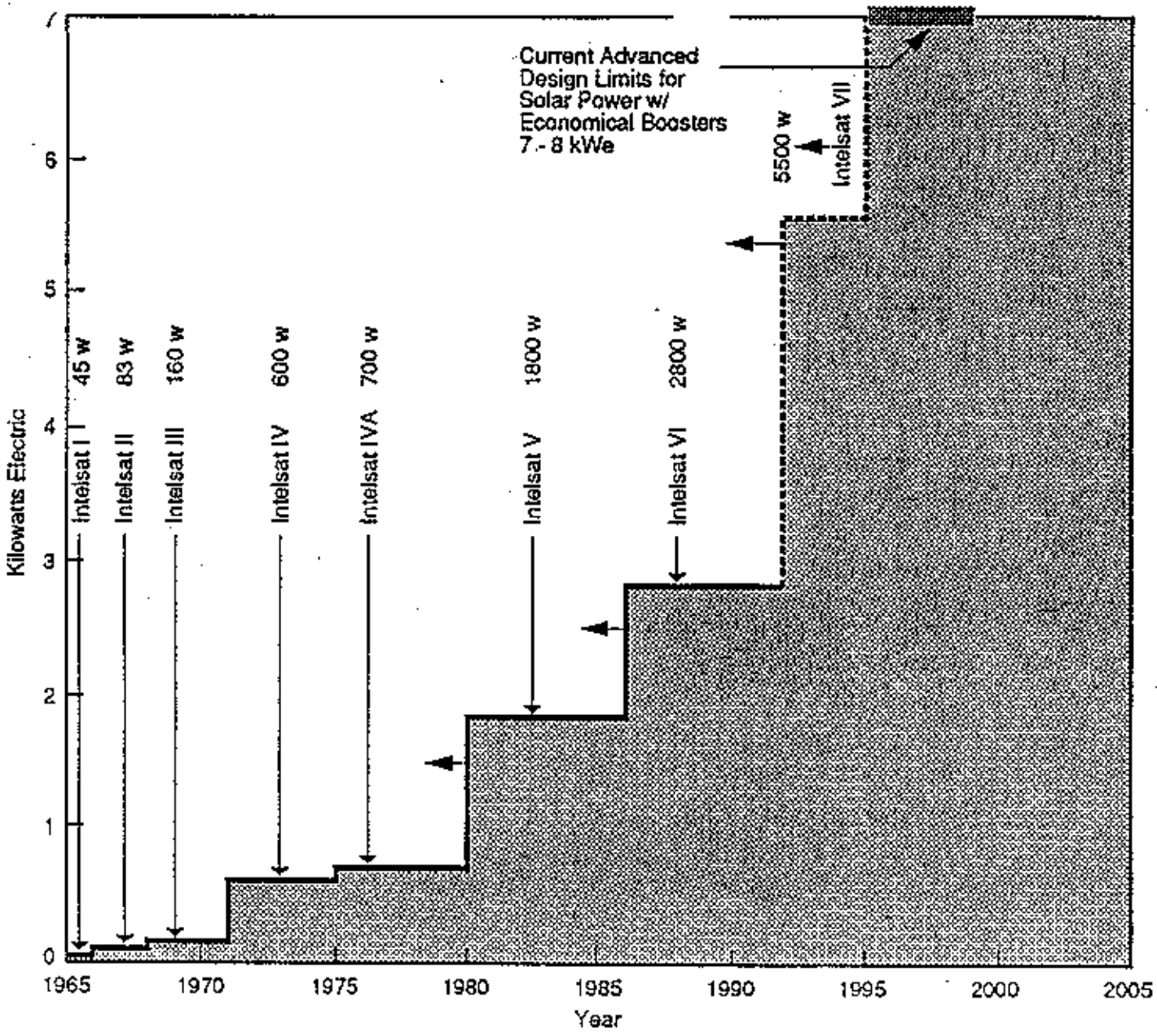


FIGURE 5. Commercial Communication Satellite Power Levels.

Iridium

- **66 Satellites, Motorola**
  (46 now up and rest in 1998)

- **Communicate anywhere in the world by hand held phone**

- **Operational ≈1998**

- **5 year life, 432 mile orbit**

- **30 $M each, 2 $B total**

- **500 W_e per satellite**

- **689 kg/satellite**

- **33 kW_e total system**
  (289 $MW_e h$/year)

International Space Station

- **Total requirement-105 kW_e continuous (Russian MIR ===> 30 kW_e)**

- **Two independent solar power supplies**

  U. S. =76 kW_e
  Russian = 29 kW_e

- **120 V DC for US and 28 VDC for Russian system**

- **American array is 108.6 ft by 240 ft**

  (≈ 26,000 ft^2, 54% of football field)

- **Mass ≈ 0.64 lb/ft^2, 16,640 lbs, 7.56 tonnes**

- **Power density ≈ 100 kg/kW_e**

- **Plus 24 batteries for US system (solar eclipse)- NiH,**

  US only: 370 lb(168 kg), life= 6.5 y

- **Plus coolant to keep batteries at 0-10 °C**

Military Power Needs in Space

Space Surveillance

• *Passive Infrared*	*20 kW*
• *Computers*	*50 kW*
• *Laser Radar*	
(Track)	*50 kW*
(Image)	*3,000 kW*

Space Radar — *5 MW*

Orbital Transfer Vehicle — *17 MW*

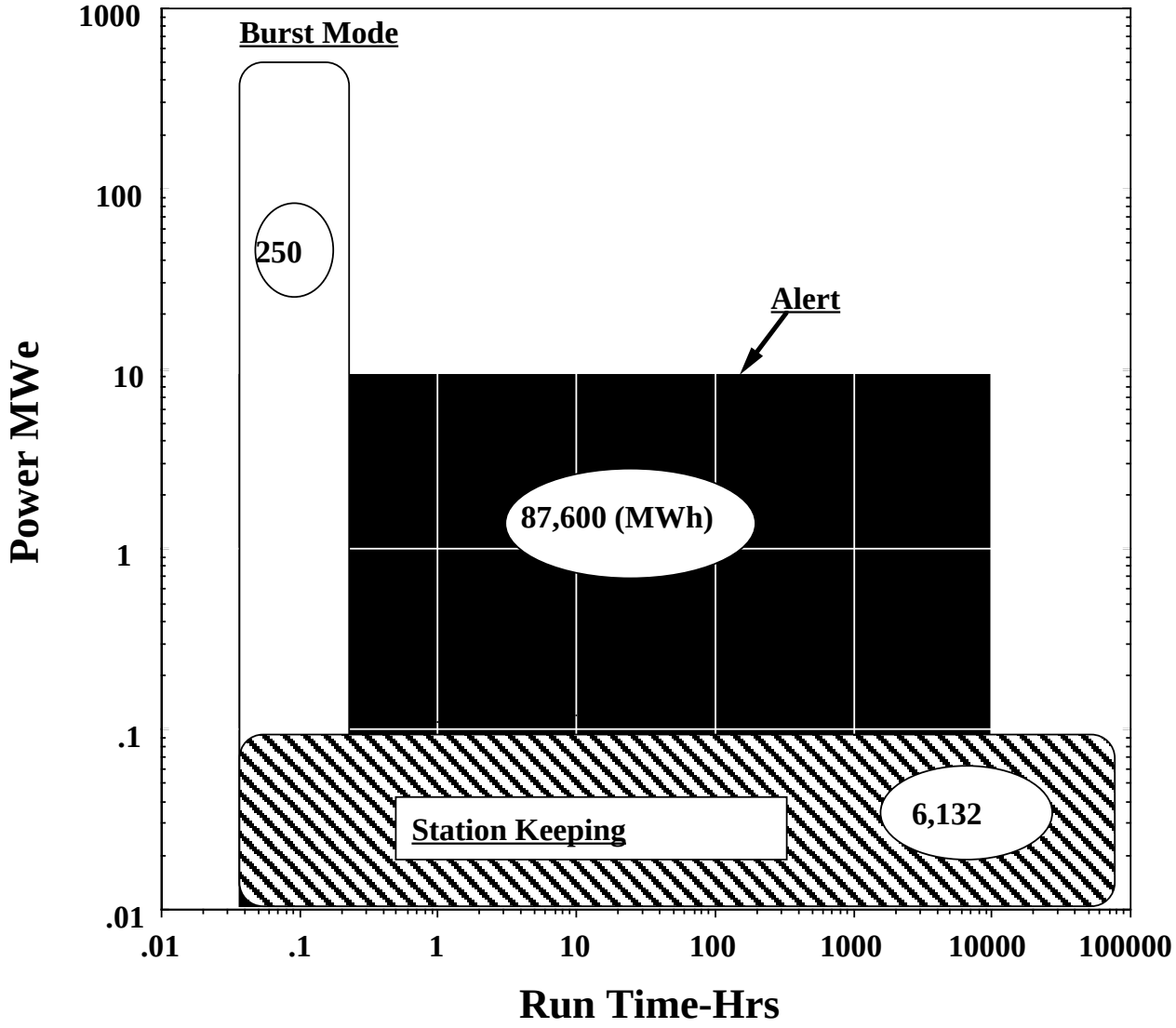
Weapons Platforms

• *Kinetic Energy Kill*	*100 kW*
• *Free Electron Lasers*	*up to 300 MW*
• *Neutral Particle Beam*	*up to 500 MW*
• *Electromagnetic Launchers*	*up to 500 MW*

There Are Three Levels of Power Required For SDI Applications

Mode	Time of Operation	Power, MW_e
Housekeeping	Continuous-7y	0.1
Alert	Up to 1 y	10
Burst	Up to 30 mins.	Up to 1000 MW_e

SDI Power Requirements



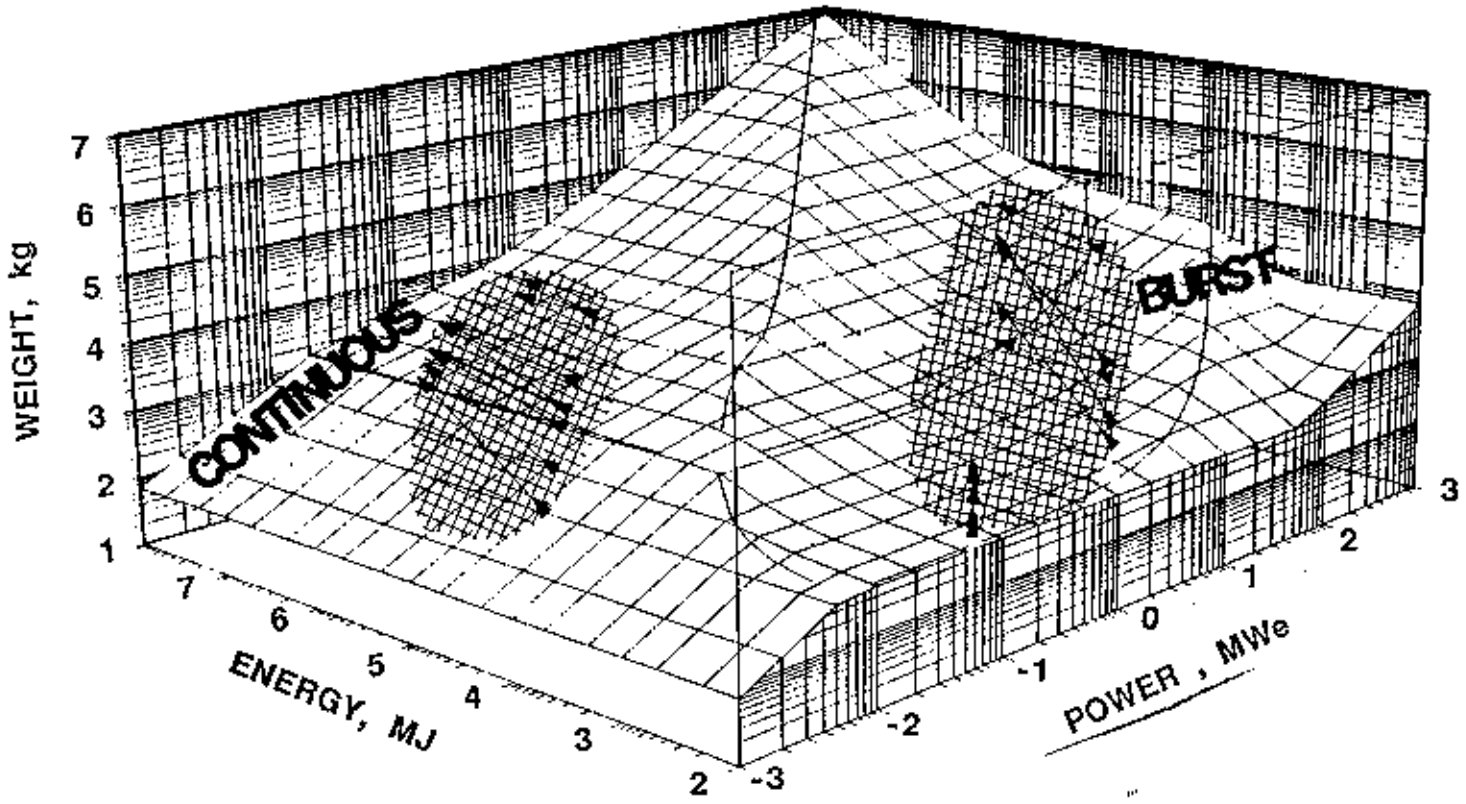


Figure 2. Forecasted Military Power Needs Regimes

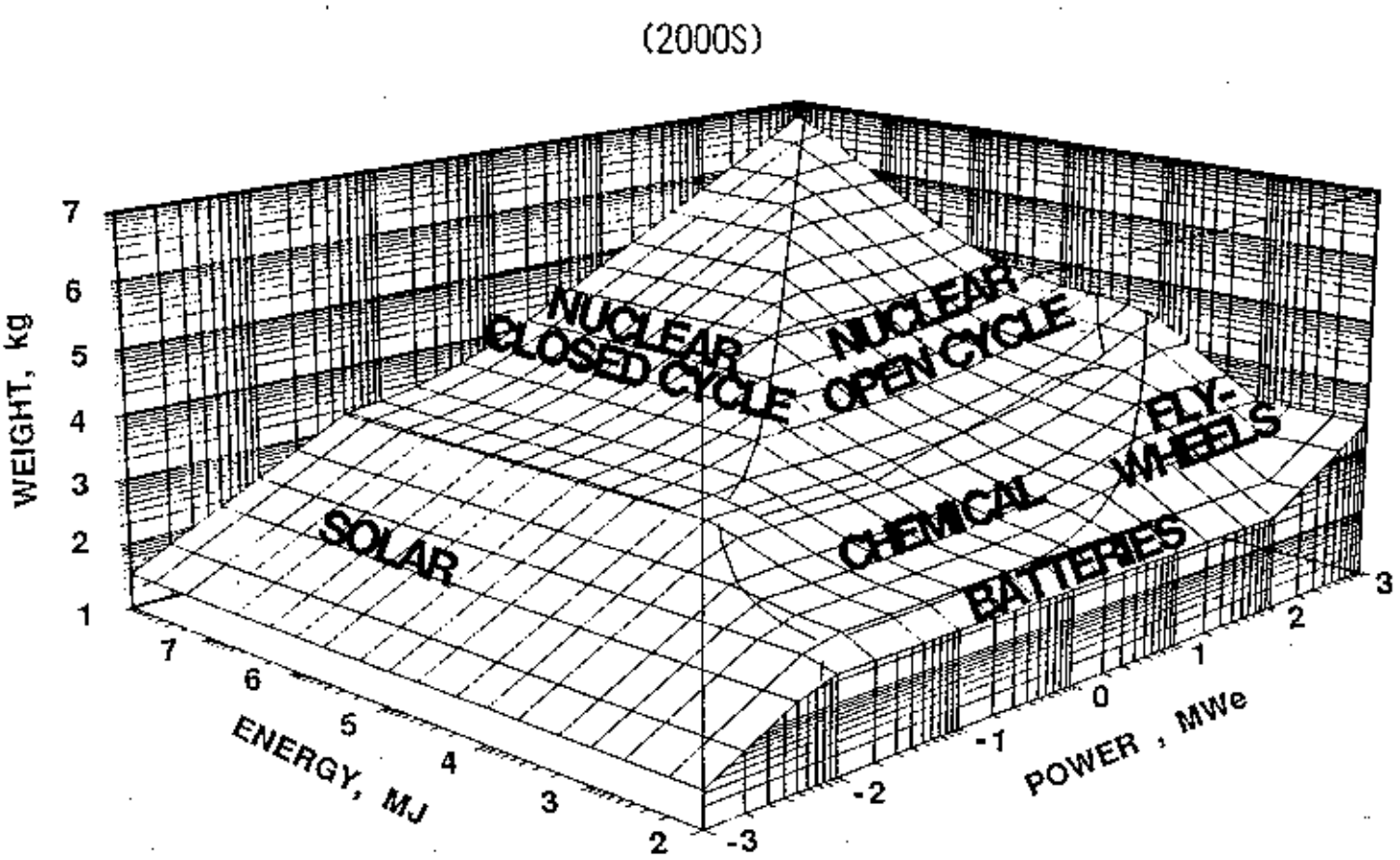


Figure 3. Forecasted Power System Wt. Vs Power & Energy Req.

Power Needs for Exploration of the Moon/Mars

Lunar Exploration

Year	Crew	Crew Duration-months
1995-2000	Robotic	-----
2000-2006	3-6	3-6
2007-2014	9-15	6-12
2015-2025	18-24	12

Mars Exploration

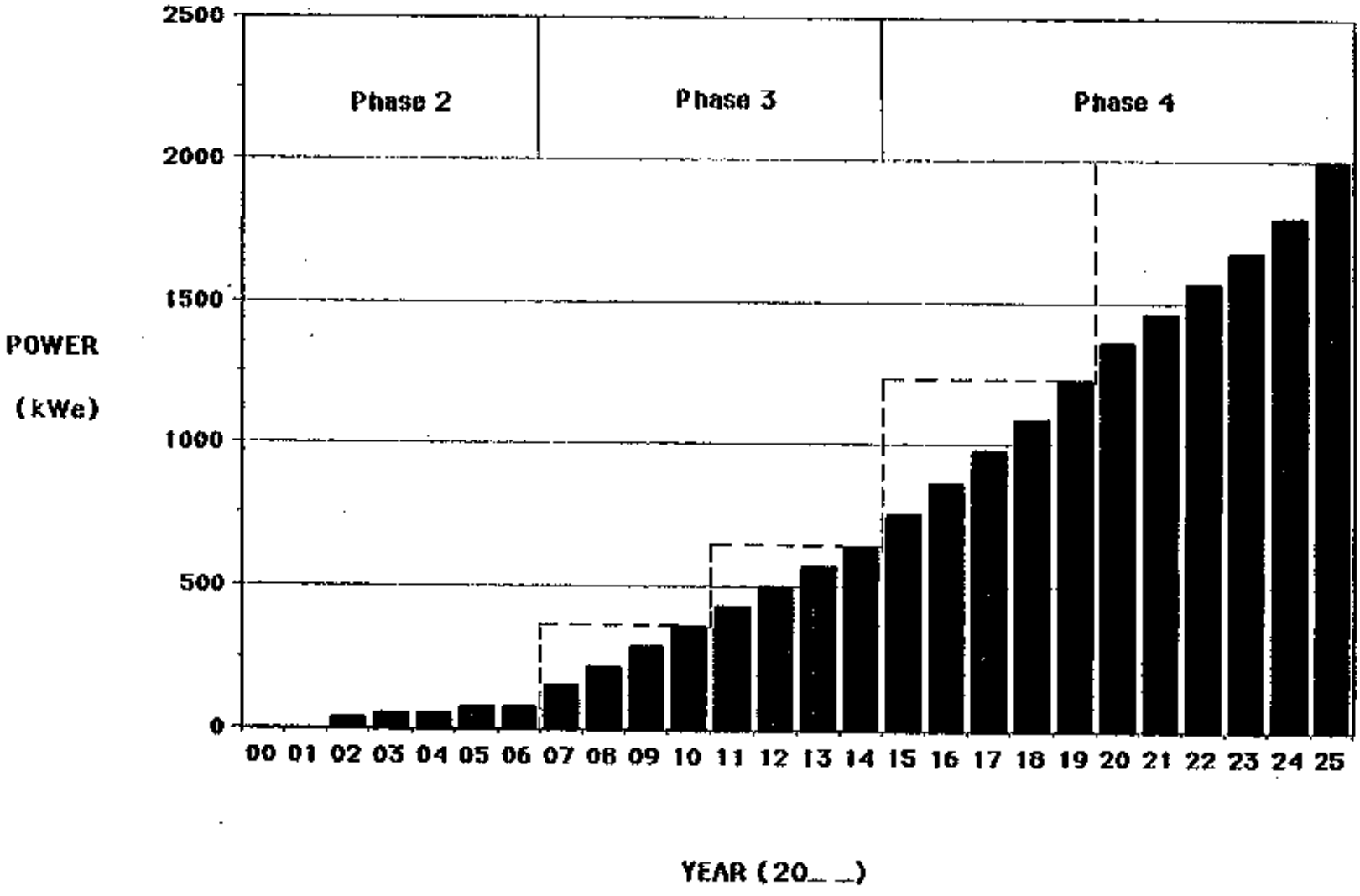
Year	Crew	Crew Duration-months
1992-2003	Robotic	------
2019	3-6	1-2 (stay)

TABLE 1

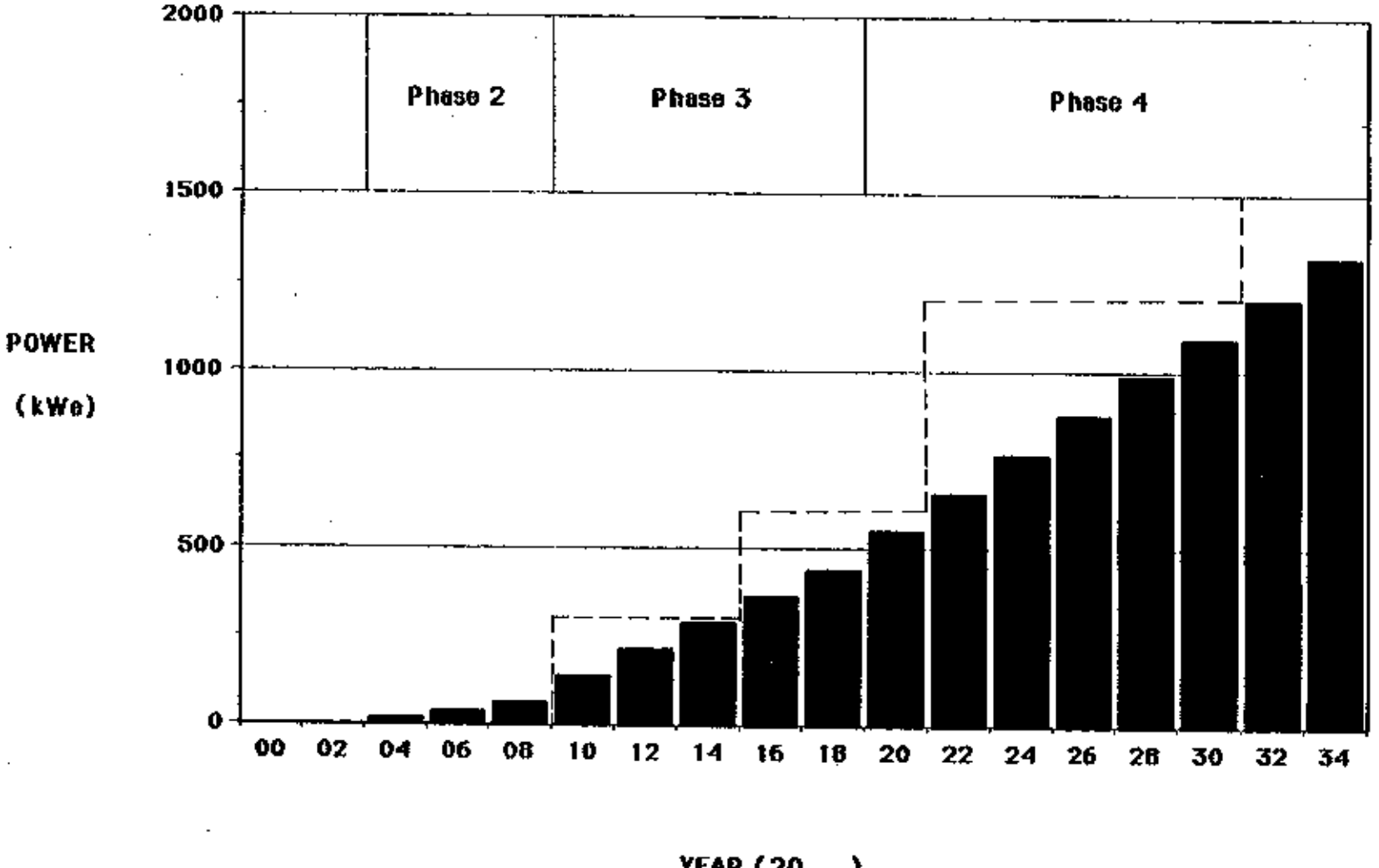
EVOLUTIONARY POWER REQUIREMENTS FOR LUNAR SURFACE BASE OPERATIONS

UNMANNED PRECURSOR	MANNED OUTPOST	INTERIM BASE	SUSTAINED BASE
2 KWe	100 KWe	500 KWe	2000 KWe
. ORBITER	. HABITAT (6 CREW)	. HABITAT (15 CREW)	. HABITAT (24 CREW)
. ROVER	. LABORATORY	. ADD'L LABS	. RESEARCH FACILITIES
.SAMPLE RETURN	. SCIENCE EXPTS	. EXTENDED SCIENCE	. SUSTAINED SCIENCE
. FARSIDE COMSAT	. LOX PILOT PLANT	. IN-SITU RESOURCES PLANT	. INCREASED LOX PRODUCTION
	. SITE PREP	. CELSS RESEARCH	. METALS PRODUCTION
	. ROVERS/TRAILERS	. SURFACE SURVEYS	. MANUFACTURING
	. LANDER/ASCENT VEHICLE	. MINING	. CERAMICS PRODUCTION
		. LOX PRODUCTION	. FOOD PRODUCTION
		. MATL'S PILOT PLANT	. PRODUCT EXPORT
		. REUSABLE LEM CARGO VEHICLE	. MASS DRIVER

LUNAR BASE POWER TIMELINE PROFILE – STEADY GROWTH



MARS BASE POWER TIMELINE PROFILE - STEADY GROWTH



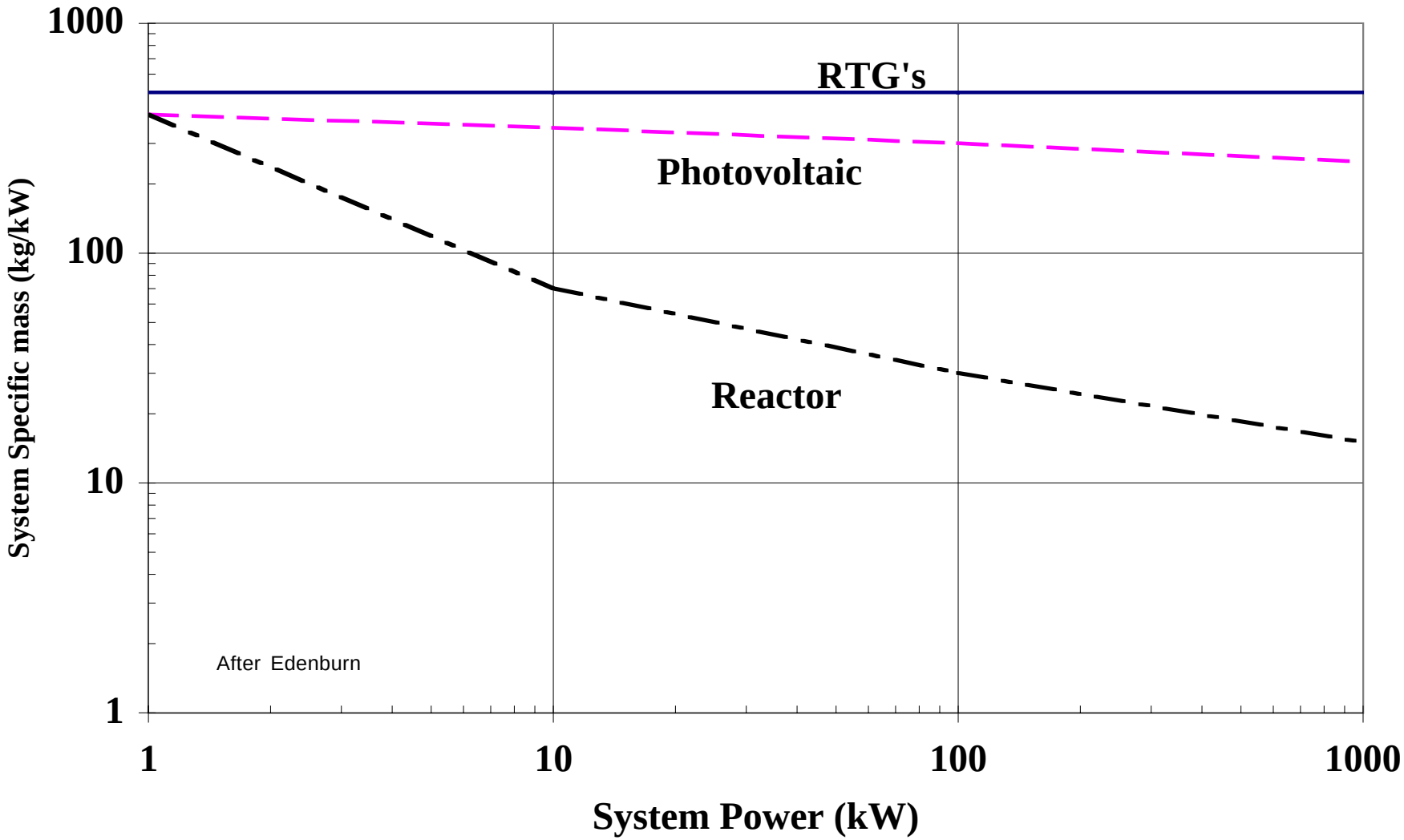
Proposal-Capture Worldwide Direct Broadcast HDTV Market

- **Market Value 9-20 $B/Sat-y**
- **5 GEO Satellites for Global Coverage**
- **Each with a 100 kW_e power supply for a K_u Band Transmitter**
- **Presently Hughes uses a 6-8 kW_e solar powered GEO satellite ($600M) for conventional TV**
- **Cost to Service Provider /Y for each subscriber**

  Fiber/Cable > $101/Y
  Direct Broadcast Satellite ≈ $2.52/Y

- **100 kW_e ==> 150 Channels of HDTV @ 3 Gbits/s**

Mass Requirements For Space Power



Mass Requirements for Space Station

Power System Mass for 100 kW_e

Solar ……..300 kg/kW_e

➔ 30 tonnes for Solar Panels

- Multiple shuttle launches (≈ 30 tonne total launch capability)
- In orbit assembly
- Large array size (1,000 m^2)
- Transport to GEO only 6 tonnes capability
- Batteries needed for “dark” periods

Nuclear…… 30 kg/kW_e

➔ 3 tonnes for nuclear

- Reentry possibility
- Political questions

Cost Considerations

- Historical Space Solar Power System Costs (30 reviews)
  - are $10,000-$12,500 per installed watt for DoD Applications
  - are ≈ $4,000 per installed Watt for Commercial applications
- Space Nuclear Power Costs are ≈ $1,000-$2,000 per installed Watt
  - For Solar ……..100 kW_e => $400-1,000 M
    (ISS is ≈ $20,000$/W_e)
  - For Nuclear …..100 kWe => $100-$200 M

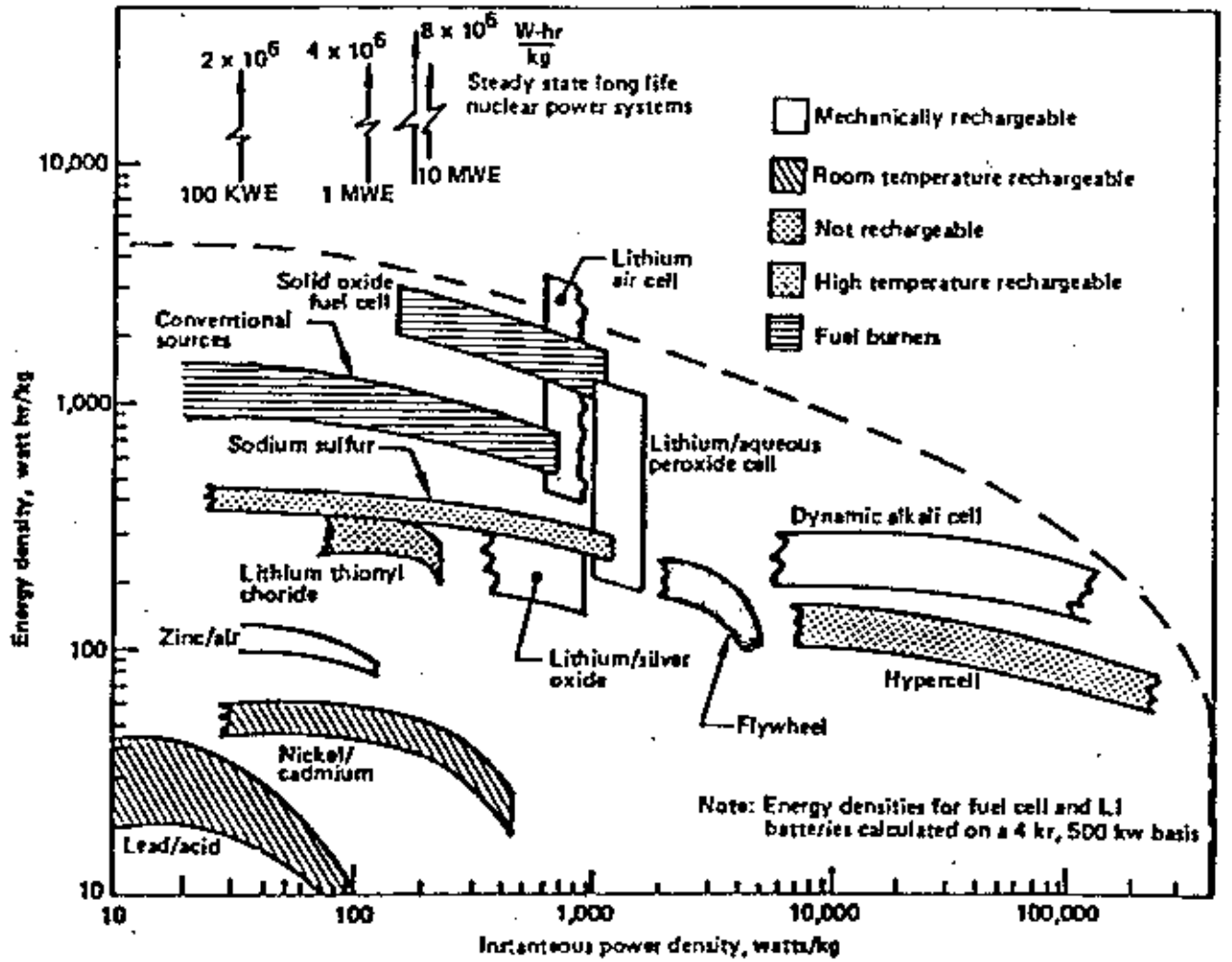

2 x 10^6
4 x 10^6
8 x 10^6 W-hr/kg
Steady state long life nuclear power systems
100 KWE
1 MWE
10 MWE
Mechanically rechargeable
Room temperature rechargeable
Not rechargeable
High temperature rechargeable
Fuel burners
Energy density, watt hr/kg
10,000
1,000
100
10
Solid oxide fuel cell
Lithium air cell
Conventional sources
Sodium sulfur
Lithium/aqueous peroxide cell
Dynamic alkali cell
Lithium thionyl choride
Zinc/air
Lithium/silver oxide
Hypercell
Flywheel
Nickel/ cadmium
Lead/acid
Note: Energy densities for fuel cell and Li batteries calculated on a 4 kr, 500 kw basis
10
100
1,000
10,000
100,000
Instantaneous power density, watts/kg

FIGURE AAA

U.S. SPACE POWER EXPECTATIONS

(TECHNOLOGY DETERMINED)