AIR FORCE SPACE POWER TECHNOLOGY PROGRAM

R. Barthelemy, Tom Mahefkey, and Tom Hebblewaite
AF Wright Aeronautical Laboratories
Wright Patterson AFB, Ohio

For the past several years the USAF program in spacecraft power technology has concentrated on obtaining major improvements in solar cell efficiency, solar array survivability, and secondary battery energy density. Because of the nature of USAF requirements in space and the limited resources available for the technology program, these areas offered the highest potential and the widest applicability. Further selectivity within these categories resulted in major programs in gallium-arsenide solar cells, nickel-hydrogen batteries, and radiation-resistant, high-temperature solar array components. These programs have been quite successful with the attainment of 18 percent GaAs solar cells, 15 W h/lb Ni-H_2 batteries, and array systems capable of operating at 500° C in high nuclear radiation environments. Future programs in these areas promise even greater improvements in these basic solar power system technologies.

Results of recent DOD space power studies show a trend towards higher power levels for future DOD missions. Consequently, the major new thrusts of the DOD space power technology program center on the development of military power systems which will extend capabilities to the 100 kW_e range by the year 2000 for the new classes of missions, while maintaining technology applicability to the 1 to 10 kW_e present (and continuing) mission class. Although NASA and COMSAT programs will provide space users with high power capabilities, they do not satisfy all military requirements, and the development of a high level, high-power-density survivable space energy technology is necessary. Plans call for technology, subsystem, and "integrated" power system efforts which emphasize performance, reliability, autonomy, and survivability. Distinct roles for both nuclear and solar power technology are envisioned.

In the next 5 years several new technology areas will be added to the baseline programs. Because of increasing military satellite power requirements and more complex spacecraft operations, efforts will be initiated to improve spacecraft power processing and thermal management. As these efforts mature, a program to integrate all technologies to provide high-power total-system capabilities will be initiated.

This briefing summarizes the military spacecraft power subsystem design requirements, development goals, and planned technology efforts.

The mission drivers of performance (weight and volume), hardening (survivability), autonomy, reliability, and miniaturization influence space mission effectiveness, cost, and in some cases feasibility in both direct and indirect fashions (fig. 1). Power system technology is mission enhancing in some cases and mission enabling in others. Both classes must be addressed in development efforts.

Survivability requirements are driven primarily by nuclear weapon and laser weapon threats (fig. 2). Both hardening and other survivability techniques (e.g., threat avoidance) are under consideration. Details of particular threats and survivability and/or hardening techniques are classified. Concentrating photovoltaic systems may find use for high threat environments, by virtue of the shielding of the cell affected by the optical components.

Increasing autonomy, that is, independence from ground station command and control, is required of military space systems (fig. 3). Power autonomy can be attained by self-management of power and fault processing, improved performance, and enhanced reliability.

Reliability (fig. 4) is in itself an important design driver for military space power systems. Military missions for LEO require 3- to 5-year life, while the GEO mission requires a 7- to 10-year life.

Performance requirements for military applications generally fall within the 1 to 5 kW_e regime for early applications (1980 to 1985) and may grow to the 25 to 50 kW_e range for some advanced surveillance applications in the 1985 to 1995 period (fig. 5). Isotope dynamic systems may find use for some special purpose applications (e.g., high hardness). Future high power applications may dictate development of a reactor power system for higher power.

Figure 6 shows the anticipated performance improvement trends for solar power systems obtainable via technology transition from present photovoltaic and battery types to more advanced devices. Major reductions in solar array weight will be realized through cell efficiency improvements via silicon to gallium arsenide to multibandgap cell transitions. Energy storage weight reductions will be placed by transition from nickel-cadmium to nickel-hydrogen to high-energy-density molten salt battery technology.

Figure 7 illustrates anticipated performance versus power level trends for reactor-static conversion systems. The technology for heat-pipe-cooled reactor thermoelectric systems could be system ready by early 1990's if development and qualification resources are invested in the 1980's. Higher temperature, higher performance reactor thermionic systems based on the same heat-pipe-cooled core to converter concept could yield energy densities of 50 W/lb or more, as compared with 25 W/lb for solar power, depending on the specific design concept and energy conversion scheme. Presently, DOE and NASA are pursuing only limited component technology development programs; major resource investments are required beyond the modest levels presently being invested if reactor power systems are to be prototyped and flight qualified and to become operational. The thrust of the high power missions for the 1980-2000 period may give impetus to enhance development. The nuclear reactor power system's projected energy density, inherent compactness, and probable ruggedness make it an ideal candidate for high power military applications requiring maneuverability, survivability, and long life.

The present Air Force power system R&D thrust is shown in figure 8. It encompasses basic (6.1), exploratory (6.2), and advanced development (6.3) in solar photovoltaics, metal gas batteries (e.g., Ni-H_2), and systems level power processing and thermal control. Coordination with DOE on reactor state of technology and applicability to military missions is also pursued.

Figure 9 shows a composite space power technology 6.1, 6.2, and 6.3 resource expenditure plan for the FY 1980-86 period. The Vanguard mission areas listed are those approved or advanced systems concepts which are anticipated users of this technology.

Figure 10 lists ongoing and planned development work unit tasks in the solar cell/array area. Major future thrusts are in GaAs and the multibandgap area.

The impact of this advanced array area is shown in figure 11, which compares conventional 8-mil silicon 5-mil coverglass flexible array weight and deployed area with improvements anticipated with advanced cell types.

Individual array hardening tasks against nuclear, laser, and particle beam type threats are shown in figure 12. Laser hardening of solar arrays is currently being pursued by the AFWAL Aero Propulsion Laboratory and the Materials Laboratory under both 6.2 and 6.3 (SMATH) programs.

Figure 13 shows the work unit breakout and time oriented development goals for battery technology. The major emphasis within the Air Force is in Ni-H_2 technology, now under advanced development. More advanced high-energy-density-battery (HEDB) concepts are presently being explored under 6.2 efforts and will enter advanced development in FY 1983.

The combined effects of improved array and battery performance is illustrated in figure 14. The shaded area represents the schematic weight decrease attainable in transitioning from Ni-Cd to Ni-H_2 and to higher performance, molten electrolyte batteries.

The tasks associated with thermal control and high power management, and their objectives are shown in figure 15. Thermal energy storage concepts could be used for heat driven cryocoolers. Thermal management and power processing for high power systems represent formidable outyear goals.

The evolving military space mission requirements are described in figure 16. Military operational uses of space were quite limited in the early 1960's. During the 1980's space will become an increasingly important military theater and by the turn of the century an important and vital segment of military communications, command, control, and force assessment. The future military use of near-Earth space will be to support and defend evolving civilian and military operations in space and to conduct traditional military functions supporting national defense objectives. Current and envisioned mission areas and functions in the mission categories of communication, surveillance, space operations, and defense impact power technology requirements.

Figure 17 illustrates a conceptual design for a space based radar (SBR) system. Several design alternatives are presently being studied by the Air Force, including a nuclear reactor powered configuration. National security requires surveillance inspection and monitoring of an adversary's weapon forces and their movements; this surveillance mission focuses on detection and attack warning. Power levels of approximately 10 to 100 kW are envisioned for radar and LWIR systems, due primarily to the need for active cryogenic cooling of the sensor.

The envisioned power requirements range as a function of IOC are shown in figure 18. The mission requirements and planned spacecraft developments give rise to both evolutionary and revolutionary power system design requirements. These requirements include life, performance, reliability, survivability, availability, and cost. The requirements may be divided into two major need categories, low power (evolutionary needs) and high power (revolutionary needs). All six of the power system design requirements are strongly influenced by the operational orbits of interest. Military orbits of interest include low Earth (400 to 600 m), both inclined and polar, half synchronous, synchronous, elliptical, and supersynchronous orbits. Interest in the later two orbit categories is based on their survivability advantages. The variety of orbits give rise to a variety of natural radiation dosages, a wide range of solar and eclipse conditions, diverse ambient thermal radiation environments, and a variety of potential weapons threat environments which must be addressed by the system designers.

The areas of common technical needs for the Air Force and NASA are summarized in figure 19. The growth towards 25 to 50 kW after 1985 seems certain. The NASA high power missions will likely center on large communication satellite applications; the military applications by surveillance missions. Both agencies must address STS-spacecraft design compatibility; throw weight to all but a few LEO's remains a design problem, hence a driver for high performance power systems. Improved array efficiency and energy storage density pace these performance needs. Reliability, life, power conditioning, and component weight introduce new performance requirements for high power systems which remain to be explored.

SPACE SYSTEM PARAMETERS

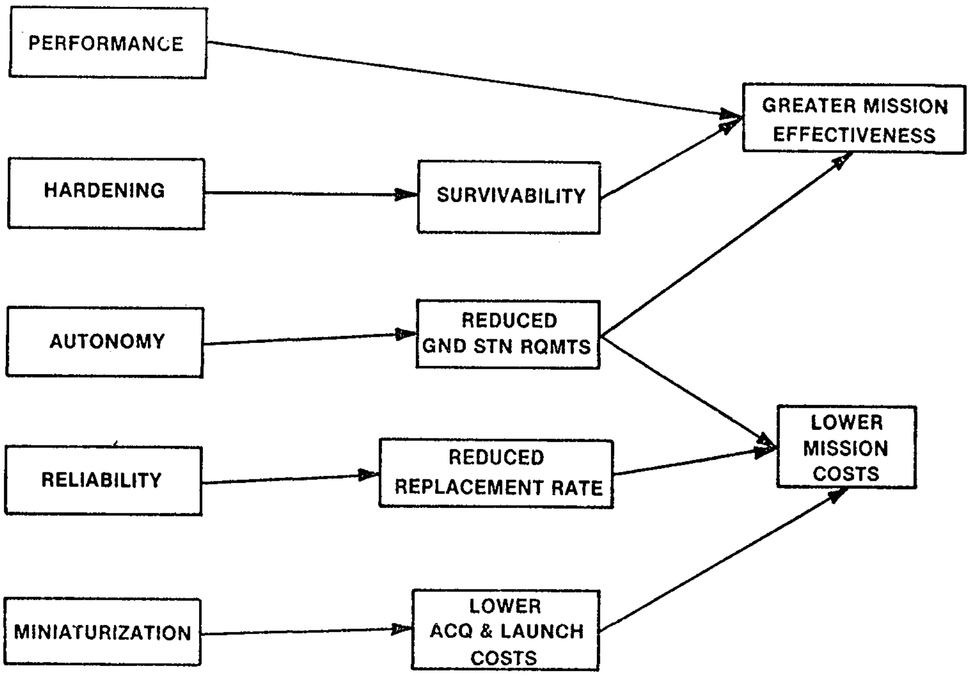


FIGURE 1

SURVIVABILITY

IMMEDIATE REQUIREMENTS (1980-1985)

☐☐☐NUCLEAR HARDENED ARRAYS (10 x JCS)
LOW LEVEL LASER HARDENED ARRAYS (SMATH I)
FLEXIBLE ROLL-UP ARRAYS
HARDENED, RECONDITIONABLE BATTERIES

MID-TERM REQUIREMENTS (1985-1995)

☐☐☐CONVENTIONAL WEAPON HARDENING
HIGH LEVEL LASER HARDENING (SMATH IV)
INCREASED NUCLEAR HARDENING
CONCENTRATOR ARRAY SYSTEMS
THERMAL MANAGEMENT SURVIVABILITY

FIGURE 2

AUTONOMY

IMMEDIATE REQUIREMENTS (1980-1985)

- LOW SIGNATURE SYSTEMS
- HIGH EFFICIENCY SOLAR ARRAYS
- HIGH PERFORMANCE POWER SYSTEMS

MID-TERM REQUIREMENTS (1985-1995)

- FAULT-TOLERANT BATTERY
- ULTRA-PERFORMANCE HIGH POWER SYSTEMS
- SMALL AREA SOLAR ARRAYS
- THERMAL ENERGY SYSTEMS

FIGURE 3

RELIABILITY

IMMEDIATE REQUIREMENTS (1980-1985)

- HIGH EFFICIENCY, LOW DEGRADATION SOLAR ARRAYS
- LONG LIFE NICKEL-HYDROGEN BATTERIES
- IMPROVED LOW ORBIT BATTERY CYCLE LIFE

MID-TERM REQUIREMENTS (1985-1995)

- 10-15 YEAR POWER SYSTEM LIFETIMES
- REDUCED BATTERY COMPLEXITY
- LOW ORBIT AND SYNC ORBIT POWER MODULES

FIGURE 4

PERFORMANCE

IMMEDIATE REQUIREMENT (1980-1985)

☐☐☐INCREASED PRIME POWER (1-5KWe)

- COMMUNICATION NAVIGATION METEOROLOGICAL SYSTEMS
- GEOSYNC ORBIT WEIGHT CONSTRAINTS
- SHUTTLE VOLUME / GEOMETRY CONSTRAINTS
- HARDENED SOLAR ARRAYS/Ni-H2 BATTERIES
- ISOTOPE DYNAMIC SYSTEMS

MID-TERM REQUIREMENT (1985-1995)

☐☐☐LARGE POWER DEMANDS (25-50KWe)

- DEFENSE AND SURVEILLANCE SYSTEMS
- SEVERE LIMITING GEOSYNC ORBIT WEIGHT CONSTRAINTS
- MODULAR SOLAR ARRAY/ADV BATTERY SYSTEMS
- NO REACTOR PROGRAM UNDERWAY

FIGURE 5

SOLAR POWER SYSTEMS

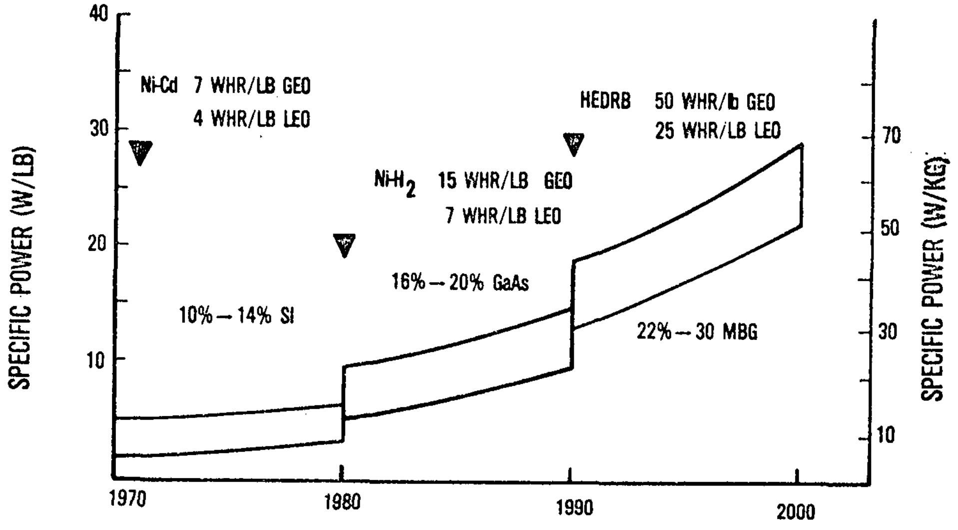


FIGURE 6

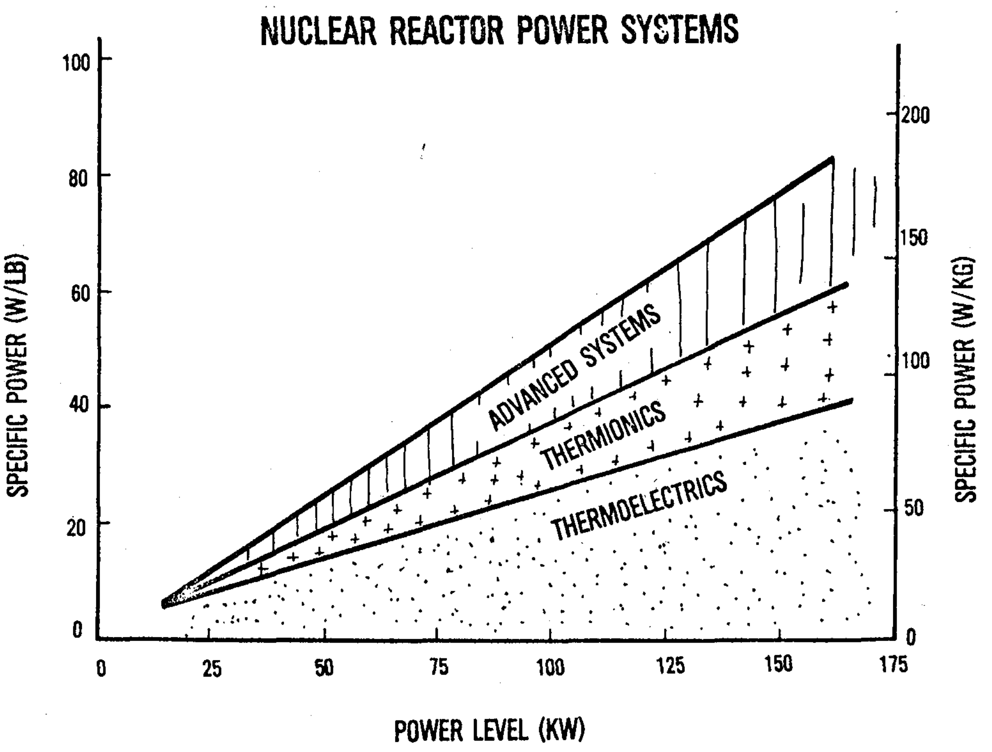


FIGURE 7

ENERGY CONVERSION BRANCH

SPACE POWER THRUST

- PROVIDE THE BASIC, EXPLORATORY, AND ADVANCED TECHNOLOGY FOR SPACE-ELECTRICAL POWER SYSTEMS
- SOLAR CELLS, SOLAR ARRAYS, METAL-GAS BATTERIES
- LIGHTWEIGHT, LOW VOLUME, NUCLEAR AND LASER HARDENED
- PROVIDE HIGH PERFORMANCE LOW POWER SYSTEMS
- DEVELOP HIGH POWER, SYNCHRONOUS ORBIT CAPABILITY
- PROVIDE TECHNOLOGY FOR SPACE THERMAL ENERGY SYSTEMS
- KEEP ABREAST OF SPACE NUCLEAR REQUIREMENTS AND TECHNOLOGY

FIGURE 8

SPACE POWER THRUST

TPO NO. 4

DEVELOPMENT GOALS: SO-1, SD-1, SD-3, SD-5, SD-6, C^3-1-6, TW-1, RI-1, L&OS

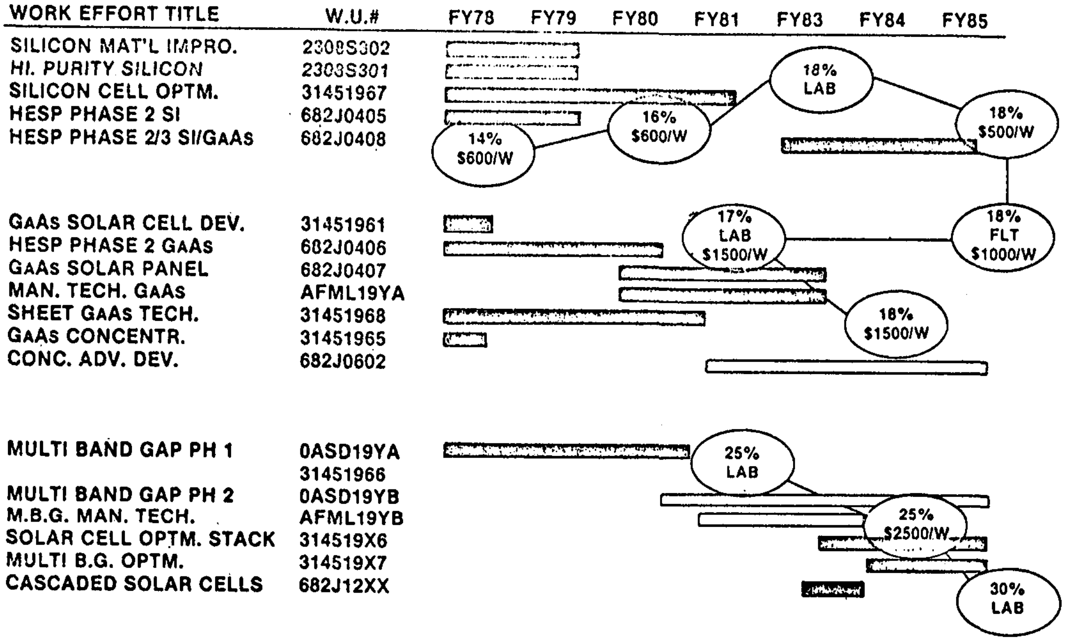
LABORATORY GOALS: HARDENED SPACECRAFT POWER SYSTEMS

VANGUARD MISSION AREAS SUPPORTED: STRATEGIC DEFENSE (SDSP, ASAP, SBR, DEW, DSSS); TACTICAL WARFARE (SDSP); RECCE/INTEL (ASAP, SBR); COMMAND CONTROL, COMMUNICATIONS (SDSP, SSS, DSCS, GPS, SATCOM); LAUNCH & ORBITAL SUPPORT; ENERGY

THRUST SUBELEMENTS	FUNDING $1000's						
	FY80	FY81	FY82	FY83	FY84	FY85	FY86
6.1	300	350	350	400	400	500	500
6.2	1344	1230	2327	2561	2865	2860	3605
6.3	1650	2300	1945	3200	5300	5500	7700
OTHER	300	500	(2000)	(2000)	(3000)	(5000)	(5000)
TOTAL	3594	4380	4622	6161	8565	8860	11805

FIGURE 9

SOLAR CELL DEVELOPMENT

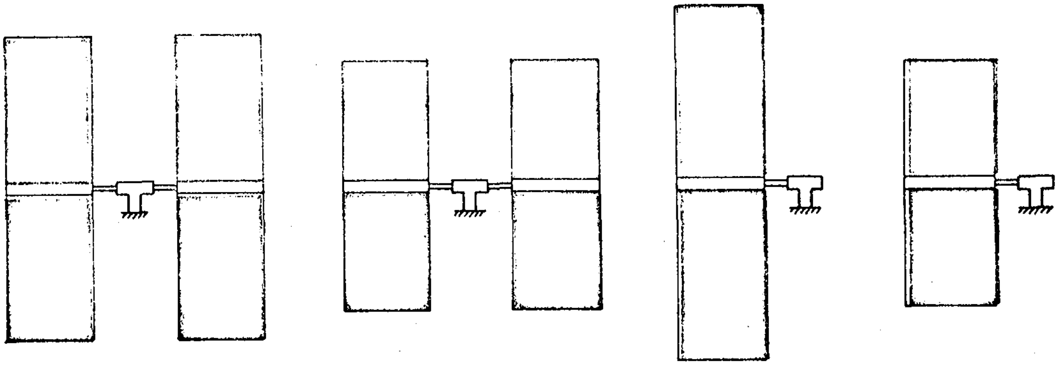


WORK EFFORT TITLE	W.U.#
SILICON MAT'L IMPRO.	2308S302
HI. PURITY SILICON	2303S301
SILICON CELL OPTM.	31451967
HESP PHASE 2 SI	682J0405
HESP PHASE 2/3 SI/GAAS	682J0408
GAAS SOLAR CELL DEV.	31451961
HESP PHASE 2 GAAS	682J0406
GAAS SOLAR PANEL	682J0407
MAN. TECH. GAAS	AFML19YA
SHEET GAAS TECH.	31451968
GAAS CONCENTR.	31451965
CONC. ADV. DEV.	682J0602
MULTI BAND GAP PH 1	0ASD19YA 31451966
MULTI BAND GAP PH 2	0ASD19YB
M.B.G. MAN. TECH.	AFML19YB
SOLAR CELL OPTM. STACK	314519X6
MULTI B.G. OPTM.	314519X7
CASCADED SOLAR CELLS	682J12XX

FIGURE 10

IMPACT OF ADVANCED SOLAR CELL TECHNOLOGY

(2KWe - 7 YRS. SYNC. ORBIT EOL)



CONVENTIONAL SILICON	ADVANCED SILICON	GALLIUM ARSENIDE	MULTI BANDGAP
AREA - 350 FT2	288 FT2	205 FT2	141 FT2
WEIGHT - 215 LBS	187 LBS	170 LBS	145 LBS

FIGURE 11

SPACE POWER THRUST ROADMAP

WEAPON HARDENING

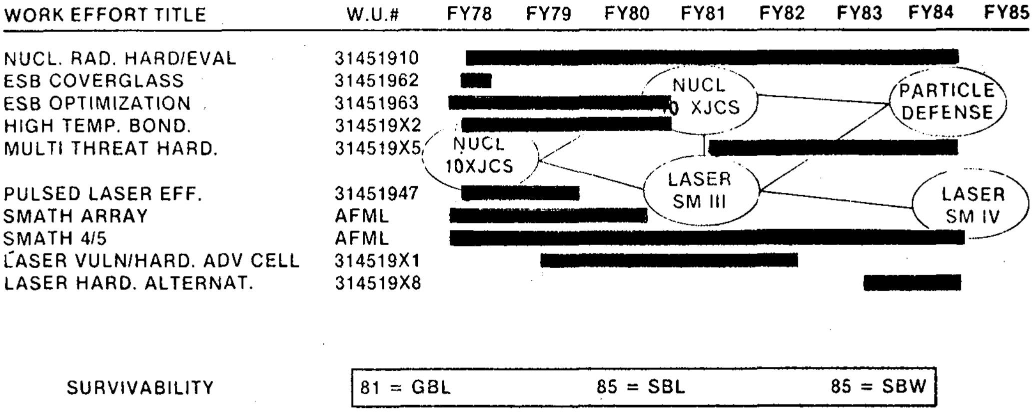
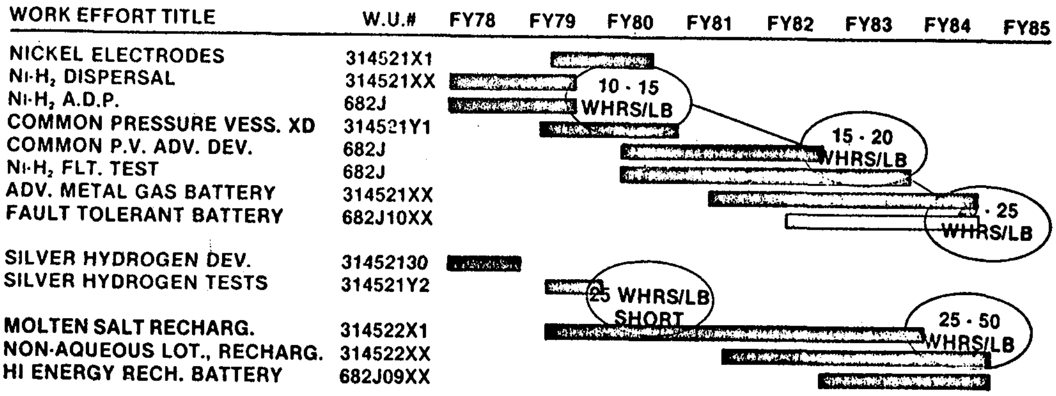


FIGURE 12

SPACE POWER THRUST ROADMAP

ELECTRICAL ENERGY STORAGE



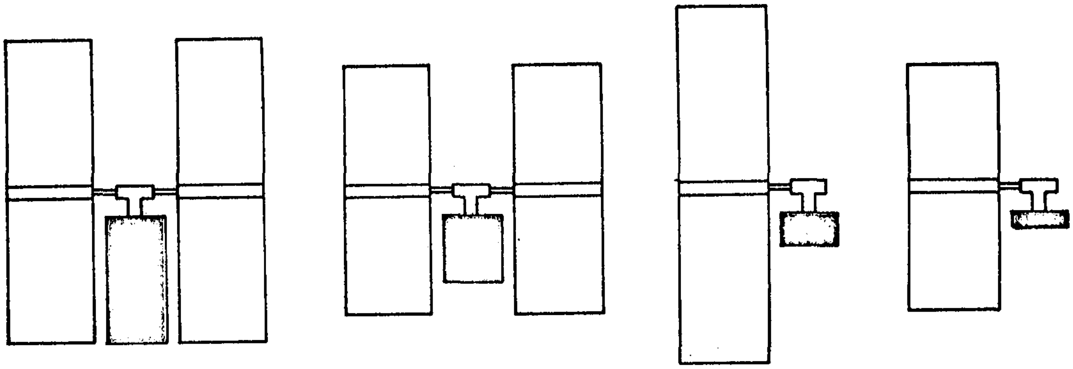
WORK EFFORT TITLE	W.U.#
NICKEL ELECTRODES	314521X1
Ni-H$_2$ DISPERSAL	314521XX
Ni-H$_2$ A.D.P.	682J
COMMON PRESSURE VESS. XD	314521Y1
COMMON P.V. ADV. DEV.	682J
Ni-H$_2$ FLT. TEST	682J
ADV. METAL GAS BATTERY	314521XX
FAULT TOLERANT BATTERY	682J10XX
SILVER HYDROGEN DEV.	31452130
SILVER HYDROGEN TESTS	314521Y2
MOLTEN SALT RECHARG.	314522X1
NON-AQUEOUS LOT., RECHARG.	314522XX
HI ENERGY RECH. BATTERY	682J09XX

PERFORMANCE | 1 WHR/LB ≈ $20 MILLION/YR (WT, LIFE, LAUNCH)

FIGURE 13

ADVANCED SPACE POWER SUPPLY TECHNOLOGY

(2 KWe - 7 YRS SYNC. ORBIT EOL)



CONVENTIONAL SILICON	ADVANCED SILICON	GALLIUM ARSENIDE	MULTI-BANDGAP
11% EFFICIENT SOLAR CELLS	14.5%	16%	25%
CONVENTIONAL Ni Cd BATTERY	ADVANCED Ni Cd	Ni-H2	HEDRB
4 WATT HRS/LB BATTERY	7 W-HRS/LB	16 W-HRS/LB	40 W-HRS/LB

FIGURE 14

SPACE POWER THRUST ROADMAP

THERMAL AND HIGH POWER

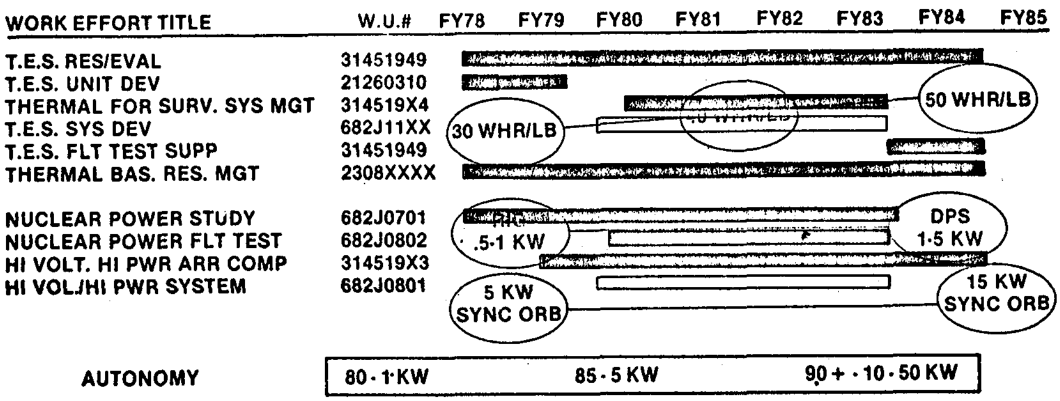


FIGURE 15

SPACE POWER THRUST

THE FUTURE

	1960	1980	2000
SCENARIOS			
STRATEGIC USSR	UNSALTED	SLIGHTLY SALTED	HEAVILY SALTED
OTHERS	NUCLEAR CONTROL	NUCLEAR PROLIFERATION	TOTAL PROLIFERATION
TACTICAL			
FIRST CLASS CAPABILITY	FEW	MANY	MAJORITY
SPACE DEPENDENCE/UTILIZATION			
STRATEGIC SURVEILLANCE	NONE	IMPORTANT	CRITICAL
TACTICAL SURVEILLANCE	NONE	SOME	IMPORTANT
TACTICAL NECESSITY	NONE	HELPFUL	NECESSARY
COMMUNICATIONS	NONE	50 %	100 %
SPACE DEFENSE	NONE	NONE	SOME

FIGURE 16

SBR Conceptual Design

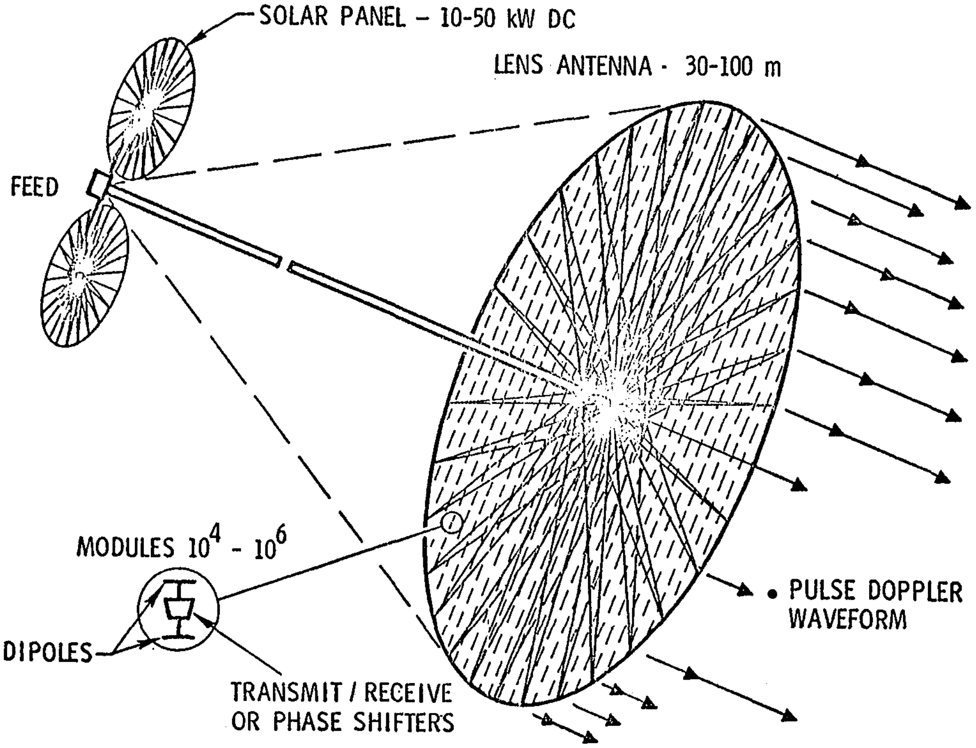


FIGURE 17

SPACECRAFT POWER REQUIREMENTS
1980 - 2000

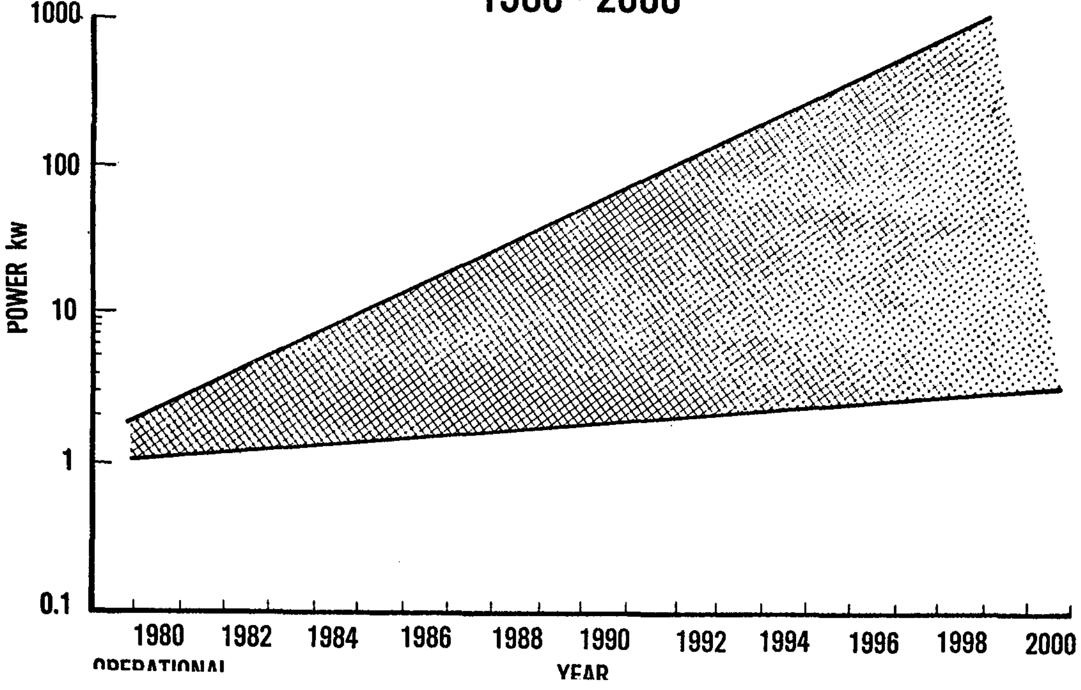


FIGURE 18

AREAS OF COMMONALITY

25 - 50KW POWER REQUIREMENTS (1985+)

SHUTTLE/IUS LAUNCH COMPATIBILITY

HIGH PERFORMANCE/LOW COST GOALS

ELECTRIC POWER/THERMAL MANAGEMENT REQUIREMENTS

FIGURE 19