MILITARY NEEDS FOR ORBITAL POWER

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SUMMARY

Results of the DOD/ERDA (now Department of Energy) Space Power Study completed in October 1977 show a trend toward higher power levels for future DOD space missions. Consequently, the major new thrusts of Air Force Advanced Technology Plans center on the development of military solar power systems which will extend capabilities to the 10-50 KW_e power range for new classes of missions while maintaining technology applicability to the .5 to 10 KW_e present mission class. Plans call for technology level, subsystems level, and integrated power system level efforts. These efforts will emphasize performance, reliability, autonomy and survivability.

INTRODUCTION

The objective of the Air Force Space Power Advanced Development Program (Project 682J) is to develop and demonstrate space power system technology to meet increasing power needs of Air Force Satellites in the post-1978 time period.

Past 682J efforts which have successfully transitioned to operational applications include the Flexible Rolled-Up Solar Array (FRUSA), Hardened Array Solar Power System (HASPS), and the 2 KW_e Long Life Battery (LLB). The 1.5 KW_e FRUSA was successfully flown on Space Test Program Vehicle 71-2. The HASPS has been selected for meeting the 7.3 KW_e prime power requirement of the SIRE (Space Infrared Experiment) P80-2 mission. The 2 KW_e LLB effort provided the baseline technology from which the 14.3 watt• hrs/Kg (6.5 watt• hrs/Lb) FLTSATCOM battery evolved.

The present FY78 efforts in Project 682J include the multiple phase Task 682J04 High Efficiency Solar Panel (HESP), Task 682J05 Nickel-Hydrogen Battery (Ni/H2), a recently completed Task 682J06 Gallium Arsenide Solar Concentrator Hardness Study (Concentrator) and a February 1978 Task 682J07 new-start Nuclear Dynamic Power System Applications/Integration Study.

In view of findings and conclusions of the DOD/ERDA Space Power Study Report, the Technology Program Plan for Space Power Advanced Development was recently modified to address the projected trend toward higher power levels and an enhanced threat environment for military satellites. The new planning initiatives include a Task 682J08 High Voltage High Power (HVHP)

System; Task 682J09 High Energy Density Rechargeable Battery (HEDRB); Task 682J10 Fault Tolerant Power System (FTPS); Task 682J11 Thermal Energy Storage Subsystem (TESS) and Task 682J12 Cascaded Solar Cell Development Program.

STATUS OF PRESENT EFFORTS

Task 682J04.- HESP Phase I has been completed with the demonstration of silicon solar cells having efficiencies of 14 percent. HESP Phase II has been initiated with the objective of demonstrating 16 percent efficient silicon cells and improved experimental quantities of 16 percent efficient gallium arsenide cells. Under HESP Phase II, recent silicon and radiation-hardened gallium arsenide developmental cells delivered to AFAPL have demonstrated efficiencies as high as 15.5 and 17 percent respectively. Radiation resistance of gallium arsenide cells has been improved to the point where some cells are superior to high output silicon cells at 1-Mev electron fluence levels as high as 5×10^{15} e/cm^2 as shown in Figure 1. As shown in Figure 2, temperature coefficients of gallium arsenide cells are clearly superior to those of silicon, making gallium arsenide cells attractive for Concentrating Photovoltaic Power System Concepts. Gallium arsenide cells have favorable values of solar absorptance (α = .78) as compared to silicon (α = .85, smooth surface cells; α = .94, textured surface cells). Both HESP textured silicon cells and gallium arsenide cells being flown as experiments on the NTS-II (Navigation Technology Satellite) are performing well after more than 223 days in orbit. Both cell types are to be included in the forthcoming DIABLO HAWK underground nuclear test.

Task 682J05.- In the area of rechargeable batteries, Ni/H_2 cell design has been completed and the initial group of twenty-six (26) test cells are being manufactured for evaluation. In addition NASA Marshall Space Flight Center has provided funds for two Ni/H_2 cells for independent test and evaluation. Twenty-four (24) cells will be built in the spring of 1978 for an Industry Dispersal Program under which independent industry tests will be conducted. The Naval Research Laboratory has expressed interest in utilizing the Air Force developed Ni/H_2 cells on NTS-III scheduled for launch in 1981. Negotiation of a Memorandum of Agreement between the Air Force and Navy pertaining to the NTS-III cells is anticipated during the second quarter of 1978. It is presently estimated that a total of forty-eight, 35-ampere-hour cells would be required for meeting NTS-III requirements. Sixteen of the forty-eight cells would be assembled into a high performance battery, integrated, and utilized as the NTS-III energy storage subsystem. A successful orbital test of early vintage Ni/H_2 cells has already been conducted on a SAMSO Special Projects Vehicle. The advanced development program Ni/H_2 cells currently being fabricated are expected to be vastly superior to these early vintage cells already flown in space in terms of cycle life, depth of discharge and energy density. Figure 3 is a schematic of the 50-ampere-hr Ni/H_2 cell design. Figure 4 is a photograph of the 21-cell Ni/H_2 battery flown on the SAMSO/SP Vehicle. Table I is a preliminary weight breakdown for a 1.15-KW-Hr Ni/H_2 Battery based upon a Hughes Aircraft Company conceptual design.

Task 682J06.- A gallium arsenide cell concentrating photovoltaic concept recently studied under a Contract with Rockwell International is considered to be a promising technology option for advanced laser threat hardness. The concept utilizes Cassegrainian optics in conjunction with a Winston collector to focus sunlight on a single high efficiency gallium arsenide cell at a concentration ratio of about 500 to 1. Cell operating temperature is maintained at approximately 120°C by an integral, distributed heat pipe radiator. The final study report (AFAPL-TR-78-30) pertaining to this concept will be distributed in June 1978.

Task 682J07.- The recently initiated Nuclear Dynamic Power System Applications/Integration Study will provide the analysis, design, and spaceflight integration considerations needed to assure a successful space demonstration of a 1.3-KW_e radioisotope-fueled dynamic power system. An important part of this study will deal with analyzing future special purpose Air Force missions which will benefit from this technology. In addition, the program will provide for (a) analysis of requirements for integration and orbital operations, (b) evaluation of nuclear and laser hardness, and (c) develop preparatory information needed for the assessment of safety and environmental impacts. The overall program is to assure Air Force applicability of the DOE Nuclear Dynamic Power System Technology.

FUTURE PLANS - APPROVED PROGRAM

Future space power advanced development plans, within the approved program, are primarily extensions of present efforts and include the following: (a) Gallium Arsenide Solar Panel work which is directed toward panel design, fabrication and spaceflight qualification; (b) HESP Phases III and IV which are for advanced cell production demonstration, flight experiment design, experiment spaceflight qualification and orbital flight test; (c) completion of single-cell Ni/H_2 efforts through orbital flight test and implementation of a Common Pressure Vessel Ni/H_2 program; (d) implementation of a Concentrating Photovoltaic Power System hardware build and evaluation effort; and (e) completion of the Nuclear Power Supply Study in support of space payload AFAPL 601 - Nuclear Dynamic Power System Flight Experiment.

Figure 5 is a Milestone Chart which encompasses present efforts and future plans within the approved program. The chart shows anticipated technology advances and when they are expected to occur, based upon present budget allocations. For example, 16 percent efficient space-qualified solar cell assemblies are expected in 1980. Demonstration of advanced solar cells through a 20,000-cell flight test is expected by 1983. Conclusive demonstration of single-cell Ni/H_2 batteries through flight test on NTS-3 should occur in 1981. Flight test of a Nuclear Dynamic Power System is scheduled for 1983.

Overall results of these efforts, compared to conventional technology, will double the end-of-life power per unit area of solar arrays, more than double the useable energy density of spacecraft energy storage subsystems, and make new power technology options such as Concentrating Photovoltaic and Nuclear Dynamic Power Systems available for special purpose DOD satellite applications.

RESULTS OF DOD/ERDA SPACE POWER STUDY

A DOD/ERDA Space Power Study was conducted during the period from February 1976 to May 1977. A preliminary report summarizing the results of this study was issued in October 1977. The objectives of the study were to identify future DOD space power requirements and recommend appropriate nuclear and non-nuclear technology development programs needed to ensure that future power requirements can be met. Study participants included SAMSO, AFAPL, ERDA (DOE), LASL, and industry. Study tasks included (a) future requirements through the year 2000, (b) nuclear and non-nuclear technology projections through the year 2000, (c) matching power systems and requirements, (d) spacecraft point designs for one navigation satellite and two surveillance satellites, and (e) recommendations.

Results of the study indicate that the majority of future single spacecraft power requirements will be in the .5 to 10 KW_e power range. However, the study also identified a significant number of potential missions with power requirements in the 10 to 100 KW_e range and beyond as shown in Figure 6. Most of the high power requirements tend to be in the surveillance, space defense systems, ECM resistant communications, and offensive systems areas. Requirements exist for electrical, thermal, and pulse power with some potential missions requiring a combination of all three power forms.

Table II presents the general findings of the study dealing with matching of power systems to mission power requirements. The approved model and extended mission model scenarios cover the .5 to 100 KW_e and beyond power regime. Solar array/battery power systems are the number one choice in the .5 to 5 KW_e range. Within this range there are special purpose isotope applications for missions where precise attitude control and stabilization, extreme hardness, and maneuvering capabilities are needed. In the 5 to 25 KW_e range, solar array/battery power systems are the first choice. There are no isotope applications in this range because of the high cost of the radioisotope fuel. Either solar array/battery power systems or a reactor, if it were available, could fulfill needs in the 25 to 50 KW_e range. A reactor would be the number one choice for power requirements beyond 50 KW_e, with solar array/battery systems being feasible in this range.

FUTURE PLANS-LABORATORY RECOMMENDED PROGRAM

Future potential mission requirements as identified in the DOD/ERDA Space Power Study have been factored into future technology program planning for space power advanced development. The Technology Program Plan was recently revised to reflect need for the following new initiatives:

- Task 682J08 - High Voltage High Power System
- Task 682J09 - High Energy Density Rechargeable Battery
- Task 682J10 - Fault Tolerant Power System
- Task 682J11 - Thermal Energy Storage Subsystem
- Task 682J12 - Cascaded Solar Cells

Task 682J08 is to develop a strong technology base for a DOD Power Module (10 to 50 KW_e) with a counter-measures capability; Task 682J09 will develop a rechargeable electrochemical battery capable of 66 watt-hrs/Kg (30 watt-hrs/Lb) for low earth orbit (LEO) and 110 watt-hrs/Kg (50 watt-hrs/Lb) for geostationary (GEO) orbit applications; Task 682J10 will demonstrate an autonomous power system where all elements of the system are controlled by local microprocessors in conjunction with a power system microcomputer; Task 682J11 will develop a 110 watt-hr/Kg (50 watt-hr/Lb) thermal energy storage subsystem for Vuilleumier (VM) cryocoolers for surveillance applications; Task 682J12 will develop 25-35 percent efficient monolithic cascaded multiple bandgap solar cells.

Anticipated results of the AFAPL Research and Exploratory Development Programs during the next 2 to 5 years were considered in developing the revised Technology Program Plan for Advanced Development.

Figure 7 is a Milestone chart which pertains to the laboratory-recommended new initiative program plans. The chart shows the expected technology advances and when they are expected to occur if the programs are approved and budgeted. Overall results of these efforts, compared to conventional technology, would triple the end-of-life power per unit area of solar arrays; more than quadruple the useable energy density of spacecraft energy storage subsystems; and provide non-nuclear, autonomous, survivable power system options to fulfill potential high power advanced mission needs. Figure 8 shows the overall Air Force past, present, and future advanced development program response to Space Power Technology. Implementation of the various tasks under the project results in technology options which are mission enhancing and mission enabling. Examples of mission enhancing tasks are the Ni/H_2 Battery and solar cell efficiency improvements which transition directly to system application upon qualification and production demonstration. The Hardened Array Solar Power System (HASPS) is an example of a mission enabling task in that the feasibility of the SIRE P80-2 mission would be questionable without the HASPS technology option. Also, the recommended HVHP task is mission enabling; that is, unless the technology is developed, certain future high power missions cannot be undertaken.

CONCLUDING REMARKS

a. The trend toward military space power requirements in the 10 - 100 KW_e range is valid, based upon the probable needs for advanced surveillance, ECM resistant communications, space-based radar, and space defense missions.

b. Performance enhancements in solar cell efficiency and battery energy density and lifetime are of major importance to spacecraft designers.

c. Design to performance, survivability and reliability/autonomy mandates are important military satellite power system requirements.

d. Advanced solar arrays and batteries will continue to be the predominant power system choice for future Air Force satellites in the foreseeable future. Nuclear power system options should be maintained for specialized missions requiring very high levels of hardness and orbit predictability.

REFERENCES

1. AFAPL-TR-77-36 - "High Efficiency Solar Panel (HESP)"; Spectrolab, Inc., July 1977.

2. AFAPL-TR-77-80 - "GaAs Concentrator Photovoltaic Power System Feasibility Investigation"; Hughes Aircraft Company, December 1977.

3. AFAPL-TR-78-30 - "Gallium Arsenide Solar Concentrator Hardness Study"; Rockwell International Corporation, March 1978.

4. AFAPL-TR-76-100 - "Investigation of GaAs Solar Cell Potential Performance and Cost"; AF Aero Propulsion Laboratory, February 1977.

5. AFAPL-TR-77-90 - "Failure Mechanisms in Nickel-Hydrogen Cells"; Hughes Aircraft Company, December 1977.

6. AFAPL-TR-77-89 - "Nickel-Hydrogen Battery Advanced Development Program"; Hughes Aircraft Company, December 1977.

7. Personal Communications with Lt Cecil R. Stuerke, AFAPL/POE-2, WPAFB, OH 45433. Air Force focal point for GaAs Solar Cell advanced development.

8. Personal Communications with Mr. Don R. Warnock, AFAPL/POE-1, WPAFB, OH 45433. Air Force focal point for Nickel-Hydrogen Cell advanced development.

TABLE I - 50 AMPERE HOUR Ni/H_2 BATTERY WEIGHT ESTIMATE

ITEM	WEIGHT (KG)	WEIGHT (LBS)
24 CELLS @ 1.29	30.96	68.25
24 THERMAL SHUNTS @ .027	.65	1.43
48 HEAT PIPES @ .052	2.50	5.51
24 RADIATORS @ .086	2.06	4.54
BATTERY CELL HDW.	1.27	2.80
ELECTRICAL & PROTECTIVE	5.45	12.01
	42.89	94.55

USEABLE ENERGY DENSITY = $\frac{C\ V_C^{*}\ N_C\ DOD^{**}}{W}$ = 26.8 $\frac{\text{WATT} \cdot \text{HRS}}{\text{KG}}$ (12.2 $\frac{\text{WATT} \cdot \text{HRS}}{\text{LB}}$)

* NOMINAL CELL VOLTAGE = 1.2 VOLTS

** DEPTH OF DISCHARGE = 80%

TABLE II - MATCHING POWER SYSTEMS TO MISSION REQUIREMENTS

SCENARIO: .5 - 100 KW_E & BEYOND POWER RANGE

- 0 SOLAR # 1 IN THE .5 - 5 KW_E RANGE; SPECIAL PURPOSE ISOTOPE APPLICATIONS IN THIS RANGE
- 0 SOLAR # 1 IN THE 5 - 25 KW_E RANGE; NO ISOTOPE APPLICATIONS IN THIS RANGE
- 0 25 - 50 KW_E - EITHER SOLAR OR REACTOR (IF AVAILABLE) IN THIS RANGE
- 0 IF AVAILABLE, REACTOR # 1 IN THE 50 - 100 KW_E RANGE (AND BEYOND); SOLAR FEASIBLE

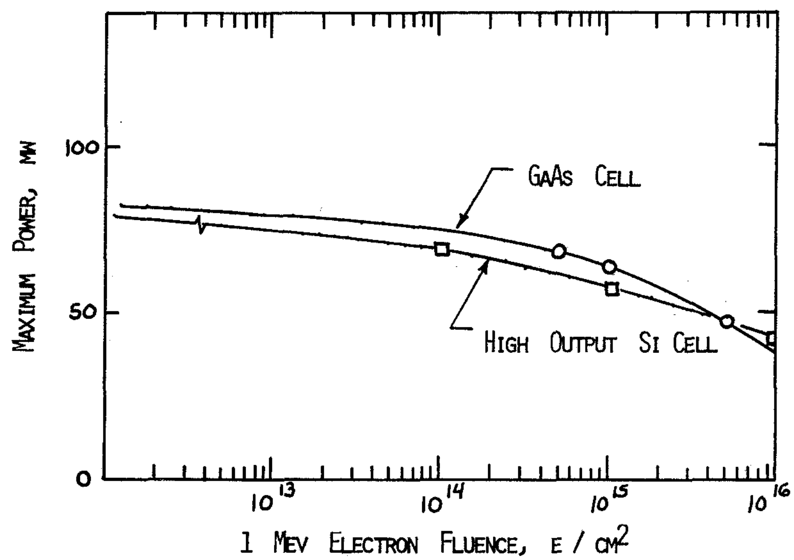

FIGURE 1. IMPROVED RADIATION TOLERANCE OF RECENT GaAs SOLAR CELLS

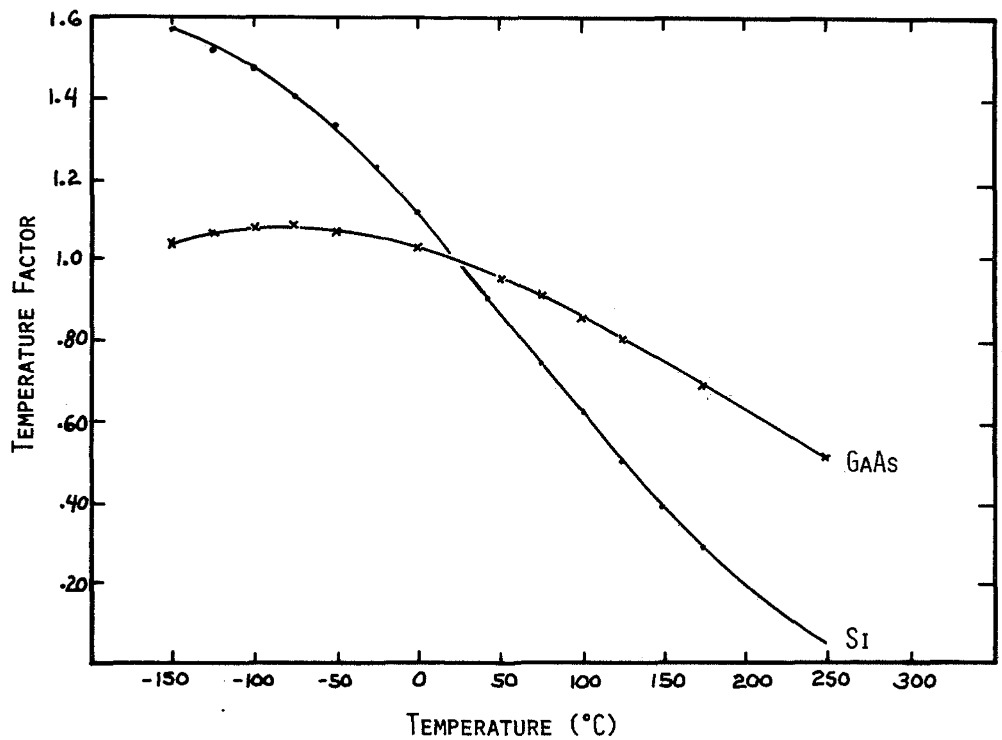

FIGURE 2. TEMPERATURE SENSITIVITY OF GaAs AND Si SOLAR CELLS

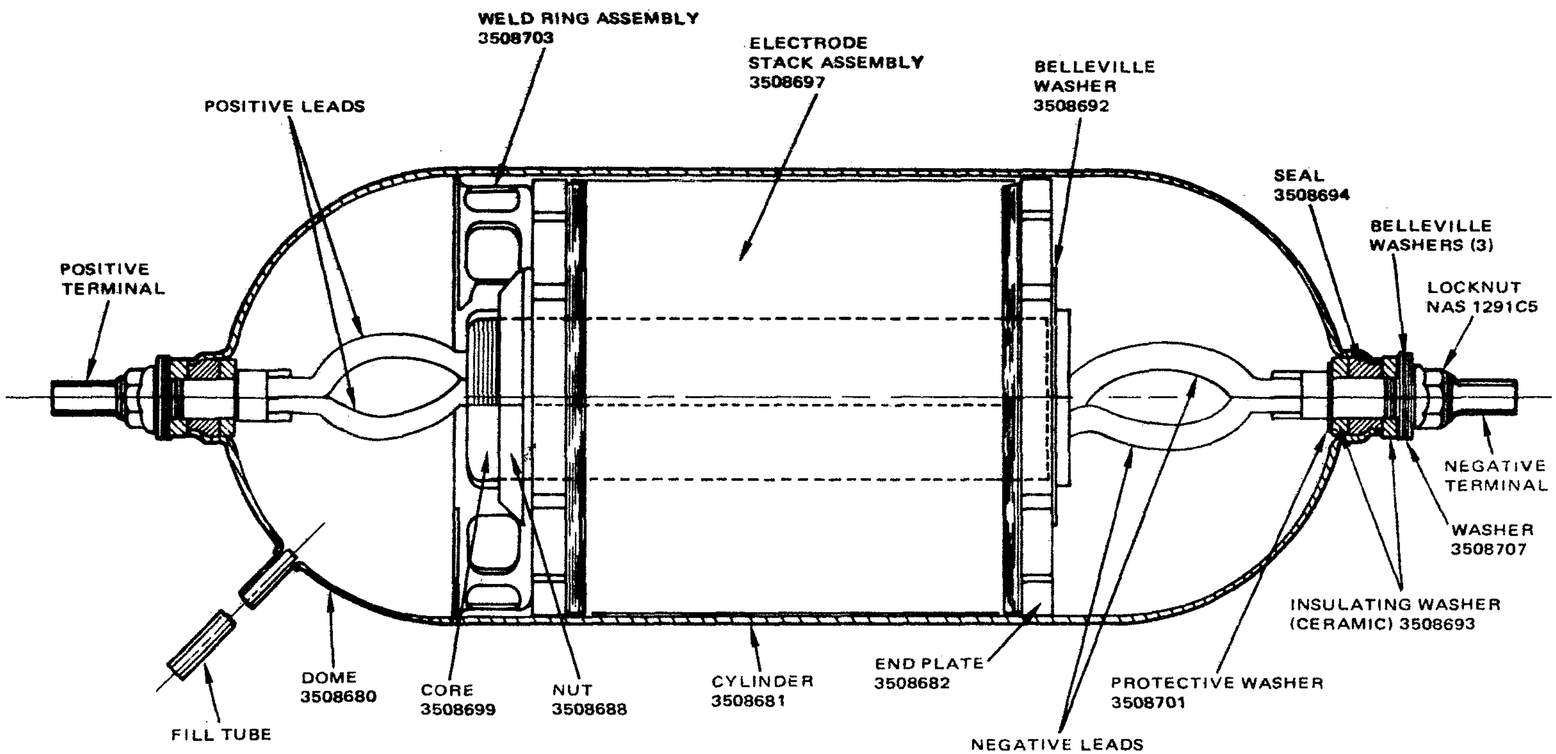

FIGURE 3. SCHEMATIC OF 50 AMPERE HOUR NICKEL-HYDROGEN CELL

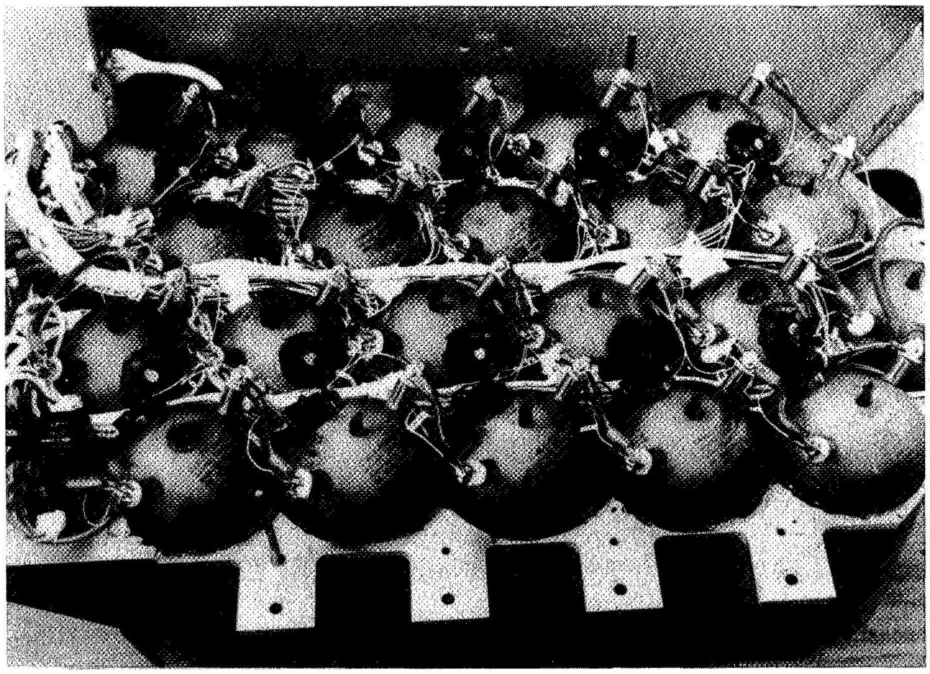

FIGURE 4. PHOTOGRAPH OF AIR FORCE NICKEL-HYDROGEN BATTERY SPACE EXPERIMENT

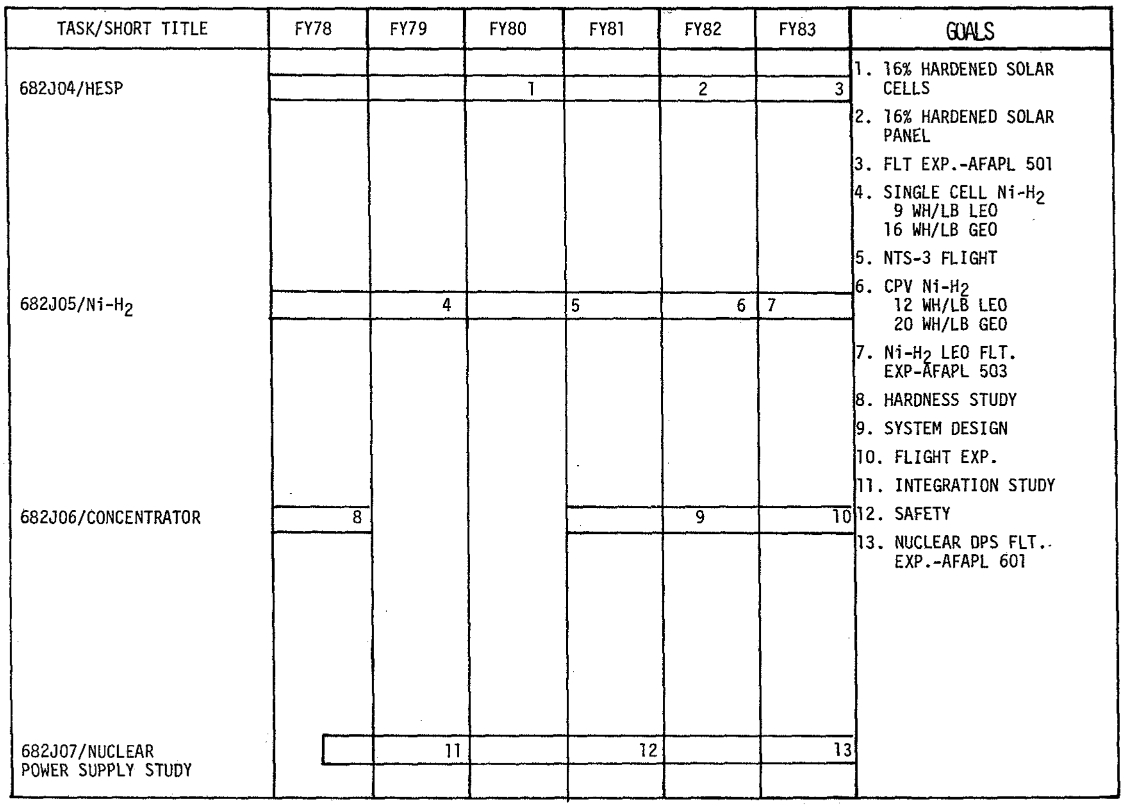

FIGURE 5. MILESTONE CHART FOR ADVANCED SPACE POWER SUPPLY TECHNOLOGY (SAMSO/AFAPL APPROVED)

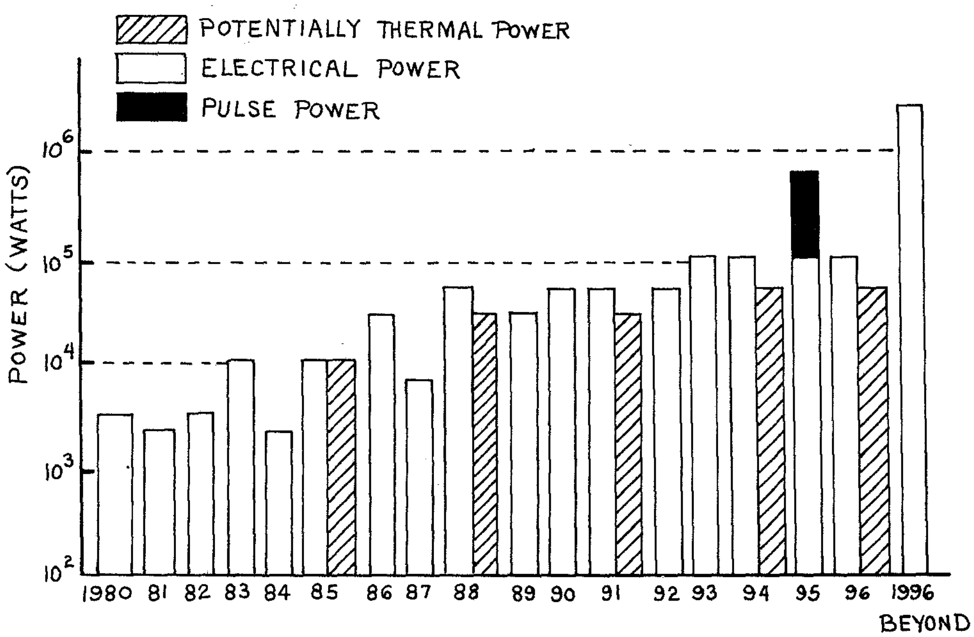

FIGURE 6. MAXIMUM SINGLE-SPACECRAFT POWER REQUIREMENTS BY YEAR

TASK/SHORT TITLE	FY80	FY81	FY82	FY83	FY84	FY85
682J08/HVHP SYSTEM		1	2			3
682J09/HEDRB				4	5	6
682J10/FTPS		7		8		
682J11/TESS	9		10		11	
682J12/CASCADED CELL				12	13	

GOALS

1. 10-50KW DESIGN TRADEOFFS
2. CRITICAL COMPONENT DEVELOPMENT
3. 25KW DETAILED DESIGN
4. CONCEPTUAL DESIGN
5. BREADBOARD BATT.
6. PROTOTYPE BATT.
   30 WH/LB LEO
   50 WH/LB GEO
7. CONTROL ALGORITHMS
8. FTPS BREADBOARD DEMONSTRATION
9. PRELIM. TESS DESIGN
10. DETAILED TESS DESIGN - 50 WH/LB
11. 300 WH TESS FLT. TEST
12. 25% SOLAR CELL
13. CASCADED CELL PANEL DESIGN & QUAL.

FIGURE 7. MILESTONE CHART FOR ADVANCED SPACE POWER SUPPLY TECHNOLOGY (AFAPL RECOMMENDED NEW INITIATIVES)

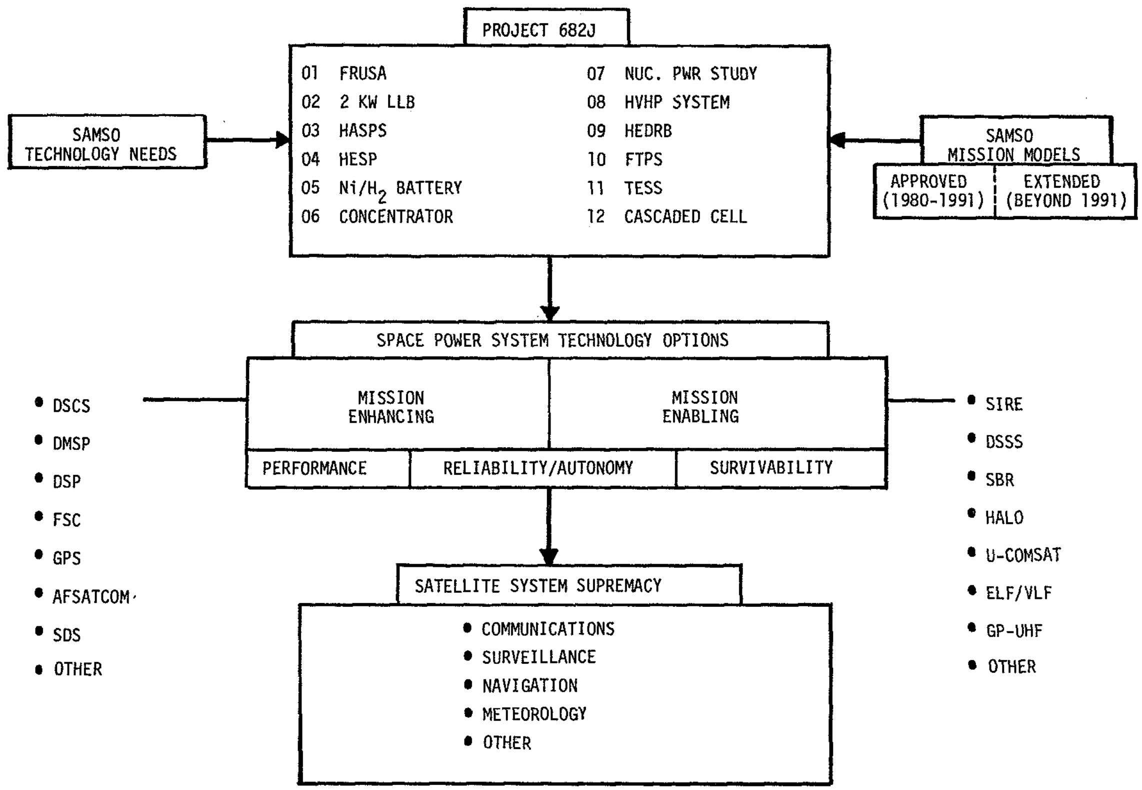

FIGURE 8. SPACE POWER ADVANCED DEVELOPMENT PROGRAM RESPONSE TO POWER REQUIREMENTS