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RESULTS FROM SYMPOSIUM ON FUTURE ORBITAL POWER SYSTEMS TECHNOLOGY REQUIREMENTS

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ABSTRACT

A two day symposium was held on May 31 and June 1, 1978 at the Lewis Research Center, Cleveland, Ohio to review the technology requirements for future orbital power systems. It provided a forum for discussion and, through industry led workshops, comments on current and planned government programs. Workshops were held in 10 technology disciplines to discuss technology deficiencies, adequacy of current programs to resolve those deficiencies and recommendations for tasks that might reduce the testing and risks involved in future orbital energy systems. This paper summarizes those recommendations.

NASA's PROGRAM in space power technology is aimed at providing the required technology base to generate, store, process, and distribute electrical energy on future space power systems. Although future energy needs in space cannot be known with certainty, two categories of need have been identified: high performance systems to support electric propulsion and advanced geosynchronous missions; and high power at low cost to support Shuttle based utilization of near-Earth space.

Transition of NASA's space program from an era that was demonstration oriented to a cost effective operational era utilizing the Shuttle presents a challenging technology goal. The NASA Office of Aeronautics and Space Technology has developed a space systems technology model (1*) which describes candidate space missions through the year 2000 and identifies their technology requirements.

Figure 1 (2) displays historic and projected average power for selected NASA missions. There is generally a smooth curve for the upper power limit for individual missions except in the case of the SPS which is orders of magnitude above the other missions. However, SPS is a power producer rather than a power user and should not be expected to fit the trend of users.

Future missions are projected to have an increase in energy requirements of one or two orders of magnitude. As exemplified by Fig. 2, the cumulative installed space solar power, since the beginning of the space program, is less than 100 kW. Yet, single missions are now under discussion for the 1980's which approach that cumulative level, with additional growth in the 1990's.

Prospective large increases in power level will necessitate technology advances in related space system areas such as energy storage, life, power conditioning, power management and physical size. One of the most critical technology needs may actually be the reduction of space energy costs in order to maintain the programs within reasonable budget levels. Figure 3 (3) shows the trend of technology required to meet the energy demand, specific cost, specific weight, energy density, array area and distribution voltage required over the next two decades.

NASA is actively involved in planning the technology programs to meet the future needs for energy in space. To provide information for the development of those plans a two day symposium was held at the NASA Lewis Research Center, Cleveland, Ohio, on May 31 and June 1, 1978, on Future Orbital Power Systems Technology Requirements.

The purpose of the meeting was to present government and industry leaders with an overview of government supported technology efforts and their plans for future programs in electric power for space. Power for electric propulsion applications was not included. It then provided a forum for discussion and, through workshops, for comments on the current and planned programs as well as the opportunity to identify areas for technology investment.

Workshops were held in 10 technology disciplines. The topics discussed included: technology deficiencies, adequacy of current programs to resolve those deficiencies, and recommendations for tasks that might reduce the risks involved in future orbital energy systems. Summaries of the workshop discussions are presented below.

PHOTOVOLTAIC POWER SYSTEMS

System studies are required to identify the technical problems associated with both near- and far-term photovoltaic power systems. These studies should develop design guidelines for commonality, modularity, materials and other design options important to standardization and its inherent reduced costs.

Since the mission models presented at the conference involve diverse power system needs in diverse orbits, the system design guidelines should be sufficiently flexible to accommodate different users without undue penalties on any user. That flexibility should also include the capability to incorporate technological improvements with a minimum of rework. It is axiomatic that for a given power module to have high mission capture rates over its expected power system life, growth capability is a firm requirement.

Power system costs have been identified as a major technological driver, and most of those costs are of nonhardware origin. Thus it may be productive to focus on the nonhardware costs such as engineering and testing. The tradeoff between cost and reliability should be investigated through incorporation of fault-tolerant system designs. System designs, which are thoroughly tested, and utilize less reliable (less expensive) components could potentially yield overall lower life cycle costs.

Energy storage may prove to be the greatest technological problem for large power systems. To eliminate exorbitant weight penalties it will be necessary to develop storage devices with more usable energy density. If that becomes a problem, large power sys-

*Numbers in parentheses designate References at end of paper.

tems may have to be designed such that they avoid or minimize storage needs.

The following major concerns were identified for large photovoltaic space power systems:

(1) Structural dynamics and attitude control problems due to solar array flexing
(2) Thermal control and heat rejection
(3) Additional emphasis is needed on in-space assembly
(4) Promising terrestrial solar cell developments should be considered for space type solar cell applications

SOLAR CELLS

Three solar cell technology areas were identified as most significant: radiation resistance, manufacturing capability, and cost reduction.

Radiation resistance was considered to have higher priority than cell efficiency although it is compatible with the objective of high end-of-life efficiency. To develop radiation resistance, better fundamental materials data on properties and control of impurities are required. Newer materials such as gallium arsenide and amorphous silicon may provide opportunities for advances. Although gallium arsenide was not felt to have a major near term impact it was recommended that GaAs cell technology should be accelerated. In particular in the areas of: contact metallization, manufacturability, material availability, and concentration.

There was a concern that firm mission commitments to use the newer technologies such as thin 2-mil cells and wraparound cells are required in order to provide the incentive to assure the manufacturing capability and availability of new technologies. Tooling buildup and pilot production requires a significant investment of time and money. And large-scale pilot production of new technologies must be demonstrated. Cost reduction, therefore, becomes a problem because high-volume production is not justified by the near-term program plans. Merging the terrestrial and space technology efforts may produce the required cost reduction but should not be depended upon, particularly as a near-term solution.

Other technology areas with potential benefits include:

(1) Welding technology, particularly for thin cells
(2) Thin cover glasses
(3) Nonglass covers
(4) Improved absorptivity control

SOLAR ARRAYS

A major problem identified was the potentially conflicting requirements of low cost and low weight. Since their respective importance is mission dependent, it was felt that an overall photovoltaic technology plan was needed for each class of missions.

System level tradeoff studies are required to develop the relationships between solar cell stack parameters and mission weight, volume, and cost so that specific technology goals can be established. These trades include: increasing stack efficiency, reducing stack cost at the expense of efficiency, reducing stack weight at the expense of efficiency and cost.

If solar array voltages are projected to increase (100s of volts), that technology base must be developed, the techniques must be demonstrated and the problems understood. Problems include not only plasma effects but also system level high-voltage interactions, such as load switching and voltage regulation.

Concentrator systems should be investigated to determine the role for high-concentration systems, their life characteristics, packaging and deployment characteristics, packaging and deployment characteristics, heat rejection requirements and spacecraft interaction.

Continued efforts are needed in the areas of: concentrator versus planar studies, concepts for on-orbit maintainability, heat rejection techniques and solar array positioning.

The following technologies were recommended as having potential benefits for the solar array subsystem, and should be included in the technology plan:

(1) Inflatable arrays
(2) Spectrum selection to increase efficiency
(3) Solar cell annealing techniques
(4) Reduce cell operating temperatures
(5) Interconnect designs for long life operation
(6) Polymer coatings for cells
(7) On-array power conditioning
(8) Techniques for converting array power to ac
(9) Integration of the array design with controls and lightweight structures for large space systems to reduce overall system costs and weight

BATTERIES

A system level study is required for large power systems which would determine mission sensitivities to weight, cost, redundancy, life, control system complexity and battery type. Previous power system trade-off studies for large systems have not adequately considered advanced battery technology capability and the relatively low battery hardware costs. Battery costs are primarily due to implementation. Redundancy, software integration and testing requirements have driven up the costs of energy storage. Present goals for battery life are not consistent with the mission planning goals. Specifically, the LEO mission battery life requirement should be 10 years and a 15-year requirement for GEO missions. This would reduce the costs attributable to battery systems for replenishment.

The best single method to reduce energy storage specific weight is to operate batteries at deep depths of discharge (DOD). Specific technology goals should be to develop the data base to operate NiCd batteries for 10-year life at >20% DOD and NiH_2 batteries for 10 years at >60% DOD. A LEO flight experiment is needed for NiH_2 at 40% to 60% DOD to assess the technology capability for electrolyte management and determine any needed refinements.

Battery capacity must be increased from the present <60 A-hr. Capacities on the order of 100 to 1000 A-hr are needed to reduce the use of multiple battery assemblies and their control electronics. These larger sizes may require active cooling. Increased capacity will have a domino effect on cost reduction by reducing complexity and increasing reliability with corresponding savings in both initial and launch costs.

For the very large missions >100 kW postulated for the 1990's, large bulk-energy storage-battery systems are not available. Work is needed on advanced batteries such as sodium-sulfur, advanced lithium or large NiH_2 to identify potential solutions applicable to large space platforms. Since these large platforms will necessitate high voltage power systems, an investigation into the interaction of high voltage and the battery subsystem is required.

FUEL CELL/ELECTROLYZER

The highest priority item identified was to expand the endurance data base for both fuel cell and electrolysis technology on cells and at test conditions representative of the energy storage requirements for future missions. Tests should be conducted on multicell stacks of large area flight weight cells designed for long life and low operating temperatures.

A conceptual design study of a fuel cell/electrolyzer storage system for a high power application is needed: to establish specific technology goals, to investigate packaging techniques and to identify areas of design such as controls and circulators with potentially high payoff for reducing costs. The study should include tradeoffs such as the degree of maintenance or replacement interval of cells and stacks versus weight and cost, efficiency versus cell weight and weight/cost versus heat rejection temperature as well as parametric investigation of the operating current density, voltage level and the potential for directly charging the electrolysis cells off the array.

A third high priority item was a breadboard demonstration of a complete fuel cell/electrolysis system including reactant control and storage, pressure balancing, heat removal and load control. This demonstration would identify problem areas and accelerate the development of the system. A mathematical model of the fuel cell and electrolysis module performance and degradation characteristics would be useful in permitting accelerated testing.

Specific technology tasks which should be initiated include:

(1) Utilization of the same cell and cell stack for fuel cells and electrolysis functions to reduce both cost and weight
(2) Development of cell materials and electrode catalysts for both fuel cell and electrolyzer technologies to increase cell endurance
(3) Endurance testing of large multicell stacks

POWER MANAGEMENT

Here again system level studies are needed to provide program direction in view of the variety of options available to the system designer. Examples of these options include the level of higher voltage, the ac versus dc distribution approach, environmental and safety problems. Component development for far-term missions should not be initiated before the system studies have been evaluated.

High power switchgear was the highest priority component technology identified. Other high power components requiring attention included not only capacitors, magnetic components and switches but also the connectors and distribution system components.

There was a recognized need to establish a standardization committee for specifications and interfaces.

As the power management system becomes better defined several other areas will surface as priorities. These include:

(1) Packaging studies emphasizing thermal problems
(2) Sensing and fault detection devices for automatic control
(3) Low cost testing techniques

LASER/MICROWAVE POWER TRANSMISSION

Currently energy transmission by microwaves is a more mature concept than laser beam transmission. Microwave systems using (10 to 12.5 cm) wavelengths have been considered for space-to-ground transmission. However, for space-to-space transmission shorter wavelengths (mm and μm) with reduced antenna area requirements might have potential.

A demonstration of high power phased microwave arrays and their scaleability is needed. Although environmental and safety problems are currently being addressed, the existing technology and the present studies are inadequate to resolve them.

Lasers for orbital energy transmission need to be long-life, closed cycle devices. The interface of laser systems with the energy conversion system should be investigated in more depth. Since single lasers have physical limitations in size and volume, phase locking techniques for multiple high power systems are required to avoid wavefront interferences which spread the beam.

Laser transmission has advantages over microwave systems that may outweigh the lower electrical to laser efficiency. However, tradeoff studies are required for that evaluation so that an equitable comparison can be made between laser and microwave systems. A systems study of potential missions is needed to define an actual application. Candidate concepts should then be evaluated and technology requirements established.

THERMAL MANAGEMENT

For high power systems, integration of thermal management concepts must take place early in the system design since heat rejection can account for a substantial part of the total system area and weight. Three critical areas were identified: (1) thermal interfaces (acquisition and transport); (2) large deployable/constructable radiators; and (3) long-life (5 to 30 yr) thermal systems incorporating maintainability.

Several types of thermal interfaces need to be considered. There is a need for efficient transport of thermal energy across flexible and disconnectable static joints. And a demonstration of a thermal umbilical using contact or fluid heat transfer for efficient thermal transport over long distances should be made. Heat rejection concepts are needed for high heat flux from concentrator systems and cooling for the proposed higher voltage systems. Heat pipes with their capability for modularity appear most applicable.

Growth in power system size will necessitate large deployable/constructable lightweight radiators. Thermal distortion of these structures is a critical engineering problem. These radiators must be modular to minimize launch volume as well as to permit growth. The additional requirement of replacement or maintenance will permit long life, thereby reducing overall life cycle costs.

Long-life thermal systems can be accomplished through improvements in design and materials selection. Advanced designs should incorporate maintainability while minimizing system complexity through the use of larger subsystems. As system size increases, the need for designs which incorporate automated space manufacture and assembly to reduce cost will become evident. Materials problems which must be addressed include heat transfer fluid compatibility and thermal coatings as well as environmental protection, space plasma, and natural radiation.

NUCLEAR POWER SYSTEMS

The major deficiency in the area of nuclear power systems is the lack of a well defined policy on the need for and desirability of nuclear power in space. The overall U.S. program was judged to be inadequate with regard to space nuclear technology. An adequate R&T program should include three prime elements: (1) conversion system development; (2) heat rejection system work, emphasizing lightweight high temperature radiators and heat pipes; and (3) high temperature materials research and characterization.

Since the trend in nuclear power systems is toward higher source temperatures, the need for high temperature materials data for the design and fabrication of advanced systems is of prime importance.

Specific data is needed on strength, creep, toughness, corrosion, joining and coatings for materials suitable for reactor systems.

ENVIRONMENTAL INTERACTIONS

Environmental problems for future large space power systems can be grouped into three categories: (1) plasma interactions, (2) radiation interactions, and (3) miscellaneous effects such as magnetic field.

Plasma interactions were identified as the most critical area for large systems and current programs are not applicable to large orbital power systems. Proposed solutions are required, their feasibility must be determined and the designs optimized. Impacts of plasma interaction include: power loss through the plasma, EMI and possible burnout of IC components, and general degradation of system life, particularly the thermal control system.

Radiation interactions consist of effects from the radiation belts as well as effects of solar and primary cosmic rays. Radiation effects cause solar cell degradation, reduces the life of electronic components and causes a hazard on manned missions or EVA.

Other environmental effects which must be considered include: microwave-ionosphere interaction, voltage differential between surfaces, environmental modification by large surfaces of the radiation belts and ambient plasma, magnetic effects and micrometeoroid impacts.

CONCLUSIONS

Because of the diverse nature of the workshops, their recommendations vary significantly in technical depth and specificity. However two common thoughts were expressed. A "front end" system study is needed in each area to guide the technology efforts. And current programs to achieve technology readiness for multi-hundred-kW power systems are presently underfunded and underscoped.

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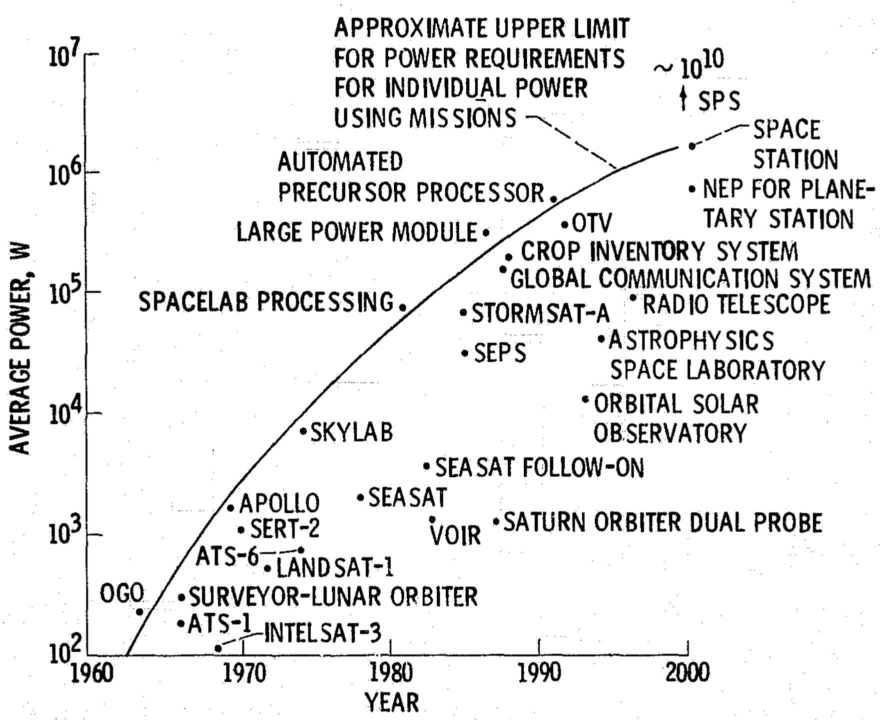

Figure 1. - Mission power requirements.

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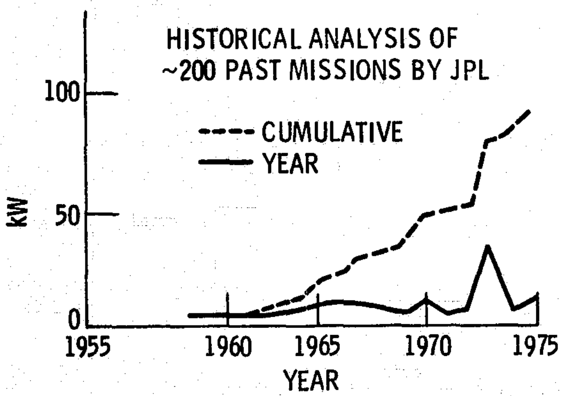

Figure 2. - Solar power launched by NASA.

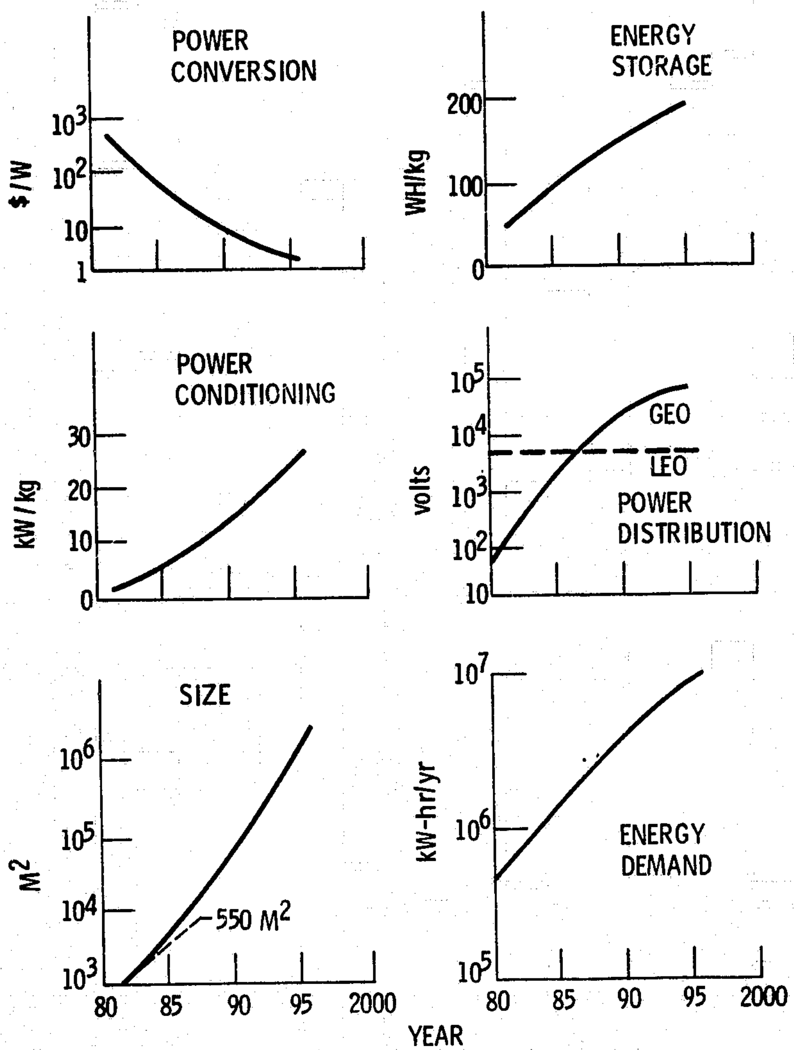

Figure 3. - Technology advancement projected demands and requirements.