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The OAST Space Power Program

Gary L. Bennett
National Aeronautics and Space Administration
Washington, D.C.

The NASA Office of Aeronautics and Space Technology (OAST) space power program has been established to provide the technology base to meet power system requirements for future space missions, including growth Space Station, Earth orbiting spacecraft, lunar and planetary bases, and solar system exploration. The program spans photovoltaic energy conversion, chemical energy conversion, thermal energy conversion, power management, thermal management and focused initiatives on high-capacity power, surface power and space nuclear power.

Introduction

Within the National Aeronautics and Space Administration (NASA) the Office of Aeronautics and Space Technology (OAST) is responsible for planning and managing NASA's aeronautics, space, and transatmospheric research and technology (R&T) programs. A primary function of OAST is to ensure that the programs are aligned toward providing the technology required to meet national needs in aviation and space (OAST 1989). The space R&T program is divided into the R&T Base and three focused programs: the Civil Space Technology Initiative (CSTI), Pathfinder, and the In-Space Technology Experiments. This paper will focus on the space power program contained in the R&T Base, CSTI and Pathfinder. Program management for the OAST space power program resides in the OAST Propulsion, Power and Energy Division.

Space Energy Conversion R&T

The objective of the space energy conversion R&T program is to provide the technology base to meet power system requirements for future space missions, including growth Space Station, Earth orbiting spacecraft, lunar and planetary bases, and solar system exploration. Power system requirements will range from a few kilowatts to megawatts, and system lifetimes from two to more than ten years. System configurations must be available for single user requirements, as well as for utility type applications, and must include a variety of power generation, storage, distribution, and management options. The program elements are

- Photovoltaic Energy Conversion
- Chemical Energy Conversion
- Thermal Energy Conversion

- Power Management
- Thermal Management

The program elements will be discussed in the following sections.

Photovoltaic Energy Conversion

The photovoltaic energy conversion program will provide the technology for photovoltaic arrays with improved conversion efficiency, reduced mass, reduced cost, and increased operating life for advanced space missions. Specific long-range goals are to develop the technology base for photovoltaic arrays with specific power of 300 W/kg, with substantial reductions in size, cost, and increases in end-of-life (EOL) power capability. Establishment of this technology will have a significant impact on all near-Earth manned and unmanned space missions, as well as interplanetary missions from near Sun to several astronomical units. This technology is also applicable to missions with power requirements from hundreds of watts to hundreds of kilowatts. Areas covered include advanced photovoltaic device research and technology development, thin film cells, light-weight solar array technology and high-power array technology for planar, as well as concentrator, concepts and configurations (OAST 1989).

The OAST-sponsored research on photovoltaic energy conversion is carried out through two NASA centers: Lewis Research Center (LeRC) and the Jet Propulsion Laboratory (JPL). The LeRC work is focused primarily on advanced solar cell technology while the JPL work is focused primarily on high-performance solar arrays. The two programs are complementary with LeRC providing the advanced, high-efficiency, radiation-resistant solar cells needed for the JPL high-performance array work (Flood et al. 1989).

The development of a high-efficiency, light-weight, rugged, radiation-resistant solar cell is an essential element of the NASA goals to achieve 300 W/kg for a deployable planar array and 300 W/m^2 at 100 W/kg in concentrator arrays. To achieve this development LeRC is focusing on indium phosphide (InP) and gallium arsenide (GaAs) and LeRC is also beginning to investigate thin-film cell technology (Flood et al. 1989).

The objectives of the InP solar cell program are to (Flood et al. 1989)

- Demonstrate a cell structure capable of achieving 20% air mass zero (AM0) efficiency with $\leq$1% degradation in power after 10 years in geosynchronous Earth orbit (GEO)

- Fabricate InP cells on alternative substrates

- Demonstrate high-efficiency, ultra-thin InP cells with improved radiation resistance (compared to GaAs and silicon)

Recently LeRC has accomplished the following in the InP program (Flood et al. 1989):

- Achieved an efficiency of 18.8% in an n/p homojunction structure
- Achieved an efficiency >17% in a cell produced by sputtering indium tin oxide (ITO) onto InP
- Fabricated some InP on alternative substrates (efficiencies 10%)
- Initiated fabrication of ultra-thin InP cells

The objectives of the GaAs solar cell program are to (Flood et al. 1989)

- Develop high-efficiency concentrator cells
- Demonstrate feasibility of the point contact junction geometry in GaAs
- Develop a v-grooved cell geometry with improved efficiency and radiation resistance (compared to the standard cell geometry)

Recently LeRC has accomplished the following in the GaAs program (Flood et al. 1989):

- Achieved an efficiency >22% with prism-covered cells operating at 100 Suns and 373 K
- Developed a domed mini-Fresnel lens that offers the possibility of raising the specific power of radiation-resistant arrays from ≤30 W/kg to about 60 to 90 W/kg
- Developed an understanding of the requirements that must be met to demonstrate a point-contact GaAs cell
- Grew a p-n junction on a v-groove surface geometry

The objective of the JPL advanced photovoltaic solar array (APSA) program is to develop an ultra-light-weight, high-performance, advanced deployable photovoltaic array design that will be suitable for a broad range of long-term NASA and U. S. commercial space applications for the period beyond 1990. The near-term goal is to achieve a specific power of 130 W/kg and the long term goal is to achieve 300 W/kg. Under the JPL program a flexible blanket array has been built based on the 55-μm silicon solar cell. The specific power of this array is 130 W/kg for a 5.3 kWe beginning of life (BOL) deployable wing (Flood et al. 1989).

The APSA design is based on near-term technology and prior experience (Flood et al. 1989):

- Patterned after the Canadian Telecommunications Satellite (CTS) and the Solar Array Flight Experiment (SAFE) solar array designs

- Consists of a flat-pack, fold-out, flexible blanket planar array
- Uses thin (55-μm), high-performance (~13.5% efficient) silicon solar cell modules
- Uses a flexible, printed-circuit blanket electrical harness
- Uses a graphite/epoxy blanket box structure
- Uses a light-weight version of the continuous longeron lattice mast deployment system
- Builds on the LeRC work on high-efficiency cells

The APSA program is now moving into a ground testing phase and will then move on toward the long-term goal of 300 W/kg. APSA clearly offers the capability to meet a wide range of mission requirements including Earth Observing System (EOS) and solar electric propulsion (SEP).

Chemical Energy Conversion

The chemical energy conversion program has been established to provide the technology base for advanced electrochemical energy conversion and storage systems required to support the low- to high-power needs of future manned and unmanned space applications, the cycle life requirements of low-Earth orbit (LEO) systems and storage life requirements of new long-duration unmanned planetary missions. Included in this program element is the development of high-performance, long-life, cost-effective systems for primary and secondary (rechargeable) power applications, advanced fuel cells, and thermal electrochemical converter concepts (OAST 1989).

The OAST chemical energy conversion program is being carried out at LeRC and JPL. LeRC is focusing primarily on nickel-hydrogen batteries (individual pressure vessel or IPV and bipolar) and advanced fuel cells. LeRC is also involved in a planned flight experiment to test a sodium-sulfur battery design. JPL is focusing primarily on lithium rechargeable batteries, having successfully transferred its lithium primary battery technology to the Air Force for use on the Centaur upper stage. Both LeRC and JPL are studying advanced battery concepts that offer even higher specific energies. The long-term goal is to achieve 100 W-h/kg. As an approximate rule-of-thumb, the nickel-hydrogen batteries are useful for power requirements $\geq$1 kWe and the lithium rechargeable batteries are useful for power requirements $\leq$1 kWe.

The objectives of the LeRC nickel-hydrogen (NiH_2) battery program are to develop improved specific energy cells (at least two times the state of the art) and improved specific volume (at least 20% better than the state of the art) cells. The approach is to optimize the design using computer-aided design (CAD) tools and to develop the technology for light-weight nickel electrodes and to optimize the potassium hydroxide (KOH) concentration. The design will be verified by testing boiler plate and flight-weight cells. This work will support future energy storage on Space

Station, Earth Observing System, Hubble Space Telescope, communication satellites and exploratory rovers.

In 1988 LeRC and Hughes won an IR&D 100 Award for their advanced design IPV NiH_2 cell. A key factor was the use of a 26% KOH solution that improves the cycle life about ten times that of the state-of-the-art (Lim and Verzwyvelt 1987). LeRC has successfully tested 26% KOH NiH_2 cells for >5600 h and has developed a light-weight nickel electrode for a high-energy density NiH_2 cell with LEO performance verified at 80% depth of discharge (DOD).

The JPL work on lithium batteries complements planned future planetary space missions which require batteries with enhanced energy storage capability, long active shelf life, long cycle life and a high degree of safety and reliability for powers ≤1 kWe. A JPL review of advanced electrochemical systems has led to a focus on the organic electrolyte system Li-TiS_2 (Subbarao et al. 1989). Such a battery system offers a 2 to 3-fold increase in energy storage capability over nickel-cadmium (NiCd) and NiH_2 batteries with a 35% to 50% reduction in battery mass and volume for 5- to 10-year lifetimes. To date JPL has developed a better controlled synthetic process for TiS_2 and has developed a fabrication process for thinner and larger electrodes.

LeRC has been investigating new catalyst systems for improved alkaline fuel cells. Studies of a new gold-platinum cathode catalyst have shown more than two times the surface area of the reference cathode catalyst (Martin and Manzo 1988). This work will continue and is integral to the surface power program to be described in a subsequent section.

Thermal Energy Conversion

The thermal energy conversion program has these goals (OAST 1989):

- Develop the technology base to provide advanced high-efficiency, high- temperature (1050 - 1400 K), long-life solar dynamic Stirling/Brayton power systems for a wide range of NASA and commercial space power requirements (specific goals include specific powers of 8 to 20 W/kg)

- Develop new thermoelectric materials with significantly higher figure of merit values to improve the efficiency of a space thermoelectric power system toward >10%

- Investigate and demonstrate the feasibility of a high-power, long-life alkali metal thermal-to-electric (AMTEC) electrode which will enable the projected efficiencies of 20% or greater to be achieved for >10,000 h

LeRC is managing an advanced solar dynamic space power program with the objective of developing small and light-weight solar dynamic systems which show significant improvement in efficiency and specific mass over the baseline design derived from Space Station technology. Technology advancements to the receiver/thermal energy storage subsystem offer the highest payoff because these are the heaviest components. Accordingly LeRC is aiming at developing a receiver with half the specific mass of the current state-of-the-art. In the first phase of this effort receivers for both Brayton and Stirling heat engines are being developed (Kesseli and Lacy 1989 and Heidenreich et al. 1989). Separately under this program LeRC is developing long lived ($\geq$10 y), light-weight, and more reflective space solar concentrators than the state-of-the-art. The concentrator program is focused on concentrator concept development and the resolution of those critical technology issues that will lead to durable, highly specular, and light-weight reflector elements (Naujokas and Savino 1989).

LeRC has been evaluating free piston Stirling engines for potential use in a wide variety of space power missions. A space power demonstrator engine (SPDE) was built by Mechanical Technology Incorporated (MTI) with the following accomplishments (Dochat and Dhar 1989):

- Operation at design stroke, pressure and temperature (T_H = 650 K; T_C = 325 K)
- Demonstrated 28 kW indicated power versus 28.8 kW goal
- Achieved 22% indicated efficiency versus 28% goal
- Demonstrated 17 kW electrical power versus 25 kW goal
- Demonstrated excellent dynamic balance
- Measured 0.03 mm casing motion amplitude at design point versus 0.07 mm maximum permissible
- Stable operation over entire operating range
- Good data correlation with MTI's HFAST Stirling engine harmonic code
- Demonstrated 87% linear alternator efficiency on dynamometer test rig

Near the conclusion of the SPDE program, the SPDE was divided into two 12.5-kWe single cylinder engines to be used as test beds for critical Stirling technology development. Work is under way now to develop a 1050 K space Stirling engine (SSE) with an EOL power of 25 kWe and an efficiency of >25% for a lifetime of 60,000 h. Much of the Stirling work is now being carried out under the CSTI program, which will be described in a subsequent section.

The AMTEC is a thermally regenerative electrochemical device for the direct conversion of heat to electrical energy. AMTEC can operate at T_H's ranging from 900 to 1300 K with predicted device efficiencies of 15% to 30%. Experimentally, AMTEC has demonstrated an energy conversion efficiency of 19% and stable electrode performance at 0.4 to 0.5 W/cm^2 for 1500 h. AMTEC offers the potential of doubling or tripling the conversion efficiency of static conversion systems which is important for mass-sensitive space missions. Current efforts are focused on testing the recirculating test cell (RTC) which is a laboratory mockup of a flight-type AMTEC converter (Underwood et al. 1989).

The advanced thermoelectric program is aimed at developing thermoelectric materials with improved figures of merit. (The figure of merit, Z, is equal to S^2/pk, where S is the Seebeck coefficient, p is the electrical resistivity and k is the thermal conductivity.) The silicon-germanium (SiGe) alloy used on the radioisotope thermoelectric generators (RTGs) on the two Voyager spacecraft and the Galileo spacecraft has a figure of merit of about $0.6 \times 10^{-3} K^{-1}$. As in the case of AMTEC, improved SiGe alloys with higher figures of merit can lead to substantial mass and cost savings for space nuclear power systems. Recent experimental and theoretical studies on n-type gallium-phosphide(GaP)-doped SiGe indicate 20% to 30% gains in the figure of merit (Vandersande et al. 1987 and Fleurial et al. 1989). Parallel improvements in the p-leg will be necessary to raise the overall figure of merit. Recent theoretical work indicates that reducing the thermal conductivity through the addition of inert particles to the SiGe may enable achievement of higher figures of merit.

Power Management

The power management program will develop the electrical/electronic technologies needed to provide safe, effective and light-weight systems to control, distribute, and condition electric power for future planetary, lunar, and Earth-orbital space missions. These missions will require (1) automation, (2) the ability to operate in hostile environments, (3) higher performance, (4) lower specific mass, and (5) the development of an "electric utility" approach to dramatically reduce cost and increase the adaptability of power systems to programmatic changes in direction. Of particular interest is the development of technologies to achieve power densities of 0.6 W/cm^3 for spacecraft power distribution, switching and control functions. Such high-density power technology is crucial to constraining the power system to 15% to 20% of the overall system mass and volume. The power management program also includes power beaming (OAST 1989).

LeRC is working on power management and distribution (PMAD) systems technology to ensure that this technology is available to meet the demanding requirements of the exploration initiative and other advanced missions. This work involves mission studies to identify the requirements and focused projects to resolve critical issues. For the former, LeRC is now: (1) studying lunar base scenarios to identify technical constraints in growing from a 20-kWe outpost to a mature multimegawatt base and (2) developing an understanding of the relation of PMAD system masses to their requirements through design analyses of Space Station Freedom and existing space power systems. For the latter LeRC is extending its development of the light-weight, versatile and safe 20-kHz alternating current distribution technology, and developing smart, fault-tolerant systems to greatly enhance PMAD reliability. A smart diagnostics system using neural nets has been successfully installed on a DC PMAD breadboard at LeRC. A theoretical structure has been developed to connect total system costs, including costs of mission failure, to the degree of redundancy (Faymon et al. 1987).

Separately, LeRC has been working to develop high-temperature power electronics. This is critical to reducing the size of the electronics radiator which grows rapidly as power levels rise. It is also very important on the lunar surface where the day temperatures are comparable to the limits of existing electronics and in other applications, such as the SP-100 space nuclear reactor, where the electronics must operate in a hot environment. Silicon carbide (SiC) offers the potential for high-temperature diodes and metal oxide semiconductor (MOS) field effect transistor (FET) power switches. LeRC has demonstrated a SiC diode and developed and characterized advanced materials at a temperature of about 870 K. LeRC is also working on high-temperature dielectrics and insulators, and LeRC is developing intercalated graphite for application to high-thermal-conductivity circuit boards.

JPL has been focusing on the development of high-density intelligent or "smart" power device technology. Program targets are low mass and low volume, high-efficiency, generic power building blocks applicable to a wide range of PMAD implementations. The overall objective is to achieve PMAD power densities of >0.6 W/cm^3 (a 20-fold improvement over the state of the art in space PMAD applications). The short-term goal is to develop hybrid smart modules containing the required basic power functions. A longer term goal is to upgrade these functions into monolithic power integrated circuits (PICs) technology. This effort offers the potential for up to 80% reductions in mass and volume and up to 90% reductions in the piece parts count in a typical PMAD system. JPL has completed breadboard testing of (1) a coreless Hall effect current sensor, (2) a low-voltage synchronous rectifier, and (3) MOS-controlled thyristor (MCT)/FET and gate turn-off thyristor (GTO)/FET high-power, high-performance switches. JPL is proceeding with the development of a monolithic synchronous rectifier and hybridization of a 20-kVA MCT/FET switching module (Klein and Theisinger 1987 and Rippel 1987, 1989a and 1989b).

Both LeRC and Langley Research Center (LaRC) are working on power beaming. LaRC has been pursuing the use of lasers to transmit power (Kwon and Lee 1989). Beam power may provide an alternative to nuclear and photovoltaic/chemical power sources for bases or rovers on the surfaces of the Moon and Mars. To date LaRC has produced 14 W of continuous wave (CW) power at 1.3 μm from a solar-simulator-pumped iodide laser and LaRC has operated the world's first solar-pumped iodide laser amplifier. A recent LeRC study has shown that a nuclear electric propulsion (NEP) cargo vehicle sent to Mars could be used to provide beamed power to a number of surface bases or installations (Cull and Faymon 1989).

Thermal Management

The objectives of the thermal management program are to (OAST 1989):

- Develop the thermal management technology for advanced high capacity and high-performance thermal management systems for future NASA space missions

- Enhance the understanding of fluid behavior and dynamics in a reduced gravity environment to establish reliable predictive models and data bases for the development of advanced space systems.

- Develop, analyze, and test various thermal energy management concepts and components for application to future spacecraft and space facilities

The thermal management program includes the following technology areas (OAST 1989):

- Film condensation, flow boiling and two-phase regimes

- Advanced radiators

- Heat pipes

- Heat pumps

LeRC has been investigating liquid sheet radiators (LSRs) which offer the potential advantage of having a lower mass than solid wall radiators and being nearly immune to micrometeroid damage. LeRC has completed a new facility to investigate large sheet flows (Chubb and Calfo 1989).

A number of capillary pumped loops (CPLs) have been developed at the Goddard Space Flight Center (GSFC) for the purpose of transferring large heat loads in space applications and they have a demonstrated heat transfer capability of 25 kW with no moving parts. GSFC has been working on controlling the speed of the mechanical pump used to complement the evaporator pumps to enhance the pressure rise (Schweickart et al. 1989).

CSTI High-Capacity Power

The Civil Space Technology Initiative (CSTI) is intended to remedy gaps in the U. S. space technology program and to help restore NASA's technical strength. The CSTI program will provide advanced technologies that are focused on three specific areas of near-term, high-priority missions: technologies to support near-term transportation needs, technologies to enhance operations in Earth orbit, and technologies that support science operations (OAST 1989). The high-capacity power program is one element of CSTI. The objective of the CSTI high-capacity power program is to develop the key technologies that satisfy the needs for long-duration and high-capacity power for future missions such as outpost habitats and extended bases associated with lunar missions. The program includes work on the following technology areas:

- Conversion systems
- Thermal management
- Power management
- System diagnostics
- Environmental interactions

The CSTI high-capacity power program is a focused technology development to enhance the capability of space power systems using the SP-100 ground engineering system (GES) reactor. The goals are to raise the specific power from 25 W/kg to 80 W/kg and to raise the power from 100 kWe (baseline SP-100 thermoelectric system) to 800 kWe. Two advanced energy conversion technologies are being pursued: free piston Stirling engines and advanced thermoelectrics. Both the Stirling work and the advanced thermoelectric work build upon the foundations laid in the R&T Base program. Under CSTI a 25-kWe/cylinder Stirling space engine is being built to operate at a heater temperature of 1050 K (which is the first step toward the goal of operating an engine at 1500 K) and a cooler temperature of 525 K (Winter 1989).

An important part of both the R&T Base and CSTI is the work on environmental interactions including experimentally and theoretically studying such phenomena as spacecraft charging and atomic oxygen attack.

Pathfinder

The Pathfinder program, which was initiated in FY 1989, is designed to provide the advanced technologies in space exploration, space operations, humans-in-space and transfer vehicles to enable a broad set of future piloted or robotic solar system exploration missions (OAST 1989). There are two power-related program elements in the Pathfinder program: surface power and the SP-100 space nuclear reactor program.

Surface Power

The objectives of the surface power program are to

- Develop solar-based power technology to a level of readiness sufficient to enable or enhance extraterrestrial surface missions
- Demonstrate critical components for a 300 W/kg AM0 solar array
- Demonstrate critical components for a 500 to 1000 W-h/kg regenerative fuel cell with high efficiency and >5000 h reliable operation

- Complete the feasibility assessment of a 55-kW/kg electric power management system

The principal technology areas of this program will be power generation (e.g., advanced photovoltaics and arrays) and advanced energy storage (e.g., fuel cells).

Space Nuclear Power (SP-100)

The objective of the SP-100 space nuclear reactor program is to develop and validate the technology for space nuclear reactor power systems that can produce tens to hundreds of kilowatts of electric power and be capable of seven years of operational life at full power. The technology areas include

- Refractory metal reactor
- Fuel pins
- High-temperature control system
- Liquid-metal thermoelectric magnetic pump
- Thermal-to-electric conversion
- Heat-pipe heat-rejection systems

The SP-100 program is a joint endeavor of NASA, the Department of Energy (DOE) and the Strategic Defense Initiative Organization (SDIO). Under the SP-100 program a generic 100-kWe space reactor power system is being designed. The reactor concept will be scalable from 10 kWe to 1000 kWe. SP-100 provides a technology base for nuclear electric propulsion (NEP) missions to the outer planets, surface power and spacecraft power. Nuclear fuel development and manufacture is under way at DOE's Los Alamos National Laboratory. Fuel tests are being conducted in DOE's reactors at the Hanford Engineering Development Laboratory (HEDL) and the Idaho National Engineering Laboratory. Radiation hardened electronics tests are under way at DOE's Sandia National Laboratories and high-temperature materials development is being conducted at DOE's Oak Ridge National Laboratory, LeRC, General Electric (GE) and Westinghouse Electric (Pluta et al. 1989).

Major components will be tested on the ground in a simulated space environment to demonstrate compliance with safety, reliability and performance requirements. Preparations have begun for reactor testing in an existing containment building at HEDL. Other major modules of the power system, including the thermoelectric power conversion are planned for testing in a vacuum chamber at GE (Pluta et al. 1989).

Directions in Space Energy Conversion R&T

The following sections tabulate the directions being pursued in OAST's space power program as derived from OAST 1989.

Photovoltaic Energy Conversion

- 300 W/kg; 300 W/m^2; radiation hard
- Efficiencies from 20% to 35% (depending on hardness)
- Array technology for near-Sun and far-Sun applications

Chemical Energy Conversion

- 100 W-h/kg secondary batteries capable of 1000 cycles
- 50 W-h/kg bipolar NiH_2 battery capable of 40,000 cycles at 50% DOD
- Advanced regenerative fuel cells for GEO applications with specific energies >200 W-h/kg
- Advanced energy storage systems with 1000 W-h/kg

Thermal Energy Conversion

- High-efficiency fixed and deployable concentrator concepts with surface accuracies of 1 to 2 milliradians and concentration ratios of 2000 to 5000
- Long-life concentrator substrates, optical surfaces and thermal energy storage materials
- Long-life, high-power density (>0.5 W/m^2) electrode technology applicable to high-efficiency (20%) AMTEC
- High-efficiency (>10%) thermoelectric conversion

Power Management

- High-power (100 kWe), high-temperature (673 K), radiation- resistant (100 Mrad) components and circuits
- Fault-tolerant PMAD systems
- Increased efficiency (>10%) laser power transmission
- Advanced packing/thermal/electrical devices (power integrated circuits)

Thermal Management

- High-capacity heat pipes, pumped loops, thermal buses
- Advanced radiators, thermal storage, fluid management

Conclusion

The OAST space power program covers a broad range of important technologies that will enable or enhance future U. S. space missions. The program is well under way and is providing the kind of experimental and analytical information needed for spacecraft designers to make intelligent decisions about future power system options.

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AIR FORCE PHOTOVOLTAICS TECHNOLOGY

JAMES S. CLOYD

STATIC ENERGY CONVERSION
TECH AREA (WRDC/POOC-2)

WPAFB, OH 45433-6563

PHOTOVOLTAICS

OBJECTIVES / GOALS

- **HIGH EFFICIENCY PHOTOVOLTAIC CELLS**
  - GREATER THAN 25 % EFFICIENCY (BOL)
  - LESS THAN 15 % DEGRADATION AT 10^{15} 1 MeV e/SQ CM
  - PLANAR AND CONCENTRATOR ARRAY USE
  - MANUFACTURABILITY
- **LIGHTWEIGHT, HARDENED ARRAYS**
  - 100 WATTS/KG, 250 - 300 WATT/SQ M
  - 10 YEAR OPERATIONAL LIFE, POWER LEVELS TO 250 KW
- **FLIGHT EXPERIMENTS**
  - DEMONSTRATE PERFORMANCE
  - ENGINEERING DATA CORRELATED WITH ACTUAL EXPOSURE
- **SURVIVABILITY**

PHOTOVOLTAICS

WHY HIGH EFFICIENCY ?

EXAMPLE : 5 KILOWATT, GEOSYNCHRONOUS (CELLS ONLY)

PARAMETER	CURRENT 18 %	25 %	30 %
WEIGHT (KG)	76	55	46
AREA (SQ M)	36	26	21
COST ($M)	5.6	4.1	3.3

PHOTOVOLTAICS

HIGH EFFICIENCY CELL PROGRAM

PROGRAM	GOAL	FY 89 STATUS
PLANAR MULTIBANDGAP	27 % AlGaAs/Ge (22 % TOP CELL)	DEMONSTRATED GRADED BANDGAP, 19 % TOP CELL
CONCENTRATOR MULTIBANDGAP	30 % EFF. GaAs/Ge (2 JUNCTION)	RECORD 24.5 % EFF., AM0 100 SUNS, NO PRIS COVER
	AlGaAs/GaAs/X (3 JUNCTION)	FIRST SPACE CELLS FABRICATED (2 JUNCTION) - 18.5% EFF.
	Ge : Si ALLOY BOTTOM CELL	MATERIAL GROWTH VERIFIED
HIGH TEMPERATURE METALLIZATION AND CONTACTS (IN - HOUSE)	550 - 600 DEGREES C SURVIVABILITY	METALS DEPOSITION EQUIPMENT RECEIVED BINARY/TERNARY PHASE DIAGRAMS NEARING COMPLETION

MANUFACTURING TECHNOLOGY
RUGGED THIN GaAs SOLAR CELLS

OBJECTIVE PROCESS TECHNOLOGY FOR:

- 3 MIL THICKNESS, 18 % EFFICIENCY
- 4 CM X 4 CM AND 6 CM X 6 CM CELLS
- TOTAL OF 50,000 SQ CMS, QUALIFIED CELLS FOR DEMONSTRATION
- HIGH TEMPERATURE (550 DEG C) CONTACTS / METALLIZATION

PAYOFF

- SO FAR, 45 % COST REDUCTION IN SUBSTRATE COST
- 35 % REDUCTION IN MATERIAL COST (BULK PURCHASES)

FY 89 STATUS

- CONTRACT MODIFICATION IN JUNE 89 (SDI ADD-ON)
- 3.5 MIL, 18.5 % EFFICIENCY, 4 CM X 4 CM CELL DEMONSTRATED

PHOTOVOLTAICS

LIGHTWEIGHT, HARDENED ARRAYS

PROGRAM	GOAL	FY 89 STATUS
ADVANCED HARDENED ARRAY (AHA)	AGILE, 40 W/KG SURVIVABLE UNINTERRUPTED POWER	CONTRACT AWARDED MAY 89 MINERAL QUARRY SAMPLES SEP 89
ENHANCED SURVIVABLE SOLAR ARRAY (ESSA)	1.5 X SMATH 2 10 X JCS CELL STACK, POWER HINGE, POWER SUBSTRATE	PHASE IA COMPLETED COMPONENT DEV, BRASSBOARD INITIATED
SURVIVABLE CONCENTRATING PHOTOVOLTAIC ARRAY (SCOPA)	15 W/KG, SMATH 2, 10 X JCS CONCENTRATOR	TRW: DIRECT TRANSITION TO SUPER BOEING: TERMINATED

PHOTOVOLTAICS

FLIGHT EXPERIMENTS

PROGRAM	GOAL	FY 89 STATUS
HIGH EFFICIENCY SOLAR PANEL (HESP) ON CRRES	PROVIDE SCIENTIFIC AND ENGINEERING DATA ON RADIATION EFFECTS	FLIGHT PANELS INTEGRATED ON VEHICLE, TESTING IN PROCESS LAUNCH PLANNED JUNE 1990
PHOTOVOLTAIC ARRAY SPACE POWER PLUS DIAGNOSTICS (PASP +)	ASSESS ARRAY ARCING AS A FUNCTION OF BIAS VOLTAGE AND PLASMA ENVIRONMENT	BRASSBOARD COMPLETED FLIGHT VEHICLE NOT YET IDENTIFIED

PHOTOVOLTAICS

ANTICIPATED FY90 "GOOD NEWS"

- AHA PHASE 1 GO/NO GO DECISION - APRIL 90
- LAUNCH OF CRRES - JUNE 90
- 27% EFFICIENT MULTIBANDGAP CONCENTRATOR CELL GO/NO GO DECISION - AUGUST 90
- IN-HOUSE CLEAN ROOM INSTALLED, PROCESS DEMONSTRATED, HIGH TEMPERATURE METALLIZATION OPTIMIZED - SEPTEMBER 90

PHOTOVOLTAICS

SUMMARY

THIS PROGRAM IS :

- BREAKING RECORDS IN MULTIBANDGAP SPACE CELL EFFICIENCIES
- PROVIDING TECHNOLOGY FOR DOUBLING WEIGHT PERFORMANCE OVER NEAR-TERM SURVIVABLE ARRAYS
- ESTABLISHING REAL ENGINEERING DATA TO OUR USERS VIA FLIGHT EXPERIMENTATION

Session 1
Multi-Junction Cell Technology