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SOLAR DYNAMIC TECHNOLOGY STATUS FOR SPACE STATION FREEDOM APPLICATION

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SOLAR DYNAMIC TECHNOLOGY STATUS FOR SPACE STATION FREEDOM APPLICATION

This presentation has been compiled jointly by the Space Station Freedom Directorate and the Power Technology Division, both at Lewis Research Center. The objective of this presentation is to emphasize the 1) rationale to incorporate solar dynamic (SD) systems onto Space Station Freedom (SSF) as the power demand increases onboard SSF, 2) SD technical progress made through the SSF Program (SSFP), 3) areas of further technology development, and 4) future plans for SD system development.

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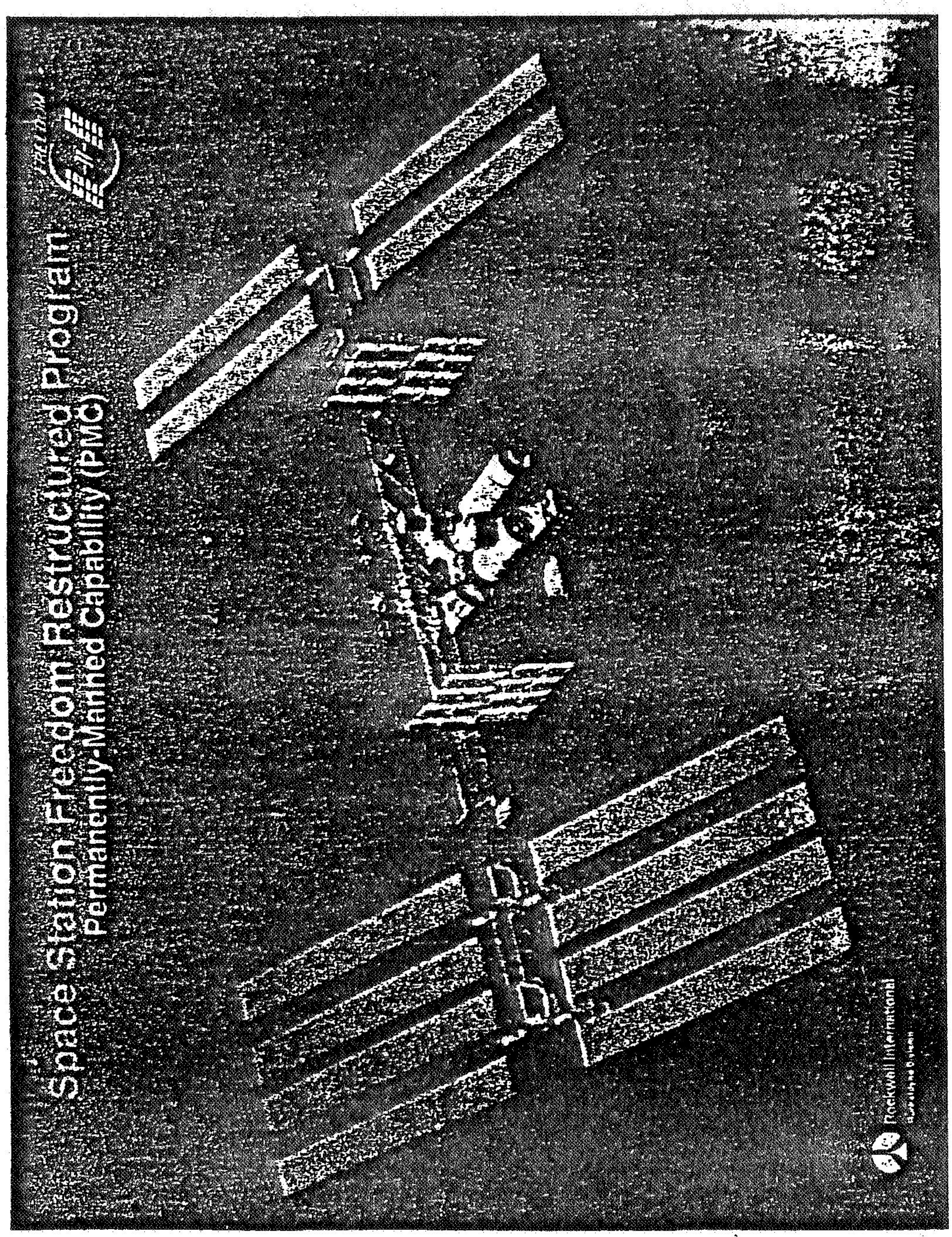
SSF HISTORICAL SYNOPSIS OF SOLAR DYNAMIC

- SSF PHASE B CONCLUDED THAT SD WAS THE VIABLE CHOICE TO COMPLEMENT PV
- SSF PHASE C/D COMPRISED OF 75 KW PV (PHASE 1) AND 50 KW SD (PHASE 2) + GROWTH
- SEVERAL PROGRAMMATIC CHANGES HAVE DOWNSCOPED SSF GROWTH
  - ★ SSF SD ACTIVITIES HALTED IN FY91
- ACTIVITIES ARE UNDERWAY TO REINSTATE GROWTH REQUIREMENTS (150 KW)
- OAET CONTINUES SD TECHNOLOGY DEVELOPMENT

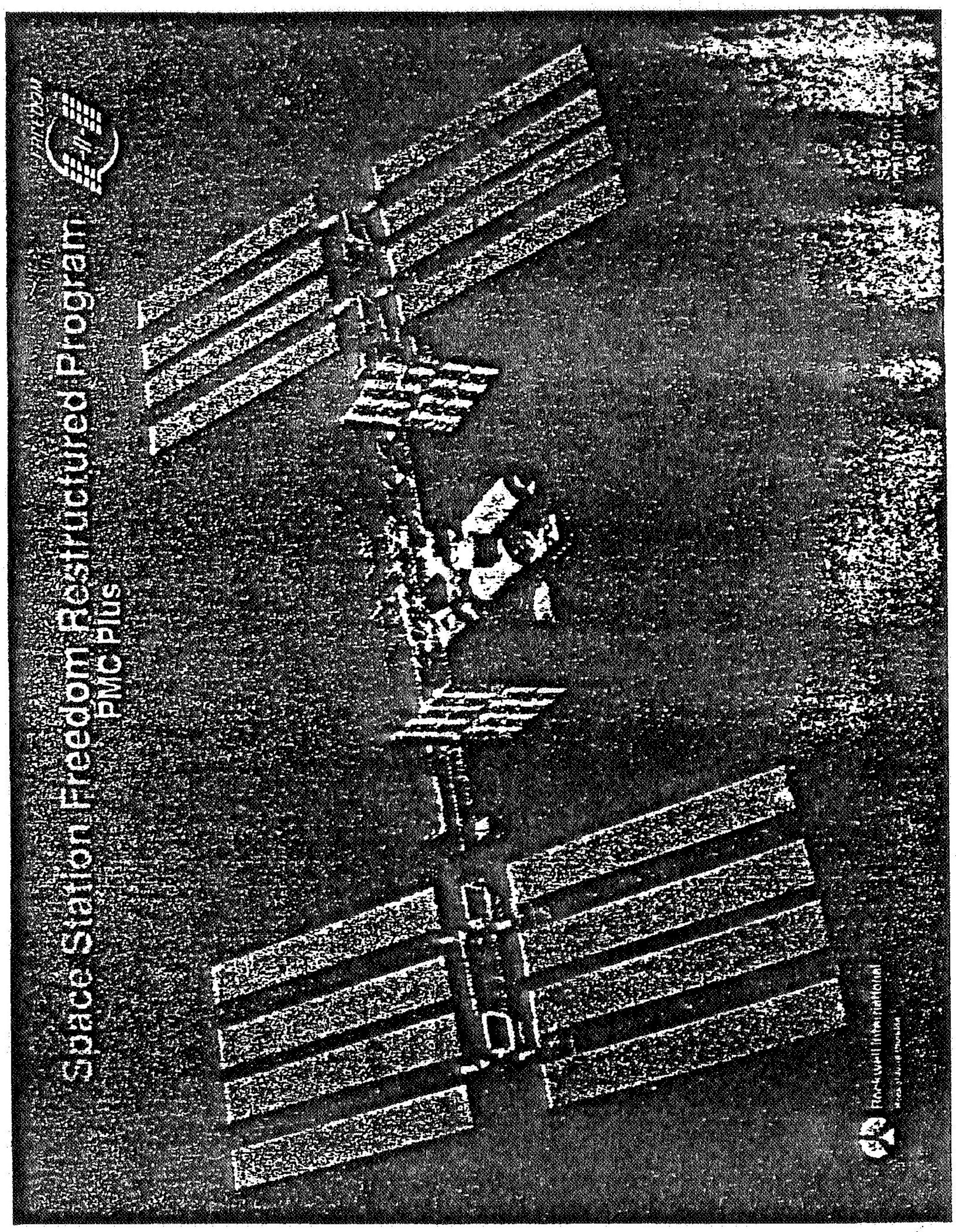
SSF HISTORICAL SYNOPSIS OF SOLAR DYNAMIC

Solar Dynamic systems have existed for a long time in the form of terrestrial applications, space system concepts, and space based component testing. At the conclusion of the Phase B portion of the SSFP, it was decided that SD power was the viable choice to complement a photovoltaic (PV) system. In fact, the Phase B baseline consisted of 37.5 kw of PV and 50 kw SD split in power generation to serve SSF's demands. As an incremental approach for the progression of SSF, the Phase C/D part of the program consisted of a "Phase 1" SSF configuration of 75 kw PV, that grows to a "Phase 2" SSF configuration of an additional 50 kw SD, and has the capability to grow to 300 kw total. Since the start of the Phase C/D effort, several programmatic changes have relaxed or eliminated requirements on the baseline to be designed for growth. These changes culminated in the halt of SD activities in the SSFP in FY91. However, efforts are underway to reinstate growth requirements upon the baseline SSF that include growth and evolution of the Electric Power System (EPS) to reach a capability of 150 kw. Meanwhile, NASA's Office of Aeronautics, Exploration, and Technology (OAET) has always pursued solar dynamic advanced development, and has been the recipient of the progress made within the SSFP.


Space Station Freedom Restructured Program
Permanently-Manned Capability (PMC)
Rockwell International

SPACE STATION FREEDOM RESTRUCTURED PROGRAM
PERMANENTLY MANNED CAPABILITY (PMC)

The Permanently Manned Capability (PMC) is a major milestone in the assembly of SSF. This is the baseline configuration to which programmatic requirements are satisfied, and to which SSF hardware/software is being designed. With respect to the EPS, this configuration consists of three PV Modules and six primary power channels. Each PV Module has a rated capacity of 18.75 kw average and 25 kw peak, and therefore the PMC configuration has a rated capacity of 56.25 kw average and 75 kw peak. However, peaking capability is limited and only available during insolation periods prior to the full battery complement. (The current baseline is to launch each PV Module without its full complement of batteries, and in some point in time, install the remaining batteries.) Each PV Module consists of these major items: two solar array wing assemblies, a thermal control subsystem, an electrical energy storage subsystems, and an electrical equipment subsystem. Two independent, primary power channels are fed from one PV Module, essentially one channel per PV wing. The PMC EPS design allows the addition of a fourth PV Module to add power to the Station, and achieve a "balanced" configuration of two PV Modules on the starboard and two on the port side.



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SPACE STATION FREEDOM RESTRUCTURED PROGRAM
PMC PLUS

Permanently Manned Capability (PMC) Plus is a term used to describe the SSF configuration at a milestone just after the PMC milestone. Regarding the EPS, PMC Plus represents the addition of a fourth PV Module of the same rated capacity as the initial three PV Modules. This configuration achieves an eight channel primary power architecture at a system rated capacity of 75 kw average and 100 kw peak power with full complement of batteries.

Currently, there are no requirements at the designers level to design or plan for subsequent increase in EPS capacity.

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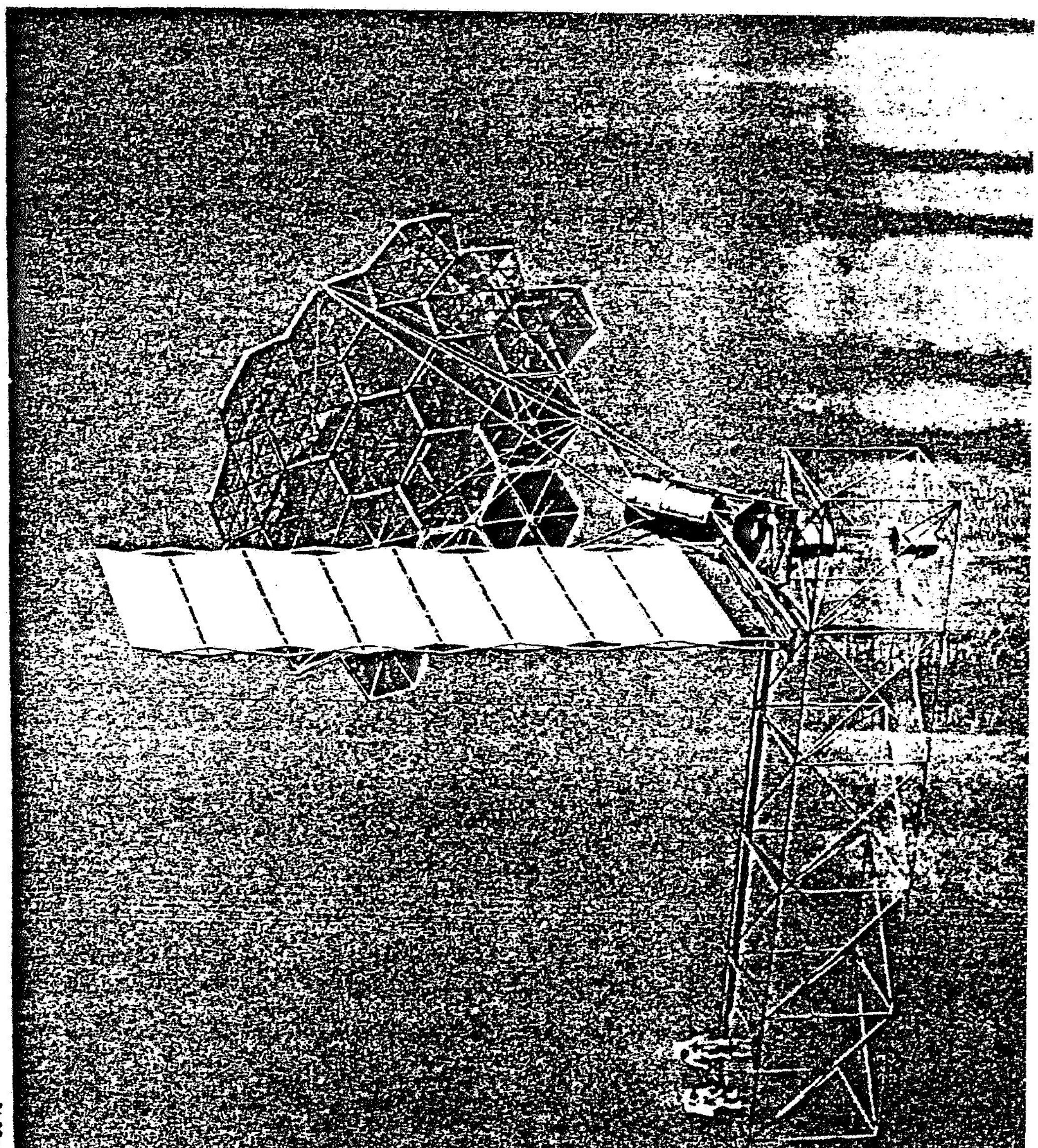


SPACE STATION SOLAR DYNAMIC POWER MODULE

Until recently, the planned design was to add solar dynamic power modules outboard of the initial PV Modules as the SSF demand for power increased. Each SD Module being designed for SSF would provide 25 kw net power to the user interface, and each consisted of:

CONCENTRATOR ASSEMBLY: 60 foot concave mirror focuses solar energy into the Receiver.

RECEIVER ASSEMBLY: Receives concentrated solar energy, and uses it to heat Helium–Xenon gas. Also, stores thermal energy for use during eclipse.

POWER CONVERSION UNIT: Hot Helium–Xenon gas drives a turbine–alternator–compressor set, producing the electrical power output.

ELECTRICAL EQUIPMENT ASSEMBLY: Controls SD module operation and converts alternator power output for delivery to users.

BETA GIMBAL ASSEMBLY: Points Concentrator Assembly at the sun as station moves through its orbit, and transfers power and data to the power distribution system.

VERNIER POINTING GIMBAL: Fine points Concentrator Assembly at the sun.

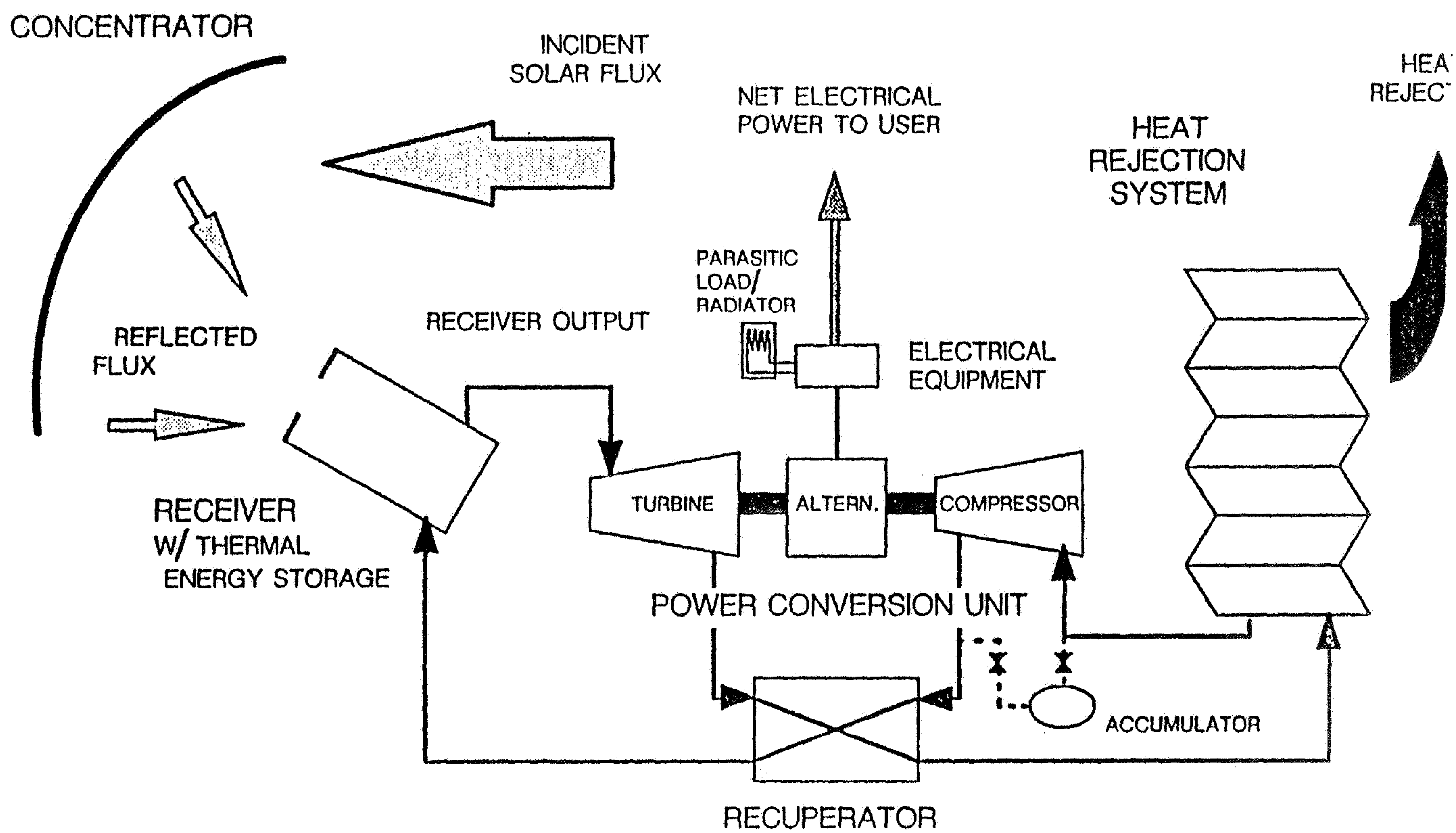
HEAT REJECTION ASSEMBLY: Radiates excess thermal energy to space to maintain necessary power levels and operating temperatures.

National Aeronautics and
Space Administration

Lewis Research Center

SPACE STATION FREEDOM

SOLAR DYNAMIC CLOSED BRAYTON CYCLE



SOLAR DYNAMIC CLOSED BRAYTON CYCLE

The key aspect of solar dynamics is that it functions as a system. SD not only coverts solar energy into electric energy (as is true of photovoltaics), but is also comprised of thermal energy storage and heat rejection functions as an integral part of its design.

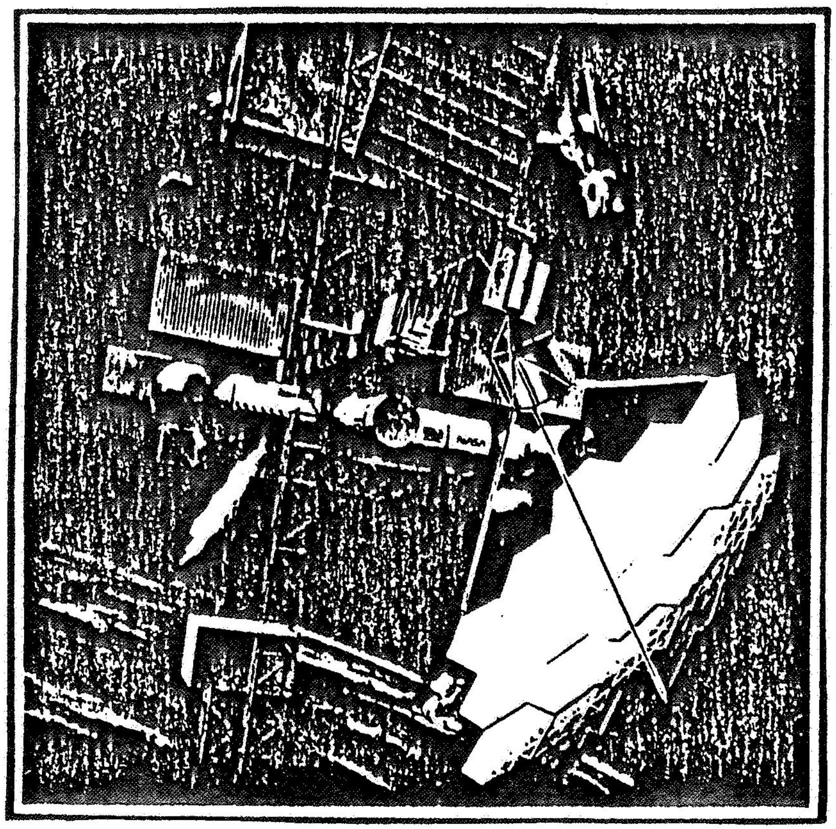
The SD system operates when solar insolation is collected by the concentrator assembly and focused at the receiver assembly aperature. The solar energy entering the receiver assembly is transferred to the power conversion unit working fluid (helium-xenon chosen for SSF SD) and a thermal energy storage material (eutectic LiF-20CaF_2 chosen for SSF SD) for heat transfer to the working fluid during the eclipse portion of the orbit. The heated working fluid enters the power conversion unit (closed Brayton cycle chosen for SSF SD) for conversion from thermal energy into electrical energy. Power is then delivered by the power conversion unit for regulation and distribution to the user. To complete the cycle, the waste heat from the power conversion unit and the electrical equipment assembly is collected by the heat rejection assembly and radiated to the surrounding environment.

SPACE ENERGY CONVERSION R&T

THERMAL ENERGY CONVERSION

MISSION & BENEFITS
- EARTH ORBITING PLATFORMS -

SPACE STATION FREEDOM

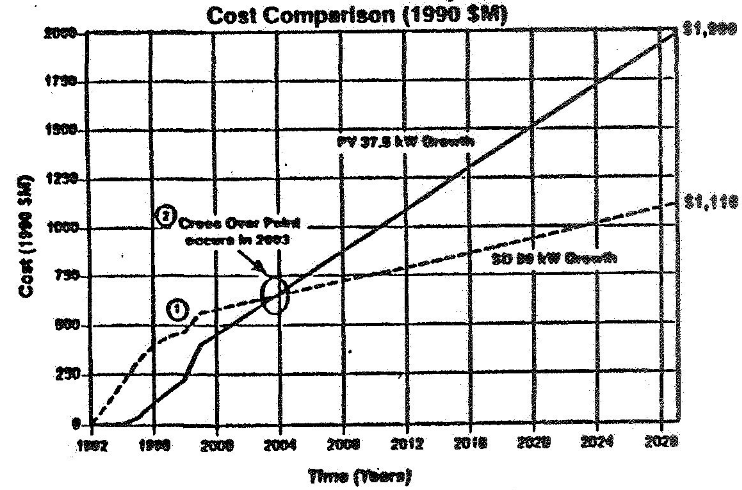


QUALITATIVE BENEFITS

- MORE FLEXIBILITY
- LONG LIFE COMPONENTS
- LESS DRAG
- LOWER MASS
- LOWER RECURRING COSTS
- LESS AGGREGATE EVA

QUANTITATIVE BENEFITS

Photovoltaic vs. Solar Dynamic
Cost Comparison (1990 $M)



Notes: 1. Step change between 1998 and 1999 is due to initial launch cost.
2. Curves based on current 18.75 kW PV and 25 kW SD power modules, in a balanced station configuration. Cross over would occur prior to year 2000 for common growth power levels.

EC91-001.4

SOLAR DYNAMIC vs. PHOTOVOLTAIC FOR SSF GROWTH

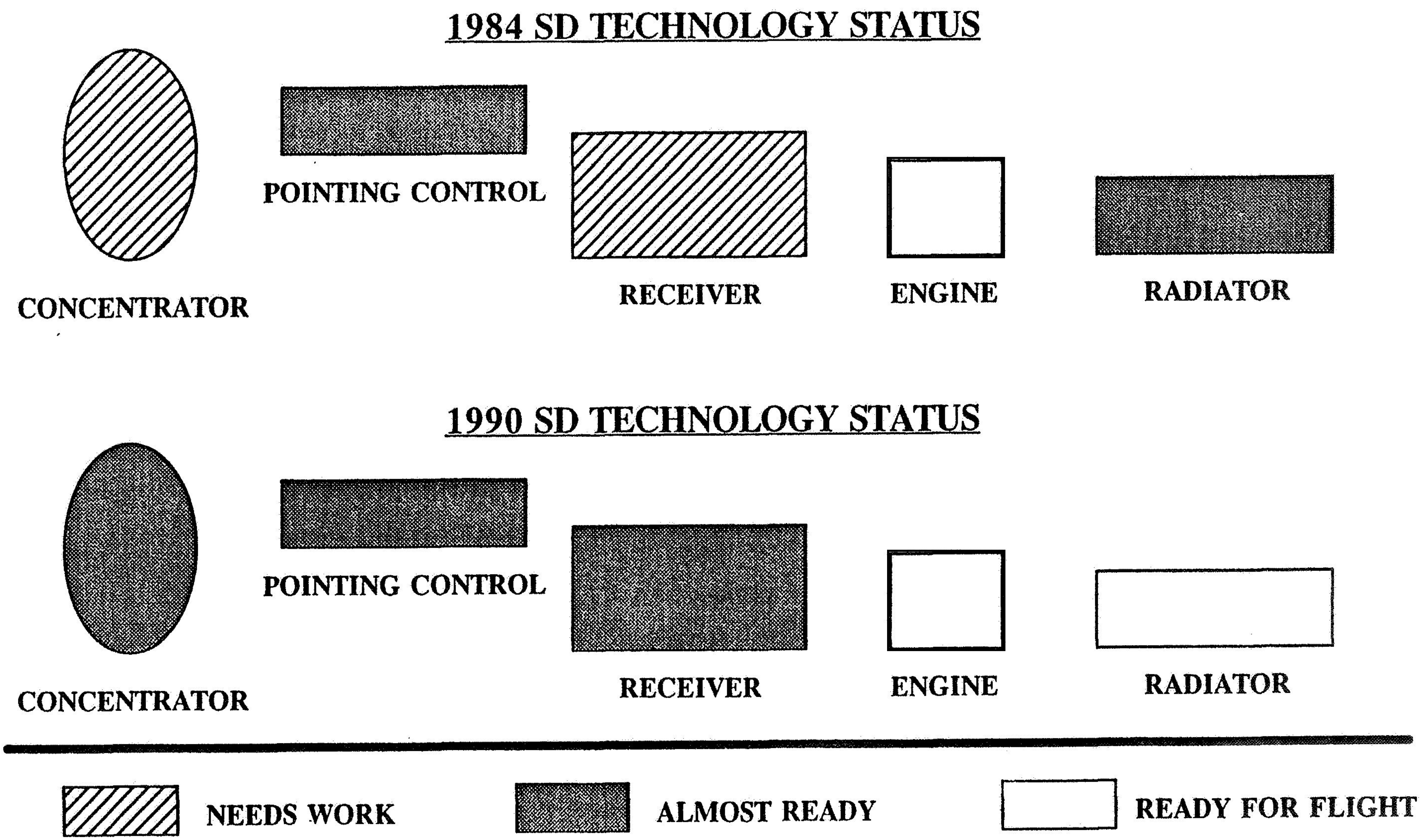
Incorporating SD as the growth power generation path for SSF is irresistibly attractive. The SD advantage goes beyond the initial, baseline PV system in that it rivals any technological advancement for any given PV component that comprises that system.

QUALITATIVE BENEFITS: For SSF, the addition of SD to complement the initial PV is a luxury that offers, not only more net power, but greater flexibility in that two types of sources in a hybrid configuration would assure an uninterrupted supply of power during periods of maintenance or in the unlikely event of a major or systematic problem in either type of source. The SD power generating and energy storage components also have longer lifetimes than the PV arrays and batteries. This results in substantial cost savings in hardware replacement, launch, and on-orbit installation costs. Because of the significantly higher solar-to-electric power efficiency, SD has a solar collection area only about 25% of that for a PV system for a given power output. This translates to about one-half the aerodynamic drag and correspondingly lower reboost requirements. Also, because SD produces more power per unit mass and has longer life components, SD means less mass to orbit. Although the SSF SD design required more manhours upfront to install than its counterpart PV, the less maintenance and resupply needed for SD quickly overcomes the aggregate manhours when the two systems are compared over the lifetime of SSF.

QUANTITATIVE BENEFITS: Studies have indicated that the various operations and hardware cost savings resulting in the use of SD power rather than PV power for SSF growth would amount to a reduction in life cycle costs of several billion dollars over the 30 year life of SSF. The results from one such study, shown here, show the comparison of adding SD vs. PV to an already existing SSF PV system. The dashed line shows the DDT&E plus production costs of 50 kw SD in the first 6 years, a noticible step indicates launch costs, and the out-year costs indicate the necessary support during the SSF lifetime. The solid line shows production only of 37.5 kw of PV in the first 6 years, launch, and out-year costs. This assumed that the DDT&E would be associated with the initial PV system. If the production costs were included, or if the growth power levels of each system were to be common (i.e., 50 kw growth for both PV and SD), then the crossover point would occur at an earlier point in time. Note that the yearly timeline is meant to only represent the SSF lifetime.

SPACE STATION SYSTEMS

OPERATIONS DIVISION



SOLAR DYNAMIC TECHNOLOGY STATUS

From a technology perspective, the SD system can be broken down into five basic technology areas: concentrator, pointing control, receiver, engine, and radiator. When SSF Phase B concluded that SD would be part of the Program, it was realized that not all technology areas of SD were ready to be developed into flight hardware. However, many technological advances have occurred as a direct result of SD being a part of the SSF Program.

1984 TECHNOLOGY STATUS: The closed Brayton cycle was chosen to be the type of engine or power conversion unit because of its proven hardware history. However, the concentrator and heat receiver technology needed some work to minimize the technical risk. Nothing like the proposed SD concentrator had been assembled in space and there were thermal questions associated with the receiver. The pointing control and radiator areas were not quite ready but no technical barriers were identified to prevent a timely development.

1990 TECHNOLOGY STATUS: When SSF SD activities were halted, several aspects of SD technology had advanced. The radiator was deemed to be common with the radiator under development for the PV module, and through many tests and demonstrations the concentrator and receiver areas had progressed to the point as almost ready for flight hardware. Although the pointing control area does not show significant progress, this area had not received the attention it deserved until recently but is still deemed as an almost ready technology area.

CONCENTRATOR TECHNICAL PROGRESS

- REFLECTIVE/PROTECTIVE COATINGS
  - DEMONSTRATED REFLECTIVE COATING DEPOSITION
  - COATING DURABILITY TESTED
- OPTICAL CHARACTERIZATION
  - DIGITAL IMAGE RADIOMETER CHARACTERIZED REFLECTIVE SURFACE OPTICS
  - OPTICAL CODE DEVELOPED FOR A FULL SIZE CONCENTRATOR
- STRUCTURAL RIGIDITY/ACCURACY AND ASSEMBLY
  - DEMONSTRATED 19-PANEL ASSEMBLY AND STRUCTURAL REPEATABILITY
  - LATCHING GUIDES DESIGNED AND BUILT
  - STRUCTURAL RIGIDITY OF LATCH AND PANEL DESIGNS MODELED AND TESTED
  - CONCENTRATOR PANEL ASSEMBLY TESTS IN MSFC NBF VERIFIED CONCEPT

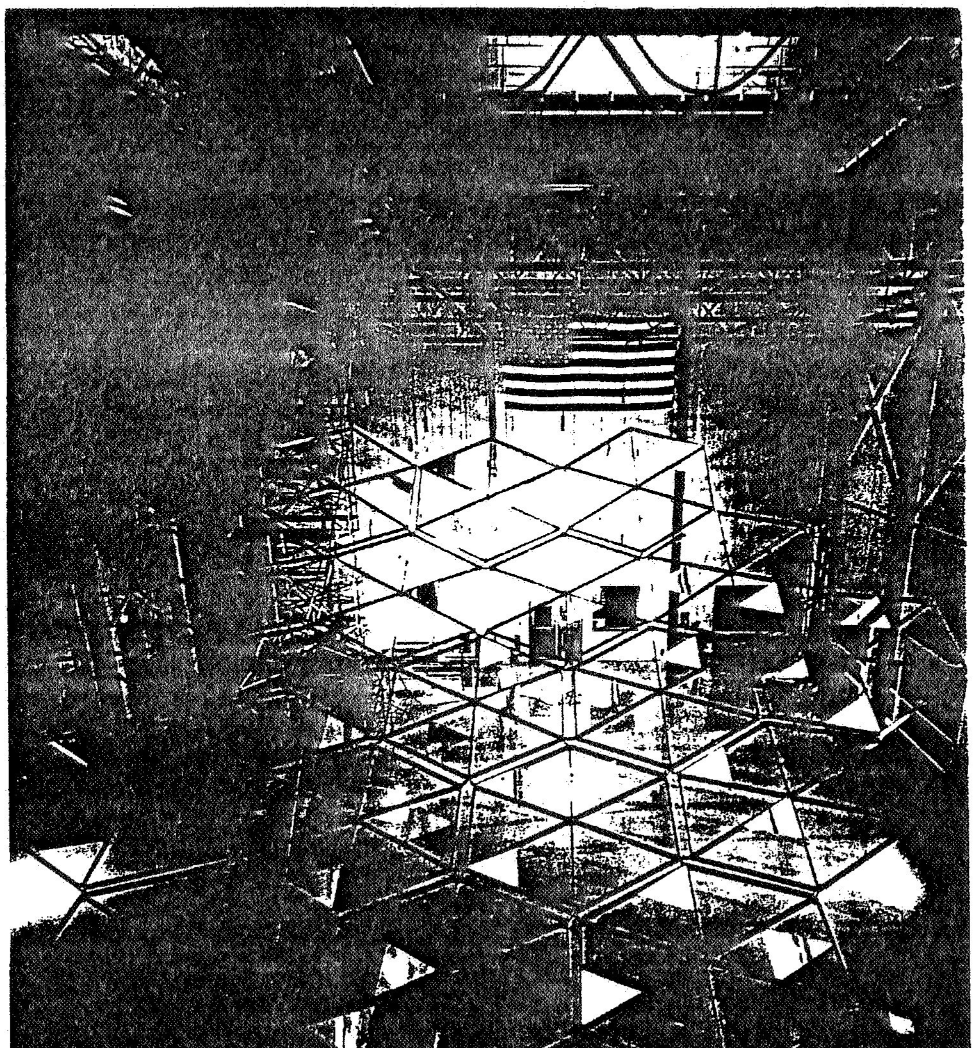
CONCENTRATOR TECHNICAL PROGRESS

Technical progress for the concentrator area can be broken down into three areas: reflective and protective coatings for the concentrator surface, optical characterization of the reflective surface and surface contour, and structural rigidity/accuracy and assembly of the concentrator panels.

REFLECTIVE/PROTECTIVE COATINGS: The need for highly reflective materials on the concentrator facets was meet by successfully demonstrating the depositing of a film of reflective coating on a concentrator facet. At the time, vapor deposited aluminum was deemed the best overall coating. Also, asher tests (simulated space environment with accelerated degradation effects) were performed on coupons of several candidate coatings to examine coating durability. LDEF data has not yet been analyzed for this purpose.

OPTICAL CHARACTERIZATION: A full size concentrator was assembled and populated with vapor deposited aluminum facets at several, predetermined locations on the concentrator. A Digital Image Radiometer (DIR) was used to characterize the reflective surface optics. Also, an optical code was developed for a full size concentrator.

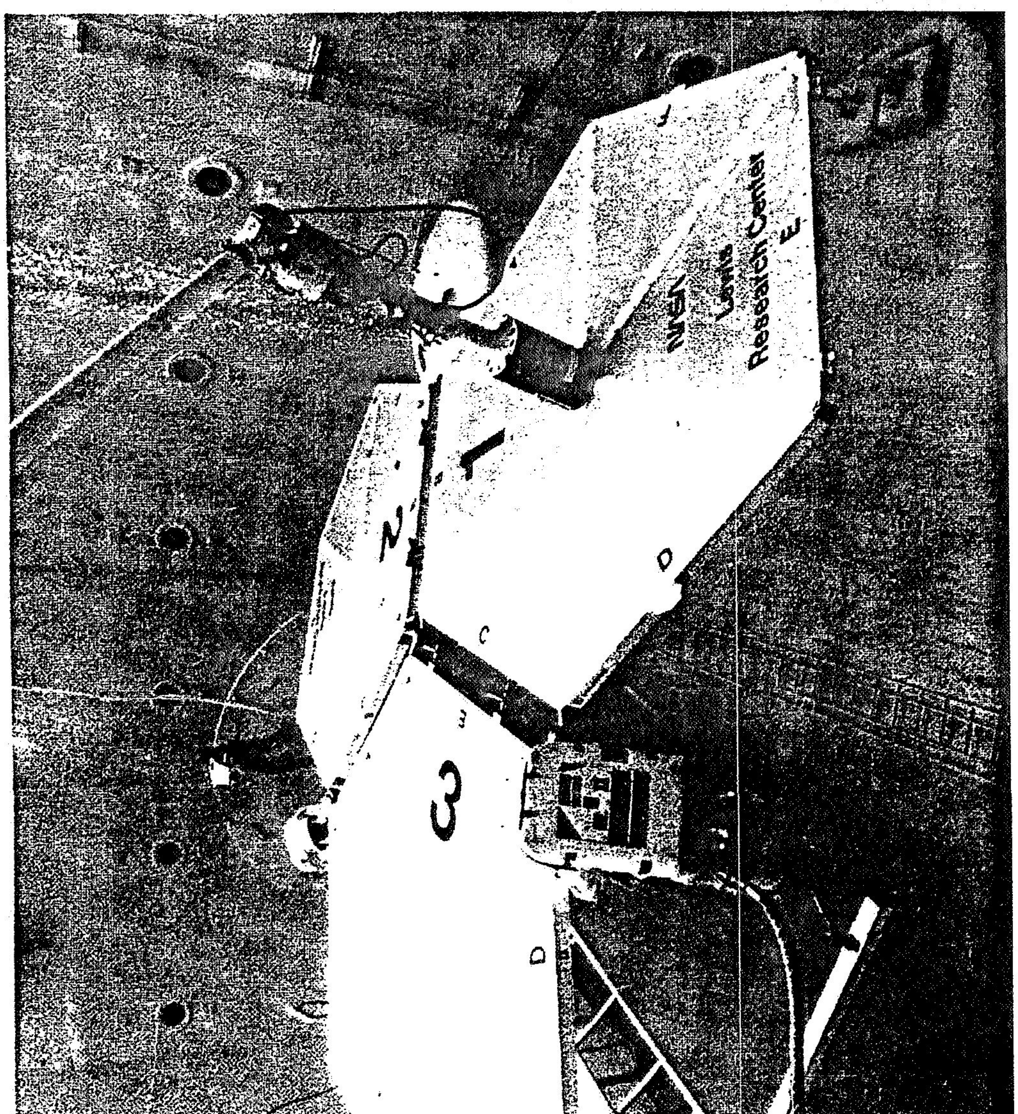
STRUCTURAL RIGIDITY/ACCURACY and ASSEMBLY: A key item for concentrator technical progress has been the demonstration of the assembly of 19 panels of a full size concentrator. In addition, several 1–g assembly/disassembly tests have assured the structural integrity of the entire concentrator, including its structural rigidity and optical accuracy. In support of this activity, latching guides were designed and built, and the structural rigidity of the latch and panel designs were modeled and tested. This area of technical progress climaxed when concentrator panel assembly tests in MSFC's Nuetral Buoyancy Facility (NBF) verified that this concept was readily achievable by astronaut interaction in a weightless environment.



CONCENTRATOR TECHNICAL PROGRESS

Shown here is a full scale assembled concentrator in the Power System Facility (PSF) building at Lewis Research Center. This concentrator consisted of 19 hexagonal panels, each of which would hold 24 triangular mirrored facets, when fully populated. Each panel is connected to its adjacent panel by unique latching mechanisms. This particular test was only populated with relatively few facets, but were positioned in predetermined, strategic locations. Several methods were used to gain data on the optical characteristics of the facets and concentrator. One method was the use of a Digital Image Radiometer (DIR). This utilized a bank of position adjustable overhead lights that would illuminate a particular facet to be tested and the reflected light would be recorded by a TV camera and fed into a computer for analysis. Another method used, that was similar to DIR but more tedious, was the tracing of a laser beam from overhead to measuring the position of the reflected beam. Also, a more comprehensive test involved the positioning of a light source at the concentrator focal point and recording data.

Of utmost significance was the ability for the repetitious assembly and disassembly of these 19 panels in 1-g without any significant differences in the optical accuracy when retested, using DIR for example. This confirmed the structural rigidity and optical accuracy of the latch and panel designs.


Research Center

CONCENTRATOR TECHNICAL PROGRESS

Shown here is a picture taken during a SD concentrator assembly test in the Nuetral Buoyancy Facility (NBF) at Marshall Space Flight Center. These series of tests, Concentrator Panel Assembly Tests (COPAT), were conducted around August 1990 and were a critical part of the early design evaluation process that allowed for reduced technical and schedule risks for: latch and guide mechanism design, baselining the concentrator configuration, and flight operations and procedures.

The objectives of these tests were to evaluate the feasibility of current concentrator latch mechanisms and guides designed for on–orbit assembly, evaluate anticipated flight operations and assembly procedures for the concentrator, evaluate astronaut positions for on–orbit assembly, and to assess handhold locations and position to gain the required leverage and line–of–sight for assembly.

The primary accomplishment from the COPAT test series was that the precision latch and guide concept and associated assembly procedures/orientations were demonstrated. These tests demonstrated the ability of successful on–orbit assembly of the SD concentrator, or in general, large space structures.

RECEIVER TECHNICAL PROGRESS

- THERMAL STORAGE MATERIALS COMPATIBILITY AND MECHANICAL STRENGTH
  - SALT EXPOSURE (20,000 hrs) HAD NO IMPACT ON CONTAINMENT MATERIAL
  - MECHANICAL PROPERTIES DATABASE WILL ENHANCE STRUCTURAL ANALYSES
- THERMAL ENERGY STORAGE PERFORMANCE IN MICRO-GRAVITY
  - CONSERVATIVE TES DESIGN APPROACH ADOPTED
    - ☆ SALT COMPARTMENTALIZATION
    - ☆ CONDUCTION PATHS
  - "ALL-ATTITUDE" CANISTER TESTS QUANTIFIED VOID IMPACTS
  - STRUCTURAL ANALYSES & THERMAL TESTING CONFIRMED CANISTER INTEGRITY
- RECEIVER THERMAL PERFORMANCE
  - TESTS CONFIRMED CONSTANT TURBINE INLET TEMPERATURE W/ CYCLIC INPUT
  - SINGLE TUBE TEST VERIFIED TES CONFIGURATION (6500 hrs of cyclic testing)
  - ALTERNATIVE, FULL SCALE RECEIVER TESTED IN THERMAL/VACUUM TANK

RECEIVER TECHNICAL PROGRESS

Technical progress for the concentrator area can be broken down into three areas:

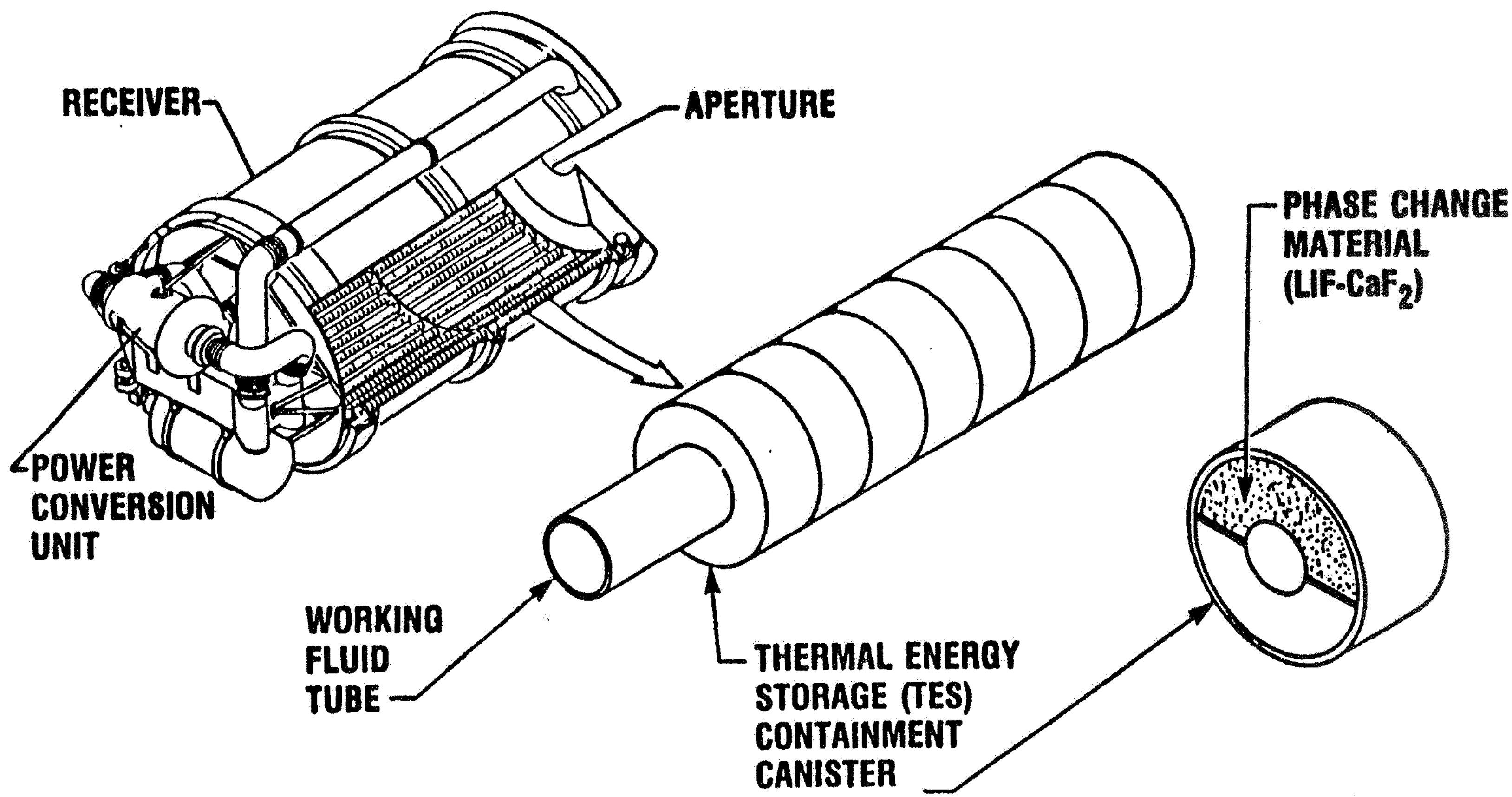
MATERIALS COMPATIBILITY & MECHANICAL STRENGTH: This area addressed the interaction between the thermal energy storage (TES) material, the material that contained the TES material and thermal cycling. The containment material, Hanes 188, was exposed the TES material, a eutectic lithium flouride calcium flouride ($LiF-20CaF_2$) salt, for 20,000 hours isothermally at 1093 degrees K. This, along with mechanical strength tests and pertinent previously recorded information showed no impact between the TES material and the containment material.

TES PERFORMANCE IN MICRO-G: Micro-gravity effects on the behavior of the TES material undergoing thermal cycling posed an interesting challenge. Location and effect of voids in the salt created during the continous freeze/thaw cycles was the prime concern. Therefore, a conservative design approach was adopted by containing the salt in many small compartments (canisters) that minimized the void concern and provided excellent conduction paths between the incoming solar energy, the containment material, the salt, and the working fluid which is to be heated. Canister tests in 1-g quantified the void impacts. These tests heated the canisters held at various attitudes relative to gravity and essentially made the canisters gravity insensitive. Structural analyses and "worst-case" thermal testing of the canisters confirmed the integrity of the canister. Therefore, since TES performance was verified by ground testing and analysis, no flight test is required for this conservative design approach.

THERMAL PERFORMANCE: From the standpoint of the heat receiver as a whole, tests have confirmed that a relatively constant turbine inlet temperature is achieved with cyclic solar input. Also, a single tube test with its respective number of canisters verified operation of the TES configuration (6500 hours of cyclic testing). As an alternative, an independent design concept has been tested at full scale in a thermal/vacuum environment. This concept uses a metallic "felt" (analogous to a brillo pad) as the TES containment material that is wrapped around the working fluid tubes and is also aimed at minimizing the effect of salt voids. Also, a solar lamp array (for vacuum use) was developed that was placed inside the receiver to radially, axially, and in time simulate solar flux in a controlled manner.

SPACE STATION FREEDOM

THERMAL ENERGY STORAGE



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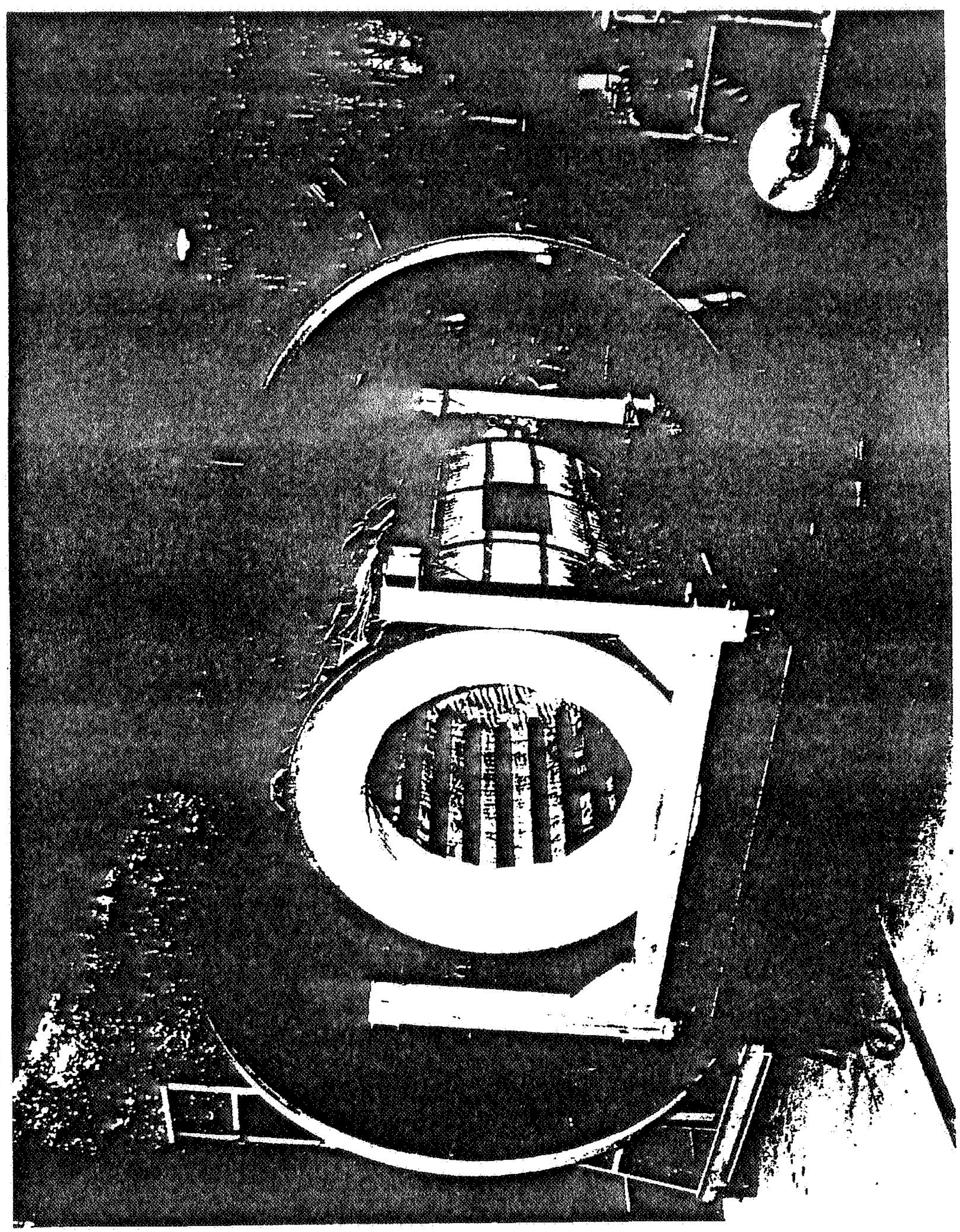
RECEIVER TECHNICAL PROGRESS

Shown here is a drawing of the heat receiver to be used in the SSF SD design. The equipment shown on the left face of the cylindrical receiver is the power conversion unit (closed Brayton cycle engine). Note that the inside of the receiver contains many working fluid tubes, in which each tube holds several thermal energy storage containment canisters.

This conservative design approach was found to not warrant a flight test.



RECEIVER TECHNICAL PROGRESS

Shown here is the full scale alternative receiver designed by Boeing. The receiver is shown being loaded into the thermal/vacuum tank at the Boeing facility. The solar lamp array was then placed inside the receiver to simulate solar flux in the tank environment.

RADIATOR TECHNICAL PROGRESS

- MICROMETEOROID AND SPACE DEBRIS IMPACT
  - FLUID PASSAGE SURVIVABILITY TESTED
  - SURVIVABILITY BETTER THAN ANALYTICAL PREDICTIONS
- DURABILITY OF THERMAL COATINGS
  - AO, UV, AND THERMAL CYCLING TESTS OF 19 CANDIDATE COATINGS
- COMMONALITY WITH PV DEVELOPED RADIATOR
  - ACCOUNT FOR DIFFERENT WORKING FLUID
  - ACCOUNT FOR LARGER POWER DISSIPATION

RADIATOR TECHNICAL PROGRESS

Technical progress for the radiator area can be broken down into three areas: micrometeoroid and space debris impact, durability of thermal coatings, and commonality with the SSF developed PV radiator.

MICROMETEOROID/SPACE DEBRIS IMPACT: Technical and design issues have arisen with the growing concern of micrometeoroid or space debris impacts on the survivability of certain hardware, especially over long operating lifetimes. Of special concern were the fluid passages that constitute the heat rejection system. It was necessary to investigate the effect of space particle impacts on the functionality of the radiator. Sections of the radiator underwent particle impact testing and the integrity of the fluid passages and their function survived better than analytically predicted.

THERMAL COATINGS: Coatings necessary to optimize the radiator efficiency and survive orbital thermal cycling were tested. Atomic oxygen, UV radiation, and thermal cycling tests of 19 candidate coatings were conducted.

COMMONALITY WITH PV RADIATOR: An effort was made to minimize technical risk by investigating the possibility of common radiators between the SD module and the PV module developed in the baseline SSF Program. This was in fact possible with the exception of a different working fluid to account for higher inlet temperatures, and the radiator area would need to be slightly larger to account for larger power dissapation.

Because no technical barriers were found and the affirmation that SD could benefit from the development of the SSF baselined PV module radiator, this technology area for SD is now deemed as ready for flight development.

ASD SYSTEMS TECHNOLOGY

SOLAR DYNAMIC TECHNOLOGY PERFORMANCE GOALS

PERFORMANCE REQUIREMENT	CURRENT SOA	ADVANCED SOLAR DYNAMICS (ASD)
<u>ORBITAL SYSTEMS</u>		
• SPECIFIC POWER	5 - 8 W/kg	16 - 20 W/kg
• CONCENTRATOR		
- MASS	4 kg/sq. m.	1 - 2 kg/sq. m.
- CONTOUR ACCURACY	4 MILLIRADIANS	1 MILLIRADIAN
• RECEIVER		
- MASS	50 kg/kW	25 kg/kW

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ASD SYSTEMS TECHNOLOGY

SOLAR DYNAMIC TECHNOLOGY PERFORMANCE GOALS

* The system specific power is affected by the total system efficiency and the total system weight. The R&D done in the Advanced Solar Dynamic Program to increase the efficiency of the major components and subsystems and to reduce their size and weight point to the improvements that can be made in the specific power of the ASD systems for future space applications.

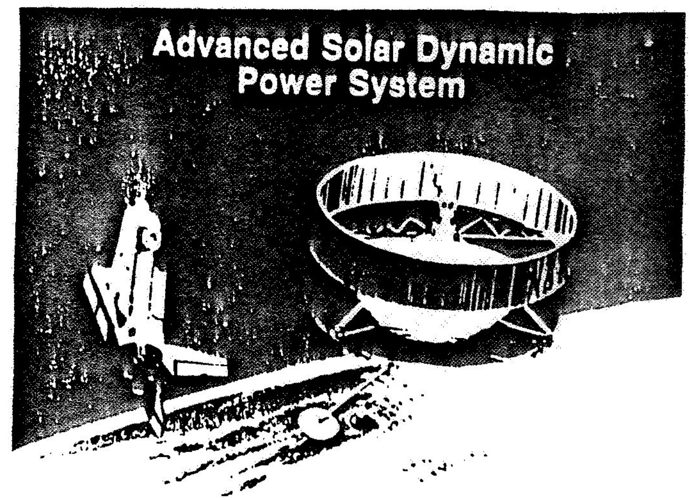
* The concentrator is one candidate for major improvements. Conceptual design studies were conducted in an effort to identify new and innovative concepts that would be lighter weight and more efficient. Of particular interest were concepts that would have the potential for achieving:
  - concentration ratios of at least 2000 to 5000. (SOA values are 1000 or less.) To achieve these high CRs means the surface contour accuracies have to be less than 1.0 milliradian.
  - high specular reflectance over the solar spectrum. Reflectances of 90 percent or more are possible using silver or aluminum as the reflecting material. Aluminum is not as reflective as silver, but it is immune to the space environment whereas silver is not. Hence for the near term, aluminum will be the prime candidate reflecting material because it is easier to work with than silver. For the long term, silver would be the preferred material.
  - low weight. The innovative concepts studied all the potential for achieving significant weight reductions. However, some have different degrees of risk associated with thier development.
  - autodeployability. This feature would be a great saving of valuable time on orbit if astronauts are not needed to assemble and deploy the concentrator.
  - long service life. The materials of construction are a critical factor that affects the service life. The space environment is a hazardous one for many materials. Therefore, the design of a concentrator must always include the optimum combination of materials so that in addition to meeting the performance requirements, it will survive for a long time, more than 10 tO 15 years.

* Since the heat receiver is the heaviest component in a solar dynamic power system, the development of light weight receivers is essential if the system specific power is to be increased substantially. To reduce the size of the receiver, ways must be found to increase the solar flux within the receiver cavity without creating hot spots and "thermal racheting". The goals of the program then are:
  - reduce the specific weight by a factor of two.
  - eliminate hot spots while at the same time reducing the receiver size.
  - eliminate "thermal racheting" through design of the TES canisters.
  - transfer of heat efficiently within the receiver by the use of heat pipe principles.

ASD SYSTEMS TECHNOLOGY

OBJECTIVES:

- IDENTIFY/ANALYZE INNOVATIVE COMPONENT/SYSTEM CONCEPTS
- DEVELOP HIGH EFFICIENCY, LOW MASS AUTO-DEPLOYABLE ADVANCED CONCENTRATOR TECHNOLOGIES
- IDENTIFY AND DEVELOP ADVANCED HEAT RECEIVER TECHNOLOGIES
- DEVELOP ADVANCED THERMAL ENERGY STORAGE TECHNOLOGIES



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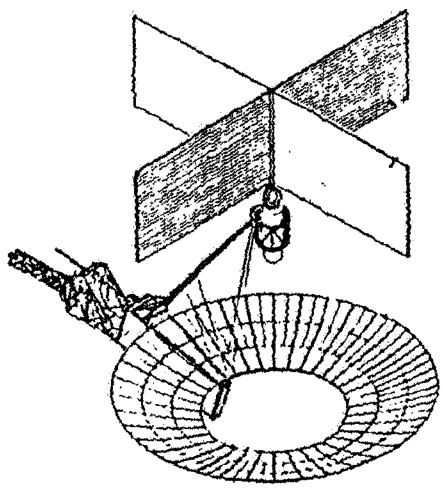
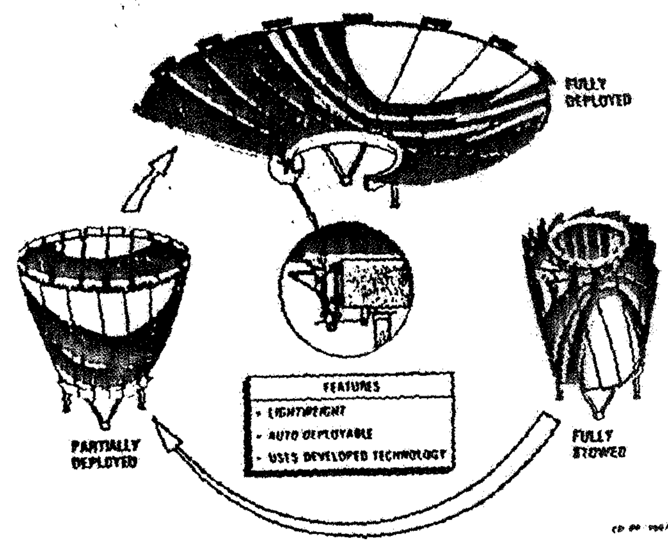
ASD SYSTEMS TECHNOLOGY

ADVANCED CONCENTRATORS

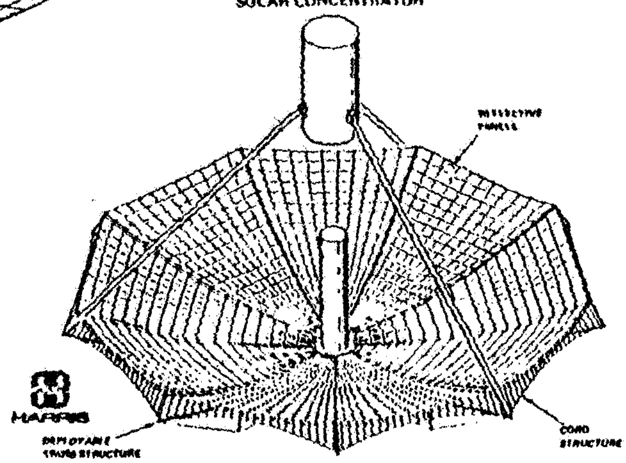
ACUREX CORP. SOLAR DYNAMIC POWER SYSTEM CONCEPT



NASA/CSU-AMC PROTOTYPE AUTO-DEPLOYABLE CONCENTRATOR



25 KW SPLINED RADIAL PANEL SOLAR CONCENTRATOR



FEATURES:

- ALL METAL HONEY COMB SANDWICH REFLECTOR PANELS
- AUTODEPLOYABLE
- HIGH SPECULAR REFLECTANCE (90%)
- HIGH CONCENTRATION RATIO (>2000)

ADVANCED CONCENTRATORS

Shown on this viewgraph are three of the four solar concentrator concepts that were devloped in the Advanced Solar Dynamic Program. The two on the left, designed by the Acurex Corp. and the Harris Corp., along with the one not shown, designed by Science Application International Corp., were contracted attempts to meet the goals set forth in the earlier VG on Goals. The concentrator concept on the right, referred to as the hinged folding panel type, is being developed under a NASA Lewis Grant by the Advanced Manufacturing Center of the Cleveland State University, Cleveland, Ohio. Of the four concepts, the one with the lowest development risk is the NASA/CSU-AMC concept because it builds on similar technology that was developed successfully in the 1960s.

The Acurex, Harris, and SAIC concepts have not been carried beyond the initial conceptual design phase due to the lack of funding.

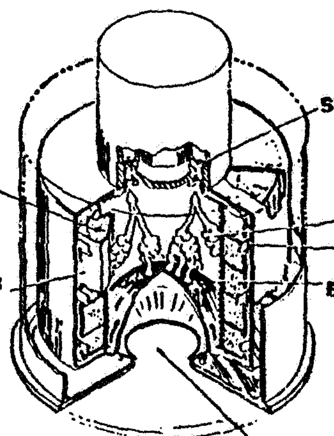
Because the hinged folding petal concept was judged to have the most promise for early development, CSU-AMC was asked to go forward a preliminary design of 2-meter diameter unit that was intended to be a reduced scale demonstration article to validate the fabrication techniques and the autodeployment features. Again, because of the lack of funding, the effort was focussed on developing the techniques for making the reflector panels. This work is nearing completion. A single reflector panel for the 2-meter concentrator is scheduled to be delivered to NASA Lewis in August 1991. This panel will have overcome some major technical problems with concentrators, namely that of being able to fabricate accurately contoured panels with a high specular reflectance that will also resist degradation by the space environment. This is one of the major technical accomplishments to come out of Advanced Solar Dynamic Program.

A parallel facet development was undertaken by the Solar Kinetics Inc., Dallas Texas under a SBIR contract. The technical effort is very close to completion. An all aluminum reflector facet which has been bonded with epoxy adhesives is scheduled to be delivered to be delivered to NASA Lewis in the near future.

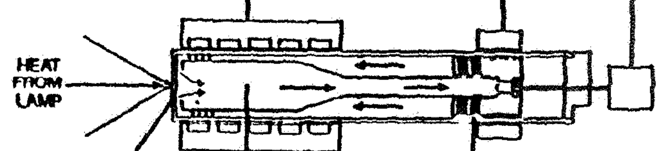
ASD SYSTEMS TECHNOLOGY

ADVANCED RECEIVERS

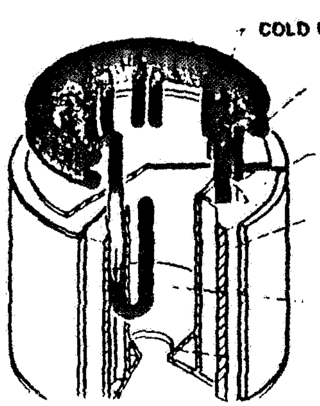
STIRLING SOLAR RECEIVER



500 WATT DIRECT FLUID ABSORPTION RECEIVER EXPERIMENT



BRAYTON SOLAR RECEIVER



FEATURES:

- DIRECT FLUID ABSORPTION RECEIVER
  - REDUCES RE-RADIATION LOSSES
- STIRLING & BRAYTON RECEIVERS
  - HEAT PIPE CAVITIES (UNIFORM HEAT FLUX)
  - WEDGE SHAPED TES CANISTERS (NO RACHETING)

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ASD SYSTEM TECHNOLOGY

ADVANCED HEAT RECEIVERS

* A solar dynamic receiver designed for space application differs from one designed for terrestrial use in that enough energy must be stored during the sun portion of the orbit (54 minutes) to operate the heat engine during the eclipse (36 minutes). This is done by melting containers of a fluoride salt that are heated during the sun portion of the cycle along with supplying heat to the engine.

* Two receivers designed for the ASD program one for the Brayton Cycle and one for the Stirling cycle both feature a heat pipe cavity for uniform distribution of the solar flux. The Stirling receiver uses a hemispherical dome to receive the solar flux while the Brayton receiver uses a cylinder configuration.

* Both of these receivers were designed to avoid two problems associated with heat receivers:

  - Hot spots are generated when heat is not removed from a surface of high flux fast enough to avoid high surface temperatures. The heat pipe feature redistributes the flux in a manner to avoid the generation of hot spots.

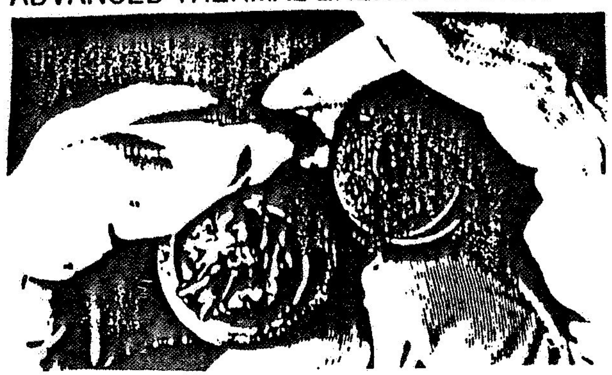
  - The thermal energy storage (TES) materials used in heat receivers expands upon melting as much as 30 percent. If provision is not made to allow melting TES flow into a void over expansion of the walls can result causing rupture of the container. If this happens repeatedly over many cycles it is called "thermal ratcheting". Both of these receivers use wedge shaped containers that are designed to avoid thermal ratcheting.

* The direct fluid absorption receiver uses a small amount of halogen gas to make the working fluid absorb the thermal energy directly in the gas instead of heat transfer from metal surfaces to the gas by convection. This means that losses from reradiation are reduced. This will reduce the concentrator and pointing requirements.

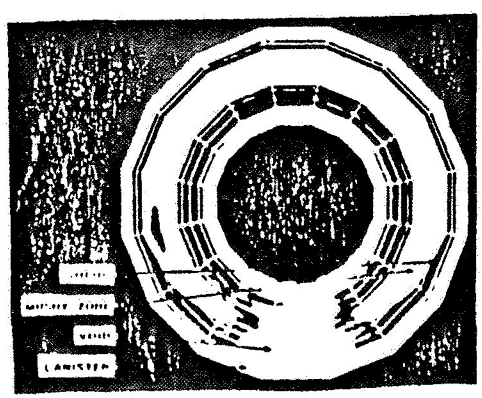
ASD SYSTEMS TECHNOLOGY

THERMAL ENERGY STORAGE

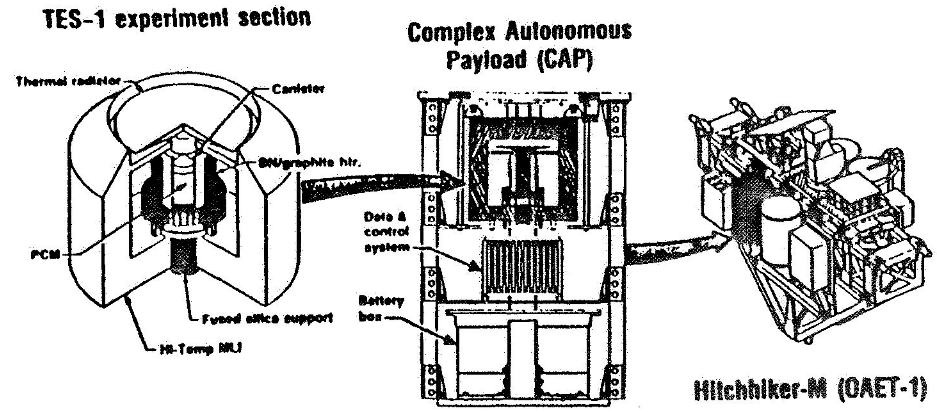
ADVANCED THERMAL ENERGY STORAGE DEVELOPMENT



NORVEX CODE DEVELOPMENT



THERMAL ENERGY STORAGE TECHNOLOGY FLIGHT EXPERIMENT



FEATURES:

- NORVEX CHARACTERIZES VOID FORMATIONS IN MICROGRAVITY
- TEST FLIGHT EXPERIMENT TO VALIDATE NORVEX
- GERMANIUM SELECTED FOR ADVANCED TES

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THERMAL ENERGY STORAGE

A solar dynamic power system for orbital space applications must have some means for storing energy during the sun phase for use during the dark phase of the orbit. The most effective way of doing this is to store thermal energy by melting a material with a high heat of fusion and then extracting it during the shade phase of the orbit. One problem is that of selecting a material that will melt and freeze at the desired operating temperature required for the efficient operation of the heat engine that is chosen to convert the heat to useful mechanical and the electrical power. A number of substances have been identified that are good candidate heat storage materials: fluoride salts and germanium. One having selected the material with the desired melting /freezing temperature, the next problem to overcome is how to cope with the high expansion (30% for lithium fluoride) that occurs on melting and the shrinkage on freezing. This chacteristic has been a problem of some concern because if it is not solved, serious damage and failure of the receiver is sure to occur. In the ASD program, a number of projects have been undertaken to resolve this issue.

A comprehensive computer code has been developed for the purpose of understanding and predicting the behavior of the material in the molten state in a microgravity environment. How the voids migrate around the container is of considerable importance because they could wander to locations where hot spots could form. To validate this code with experimental data, a flight experiment has been designed for execution aboard the Space Shuttle. This experiment, designated Thermal Energy Storage Technology (TEST) flight experiment is scheduled for 1993.

Other supporting research has been conducted on such problems such as:
* finding container materials that will resist the corrosive effects of the molted salts.
* developing receiver/container designs that circumvent the problems that void formations can cause.
* finding TES materials that have a higher heat of fusion.

ASD SYSTEMS TECHNOLOGY

2 KILOWATT GROUND TEST EXPERIMENT

OBJECTIVE:

VERIFY THE READINESS OF SOLAR DYNAMIC SYSTEM TECHNOLOGIES

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2 KILOWATT GROUND TEST EXPERIMENT

APPROACH:

- DESIGN, DEVELOP, FABRICATE, AND GROUND TEST A 2.0 kWe SOLAR DYNAMIC SPACE POWER SYSTEM THAT:
  - IS SCALABLE TO 20 kWe RANGE
  - IS FLIGHT - CONFIGURED
  - INCORPORATES RELEVANT FEATURES OF SSF SOLAR DYNAMIC POWER MODULE DESIGN

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PROJECT ELEMENTS

- **SYSTEM DESIGN AND ANALYSIS**
- **SUBSYSTEM DDT&E**
- **INTEGRATED SUBSYSTEM TESTS**
  - CONCENTRATOR/HEAT RECEIVER TEST IN A SOLAR FACILITY (SANDIA OR EDWARDS)
  - THERMAL FLUID LOOP (RECEIVER/PCU/RADIATOR) TESTS IN VACUUM CHAMBER
  - MULTI-SOURCE POWER SHARING TESTS IN EPL TANK 5
  - TOTAL SYSTEM TESTS WITH SOLAR SIMULATOR IN VACUUM CHAMBER

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TECHNOLOGY ISSUES ADDRESSED

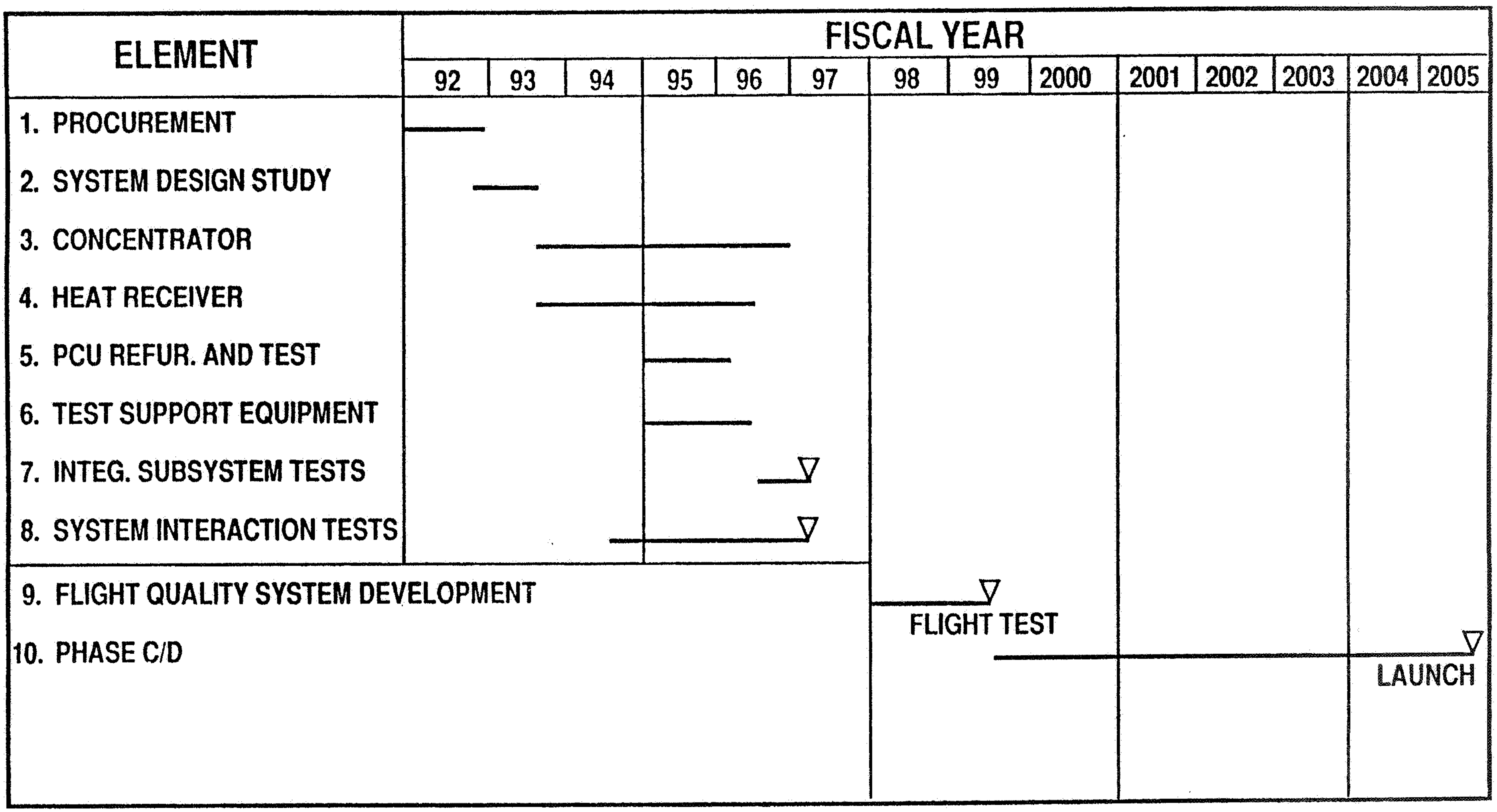
SYSTEM LEVEL

- SOLAR DYNAMIC SYSTEM INTERACTIONS
- SCALABILITY
- POWER SHARING (AC & DC) SOURCES

SUBSYSTEM LEVEL

- CONCENTRATOR
  - FABRICATION PROCESSES
  - OPTICS
  - DEPLOYMENT
- PCU
  - START-UP
  - TRANSIENT OPERATION
  - OFF-DESIGN OPERATION
- HEAT RECEIVER
  - HOT SPOTS
  - THERMAL RATCHETING
- RADIATOR
  - DEPLOYMENT
- CONTROLS
  - PARALLEL OPERATION
  - LOAD FOLLOWING

2 kW GROUND TEST EXPERIMENT SCHEDULE & FUNDING REQUIREMENTS



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SD STATUS SUMMARY

- SOLAR DYNAMIC SYSTEMS HAVE HISTORICAL CREDIBILITY
- SD POWER IS THE PRUDENT CHOICE FOR SSF GROWTH POWER
- SOLAR DYNAMIC TECHNOLOGY IS READY
- NASA/OAET IS COMMITTED TO FURTHER SD FOR SPACE APPLICATIONS
- GROUND TEST FOR A SPACE BASED SD SYSTEM IS ACTIVELY BEING PURSUED

SD STATUS SUMMARY

Solar Dynamic systems have obtained credibility throughout their history. From gaining momentum in their development in the 1960s, to terrestrial testing and applications, to progress made in the Space Station Freedom Program, SD is a bonafide contender for space applications. One such application is for SD to be the growth power generating system onboard SSF. Compared to the SSF baselined PV system, or any technological advance in any one area of a PV system, SD is irresistibly attractive and is the prudent choice for SSF growth power.

It has been presented that all facets of SD technology are now ready. Significant progressed has been achieved in the past few years that verifies technology readiness, and, in fact, NASA and its Office of Aeronautics, Exploration, and Technology (OAET) are committed to further the progress of SD in becoming reality for space applications.

Finally, in the spirit of SD commitment and to assure ourselves that these technologies can indeed perform exceptionally well together as a system, a ground test for a whole space based SD system is actively being pursued. This activity has been earmarked a budget in the range of $15–20M beginning in FY92 and lasting approximately five years. This activity is structured such that development of flight qualified hardware would be the next natural step in the progression of solar dynamic systems.