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Conceptual Definition of a Technology Development Mission for Advanced Solar Dynamic Power Systems

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NOMENCLATURE

Symbols*

A	-	Area
BTU	-	British Thermal Unit
Cal	-	Calorie
Cp	-	Heat Capacitance
CG	-	Center of Gravity
D	-	Diameter
E	-	Energy
HR	-	Hour
Hx	-	Heat Exchanger
I	-	Electric Current
J	-	Joule
Kg	-	Kilogram
KJ	-	Kilojoule
KW	-	Kilowatt
L	-	Length
Lb	-	Pound Weight
M	-	Meter
Mol	-	Mole Volume
N	-	Number of a Kind
P	-	Power
Q	-	Heat Energy
R	-	Rate of Events
S	-	Solar Insolation = 1.40 $\frac{KW}{M^2}$ in LEO (NASA TM82585)
T	-	Temperature

NOMENCLATURE

(continued)

Symbols (continued)

UV - Ultra-violet

V - Volume

W - Weight

a - Focal Length of Parabola

g - Gravity

h - Film Coefficient (Heat Transfer)

s - Unit Spacing, (cm.)

t - Thickness of Material

w - Watt

x - "X" coordinate of Parabolic Surface

y - "Y" coordinate of Parabolic Surface

α, α' - Concentrator Rim Slope or One Degree of Freedom in Pointing of Concentrator

β' - Second Degree of Freedom in Pointing of Concentrator (β' vector at right angles to α' vector)

Δ - Change in Parameter

η - Efficiency

θ - Concentrator Rim Angle

ρ - Density of Material

* - Usual Designation of Chemical Elements

Acronyms

AGT - Automotive Gas Turbine

BRU - Brayton Rotating Unit

DOE - Department of Energy

EVA - Extra Vehicular Activity

NOMENCLATURE

(continued)

Acronyms (continued)

FPSE - Free Piston Stirling Engine

IOC - Initial Operating Capability

LEO - Low Earth Orbit

MRWG - Mission Requirements Working Group

PCS - Power Conversion System

PMAD - Power Management and Distribution

SDPS - Solar Dynamic Power System

SDPTF- Solar Dynamic Power Test Facility

SOA - State of the Art

TDAG - Technology Development Advocacy Group

TES - Thermal Energy Storage

TESM - Thermal Energy Storage Material

Superscripts & Subscripts

B - Brayton

R - Rankine

S - Stirling

ave - Average

c - Concentrator

e - Electric

i - Internal; Inner

m - Mean

o - Overall; Outer

t - Thermal

ts - Thermal Storage

1.0 SUMMARY

A study was performed to provide an initial conceptual definition of a solar dynamic power Technology Development Mission (test facility) on space station for the purpose of evaluation of advanced solar dynamic power systems, sub-systems and components. The advanced solar dynamic power system technology includes high temperature Brayton, Stirling, and non-organic Rankine power conversion systems. This study was to consist of the following five tasks:

Task I - Identification of Critical Technologies

Task II - Determination of Experimental Requirements

Task III - Documentation of Experiment Requirements

Task IV - Conceptual Equipment Design

Task V - Preliminary Evolutionary Plan

The scope of the study was limited by the funding.

This study provides an assessment of the current state-of-the-art of solar dynamic power systems (SDPS), defines the critical technologies of advanced SDPS, a test plan for testing the advanced technology power systems, a recommended power level for testing, a listing of desired instrumentation, an estimate of the maximum size and weight of a possible experiment, power requirements, data communications, stowed dimensions, EVA, electrical block diagram, completed Mission Requirements Working Group and Technology Development Advocacy Group Forms, and an overall project plan.

1.0 SUMMARY (continued)

The major findings of this study are:

1. The advanced Solar Dynamic Power System (SDPS) technologies which could be tested on the SDPTF are:

   - High temperature Brayton with super alloy, refractory and/or ceramic components.
   - Intermediate and high temperature Stirling free piston engines.
   - High temperature (non-organic) Rankine

2. The critical advanced components or technologies which require development are:

   - Lightweight, high efficiency, long life deployable concentrator/truss structures.
   - Integrated heat receiver/thermal storage components for each of the advanced systems.
   - High efficiency, long life power conversion systems for each advanced thermodynamic cycle.
   - Advanced heat pipe radiators.
   - Systems safety.

1.0 SUMMARY (continued)

3. The major uncertainties in advanced solar dynamic power systems are lifetimes of concentrators in the LEO environment, impact of zero-g on thermal energy storage (TES) materials having substantial volume change as phase changes, impact of zero-g on two phase working fluids and shutdown and restart of certain systems.

4. The SDPTF can be designed to test power systems subsystems and components over the range of 5 to 20 KWe (20-80 KWt). Most testing will be limited to a 5 to 7 KWe (20-28 KWt) range through use of sun shades or shutters, which reduce the area of the concentrator or by de-focusing a number of facets. Testing of larger scale components or systems would require the installation of up to 12 additional mirror facets.

NOTE: The power level range selected above is based on judgement only. It is believed that the technology will be scalable up or down to the largest or smallest NASA mission envisioned from this power range.

5. The SDPTF requires an unobstructed view of the sun. It also represents additional drag and mass. The SDPTF is ideally located on the center line (center of gravity) of the space station. An ideal location would be the crossbeam designated for experiments requiring an unobstructed view of space. The test facility will require both α' and β' pointing in this location similar to the α and β joints on space station.

1.0 SUMMARY (continued)

6. The SDPTF will also provide platforms for long time testing of coated mirror and radiator samples at operating temperatures.

7. No unattainable technologies have been identified that would prevent installation and utilization of a solar dynamic power test facility aboard space station.

2.0 OBJECTIVE:

The objective of this effort is to prepare a conceptual design of a solar dynamic power test facility located on space station for testing and evaluation of advanced technology components, subsystems, and systems.

The general objective is the main theme of this limited effort. However, there are many other sub-objectives which are important. The more important sub-objectives are summarized below:

- Assess current and projected state-of-the-art of solar dynamic power systems.
- Identify critical technologies.
- Prepare a test plan for the SDPTF.
- Define system dimensions and mass.
- Define all resource requirements, including power, data communications, orbit altitude, extra vehicular activity (EVA), location, contamination, etc.
- Define all precursor activities for space station testing and an overall program schedule.

3.0 INTRODUCTION:

Solar dynamic power systems (SDPS) are an integral part of the hybrid power system baselined for the IOC space station. Advanced solar dynamic systems are attractive candidates for the growth space station and other NASA missions because of their advantages over photovoltaic power systems. The advantages include higher efficiency, reduced mass, reduced drag area and reduced cost. (Ref. 1) The reduced drag area results in a further weight saving, namely, a reduction in fuel required to maintain the orbit parameter.

In view of the potential benefits of advanced SDPS's, there is a need to develop, test, and demonstrate these benefits in the actual space environment. The objective of a solar dynamic power test facility on space station is to provide a dedicated area in the actual environment for testing advanced technology components, subsystems and total SDPS's.

A typical Solar Dynamic Power System operating in low earth orbit (LEO) will include the major components shown in Figure 3-1. They are:

- Concentrator
- Heat Receiver
- Thermal Storage (Separate or Integral with Receiver)
- Power Conversion System (PCS)
- Radiator (Heat Rejection System)
- Structure

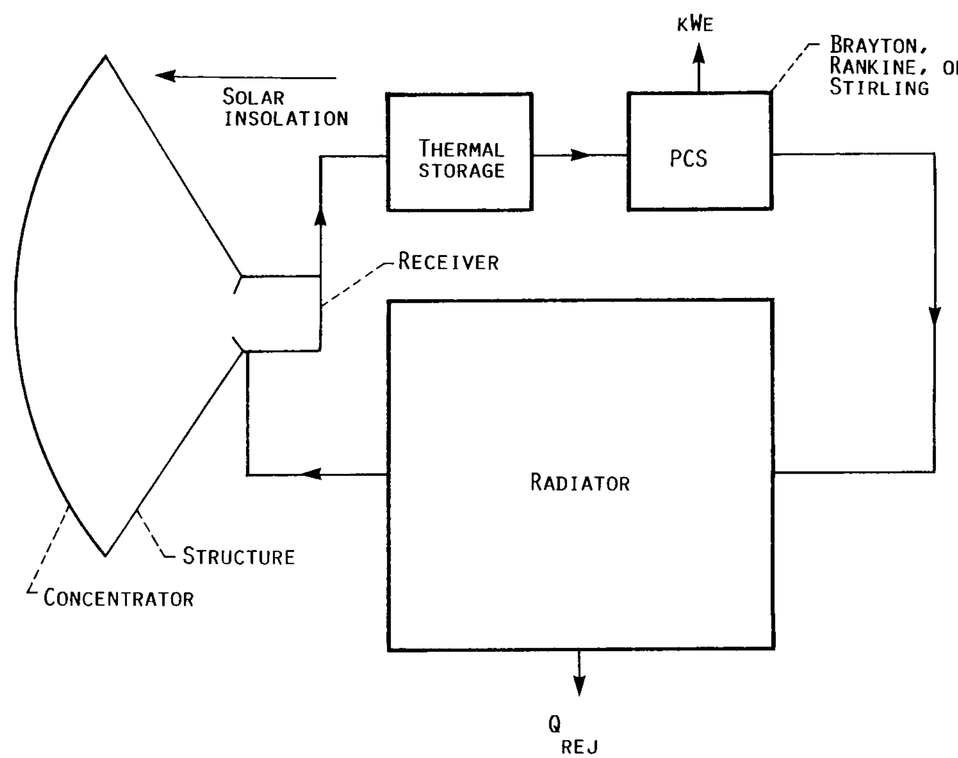

FIGURE 3-1. - SOLAR DYNAMIC POWER SYSTEM.

3.0 INTRODUCTION: (continued)

Not shown in Figure 3-1, but necessary for a Solar Dynamic Power System (SDPS) are the following:

- Pointing System
- Control System for the PCS
- Power Management and Distribution (PMAD) System
- Piping or Ducting
- Data Acquisition & Transmittal
- Special components required by particular PCS (Brayton, Rankine, or Stirling)

The solar insolation is intercepted by the concentrator and reflected to the receiver where it is transferred to the working fluid of the PCS at an appropriate/design temperature. The SDPS in LEO must include a thermal energy storage system to provide operating power during the shade portion of the orbit. A thermal energy storage system utilizing the latent heat of fusion of an appropriate salt or salt eutectic could be integrated with the receiver or designed as a separate component.

The PCS includes the prime mover (turbine, piston) of the system, converting heat into mechanical energy, and alternator to convert mechanical energy into electrical and a pump/compressor to move the working fluid through the cycle. All SDPS's will include heat regeneration to maximize system efficiency (transfers heat from the working fluid between the PCS and the radiator to the working fluid between the radiator and the receiver). The regenerator may be integrated with the PCS or as a separate heat exchanger such as for the Brayton System.

3.0 INTRODUCTION (continued)

The radiator is required to reject waste heat from the working fluid and complete the thermodynamic cycle. The radiator may consist of a pumped loop or a heat pipe assembly. Heat pipe technology may also be utilized in the integrated receiver/thermal storage subsystem to smooth out temperature distributions and minimize size.

The location, arrangement and orientation of various components is important for proper system operation. Suitable structure is therefore required. The aperture of the receiver must be located at the focal point of the concentrator (parabolic mirror). The concentrator is pointed at the sun and a planar radiator should be located edgewise to the sun. The power system is a closed loop system with the major components interconnected by piping. The piping or ducting may also be designed to provide a structural function.

The pointing system must be capable of sensing and pointing the concentrator accurately at the sun. Pointing accuracies of $\pm 0.1^{\circ}$ may be required for the advanced Brayton, Stirling and Rankine PCS's. The pointing accuracy required is a strong function of the concentrator accuracy and the maximum operating temperature of the heat receiver, which is dictated by the thermodynamic cycle requirements. As the temperature of the heat receiver increases, concentration ratio increases, aperture diameter decreases, and pointing accuracy required increases. It is also necessary to provide frequency or speed control of the rotating PCS package. In the past, a parasitic load control has been used to control speed.

3.0 INTRODUCTION (continued)

If the electrical power generated by the SDPS is utilized by the space station, power management and distribution (PMAD) is required for system testing. If the electrical power is discarded, it must be resistively dissipated and radiated as heat (separate radiator).

The SDPS being tested in the test bed on space station will be instrumented to monitor and control its operation. These data will be acquired and transmitted to earth for control and evaluation purposes.

Certain specialized equipment or controls may be required as a function of the particular power system being tested. Such equipment identified during the conceptual design will show up in the equipment list.

4.0 CRITICAL TECHNOLOGIES

In order to define the critical technologies of SDPS's, it is necessary to assess the current state-of-the-art (SOA), compare this to the projected SOA for the 1990's, and determine what must be done to meet the projected SOA. This assessment follows:

4.1 STATE-OF-THE-ART (SOA) - ASSESSMENT:

The current SOA of the technologies associated with the design and fabrication of the major components of a SDPS are at various stages or levels of development. The assessment of the current SOA of SDPS`s is based on inputs from contractors, LeRC in-house analyses and prior LeRC contracted effort. (Ref. Nos. 2 thru 4)

4.1 STATE-OF-THE-ART (SOA) - ASSESSMENT: (continued)

The projection of the SOA to the 1992 + time frame is based on communications with the SDPS community tempered by judgmental selection of performance and weight goals. The current SOA and projection to the 1990's is discussed separately for each of the major components in the following sections.

4.1.1 CONCENTRATOR:

A substantial technology and data base exists for terrestrial applications of solar power systems under the development of the Department of Energy (DOE). However, the DOE goal for concentrators is minimum cost per KWe over the lifetime of the system. Terrestrial concentrators must have a cost effective lifetime while being exposed to wind, dust, sand, rain, hail, etc.; that is, all the elements of terrestrial weather. The design of these types of concentrators include allowance for maintenance such as periodic cleaning, repair, and/or replacement.

The requirements for a space type concentrator are considerably different than for the terrestrial application. These requirements include the following:

- Large, lightweight, deployable or erectable concentrators.

- A 5 to 10 year lifetime while exposed to the combined environment of LEO. This exposure includes Ultra-Violet (UV), Atomic Oxygen, Micro-meteoroids, interaction with the charged particles of the LEO plasma, etc.

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4.0 CRITICAL TECHNOLOGIES: (continued)

An effort was initiated by NASA in 1960 - 1970 on development of the concentrator, receiver, and thermal storage subsystems. This technology has not been utilized, to date, on NASA missions. In spite of the lack of flight experience, there is a high probability that the current technology base would yield a concentrator design, which would perform as predicted at beginning of life. The major question is how will the concentrator perform over its lifetime.

The technology for concentrators is expected to advance by 1992. The technology thrust will be toward advanced concentrators of high accuracy and lightweight deployable or deployable structure with erectable mirror facets. The target weight goal will be on the order of 1.2 - 1.5 Kg/M^2 (0.25-0.3 $Lbs./Ft^2$), while meeting the required accuracy for the respective PCS. Target reflectivity will be 0.9 over concentrator lifetime.

The concentrator technology available in 1992 for advanced Solar Dynamic Power Systems is projected to be as follows:

- A lightweight, deployable truss type structure with erectable facets meeting a weight of 1.5 Kg/M^2.

- The erectable approach will require EVA. Should a completely deployable technology be developed, it will be used and EVA eliminated.

4.1.1 CONCENTRATOR (continued)

- The concentrator shall have a reflectivity of 0.90 over its lifetime.
- The concentrator is a separate component which is attached to the receiver by support structure This attachment will require EVA.

4.1.2 RECEIVER/THERMAL STORAGE:

There is a substantial technology and data base for the design and operation of receivers for terrestrial applications. The data base for thermal storage is substantially less. The analytical tools developed for terrestrial thermal storage applications will be useful for the space applications. However, the designs will require substantial modifications.

An advanced space type receiver must provide long life, minimum size and minimum weight, while meeting the operating temperature of the respective PCS. The receiver must be capable of transferring the concentrated heat flux to the working fluid without developing hot spots or burnout during the 5 to 10 year life of the system.

As noted in Section 4.1.1, an effort on receivers was initiated by NASA in the 1960's. A receiver for the 10 KWe Brayton Rotating Unit (BRU) was designed, as shown in Figure No. 4-1, and fabricated entirely of Nb-1Zr, using LiF as the heat storage medium. Endurance testing of three tubes covered 2000 hours and 1250 sun-shade cycles. The tubes retained their mechanical integrity, that is, no cracks or leaks were detected. However, there was trapping of the LiF and swelling of various convolutions. The 1250 melt-freeze cycles of testing represent approximately 1/40 of the

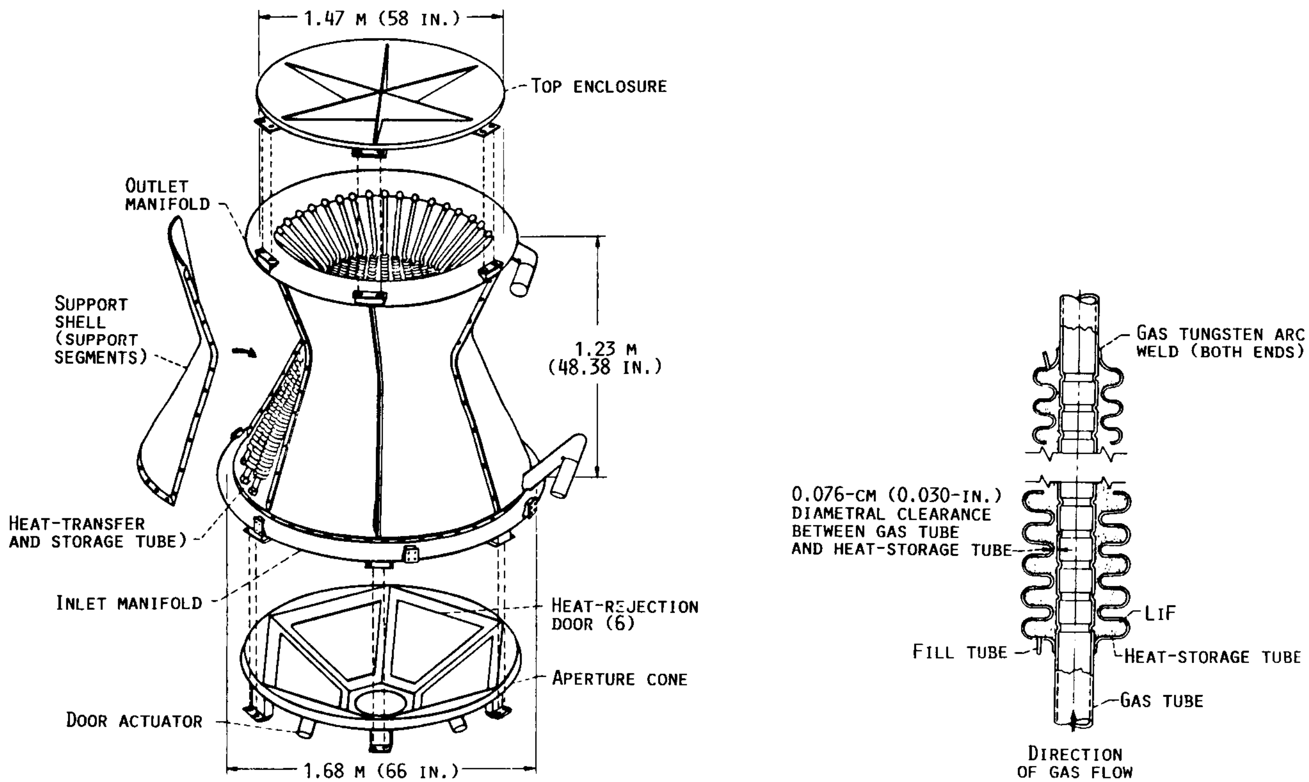


FIGURE 4-1. - BRAYTON HEAT RECEIVER FINAL DESIGN AND HEAT-TRANSFER TUBE.

cycles expected in seven years. The testing was conducted under the severe condition of one g. Although distorted, the tubes exhibited no cracks or fractures. The design gives good indication of validity under the actual zero-g condition. However, extended testing under zero-g is called for. The specific weight of this design is estimated at 23 Kg/KWe (1960 - 1970 SOA).

In view of the current SOA for receivers/thermal storage, substantial advances in technology will be required. Current designs locating the thermal storage material external to the tube containing the working fluid require that all the heat transferred to the working fluid must be conducted through the thermal energy storage material (TESM). This design could lead to hot spots and burnout if the void in the TESM occurred in a critical manner. Advanced design concepts could utilize heat pipes to transfer the incident heat flux to the working fluid and TESM at near constant temperature. A current concept proposed by Sundstrand for the Rankine SDPS is shown in Figure 4-2. This concept has the concentrated solar flux incident on a cylindrical array of axial heat pipes which are surrounded by circumferential load leveling heat pipes. The axial heat pipes transfer the deposited solar energy to the thermal energy storage (TES) material and the working fluid in parallel during the sun portion of the cycle. The TES canisters are located within each axial heat pipe. The axial heat pipes then transfer the stored thermal energy from the TES canisters to the working fluid during the shade portion of the cycle.

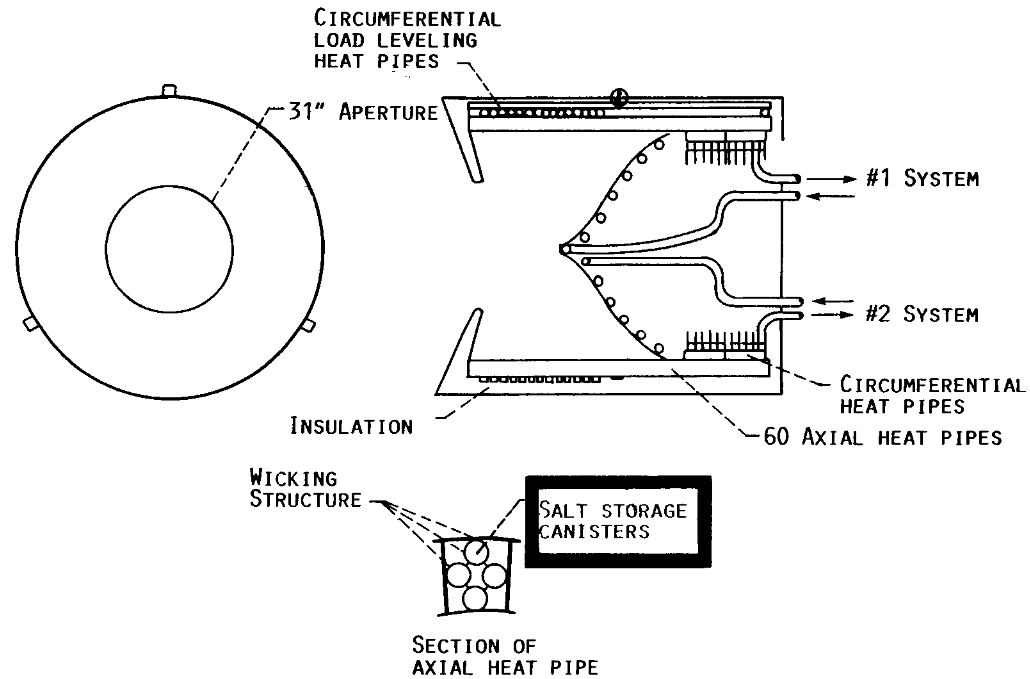


FIGURE 4-2. - HEAT RECEIVER CONCEPT.

4.1.2 RECEIVER/THERMAL STORAGE: (continued)

There is the design option of separating thermal storage from the receiver. In this concept, the heat flux incident on the receiver is transferred to the working fluid and the excess heat is transferred to thermal storage downstream of the receiver. The transfer of excess heat is accomplished by raising the peak receiver temperature if not limited by materials or reducing the peak temperature of the thermodynamic cycle with a reduction in performance. In either case, it is expected that this option will result in a weight penalty for the receiver/thermal storage system.

The receiver/thermal storage technology available in the 1992 + time frame for the SDPTF on space station is projected to be as follows:

- The receiver and thermal storage will be integrated into a single component.

- The thermal storage will be accomplished via the heat of fusion of an appropriate salt or salt mixture. The TES salts will have discrete melting points covering the temperature range of 1025K to 1400K.

- The thermal storage material and the working fluid will be close coupled thermally via a heat pipe or a good conduction path.

- The receiver efficiency is a function of its peak temperature, as follows:

Salt Melting Temp.	Receiver Eff.
1025K	.90
1400K	.84

- The weight goal for the receiver/thermal storage system is estimated at 12 Kg/KWe or lower.

4.1.3 POWER CONVERSION SYSTEMS (PCS'S):

The candidate PCS's include the advanced Brayton, advanced Rankine, and Stirling heat engines for conversion of thermal energy into mechanical energy. A Rice type alternator (linear alternator for Stirling) will convert mechanical energy into electrical energy. A suitable pump or compressor is utilized to circulate the working fluid of each PCS.

The Brayton and Rankine power systems have accumulated many millions of hours of operation on the ground and in the air. The Brayton PCS has operated in the range of 900 - 1250K with air as the working fluid (open cycle systems). NASA-LeRC operated a 10 KWe, closed cycle system using a mixture of He and Ar for 38,000 hours. The Rankine PCS has operated in the range of 600 - 675K with various working fluids, such as Toluene and Dowtherm A. The technology bases for these PCS's are very mature and one may expect these systems to perform as designed. However, neither of these PCS's have operated in space. The technology base for the Stirling PCS is relatively immature in comparison to the Brayton and Rankine. The Stirling technology is currently being developed in the SP-100 Program.

A comparison of the performance (overall system efficiency) of the various PCS's is shown in Figure 4-3. This performance data is preliminary information, covers a limited temperature range and is only indicative of what an advanced PCS may provide. The optimum temperature of advanced PCS's (maximum system efficiency) has not been identified in this performance comparison, but is certainly beyond the 1125K temperature. An alternate option is to optimize the system for least mass. The high temperature advanced PCS`s will yield substantial trading of efficiency verses mass via radiator temperature.

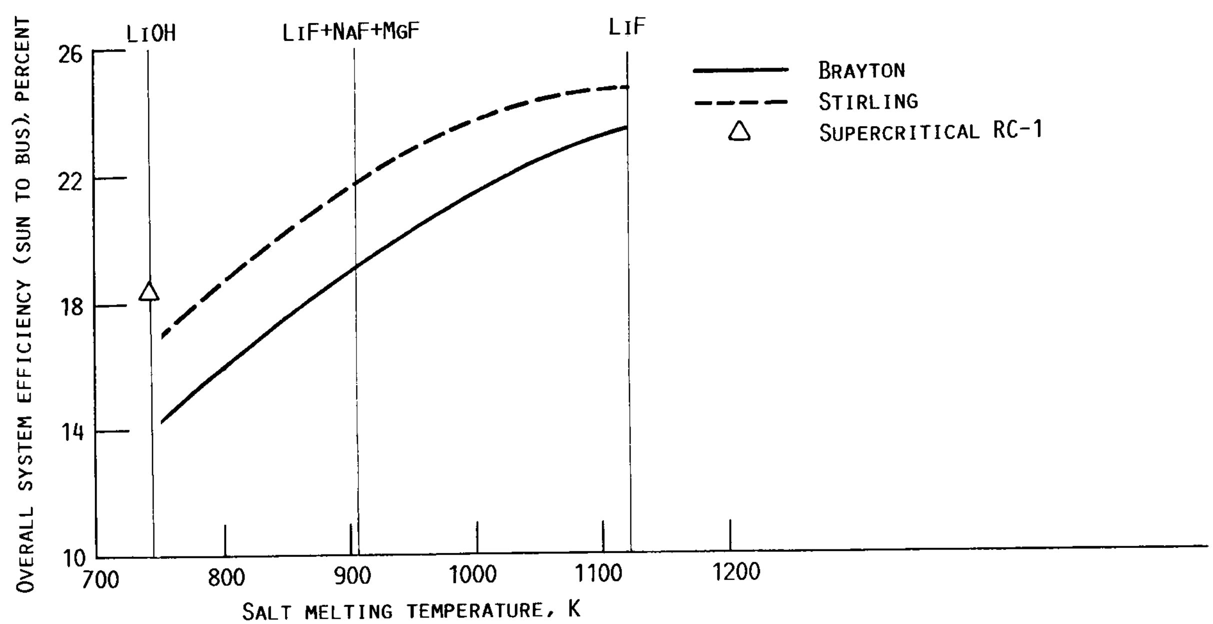


Figure 4-3. - Preliminary data on overall system efficiency of Brayton, ORCS, and Stirling solar power systems for various receiver temperatures - 20 kWe system.

4.1.3 <u>POWER CONVERSION SYSTEMS (PCS'S)</u>: (continued)

The performance data is representative of current SOA technology except for the free piston Stirling which has yet to be demonstrated at 20 KWe. The low temperature Brayton and Rankine technologies are mature and are therefore being considered as an option for the IOC space station. Because of this maturity, the PCS efficiency at a particular temperature is not expected to change by the 1992 + time frame. The Brayton and Stirling PCS's may be limited by current commercial materials to maximum cycle temperatures of 1100K or less, if 5-10 year life is required. Development of higher temperature materials such as ceramics or the refractory metals would permit operation of the Brayton and Stirling PCS's at higher temperatures with the associated performance gain. The performance of a Rankine PCS using an alkali metal (Potassium) as the working fluid and operating at a peak cycle temperature of 1125K is attractive. A Potassium Rankine cycle operating between temperatures of 1125K and 611K (heat rejection) could yield cycle efficiency near 34% (Ref. No. 5) and overall system efficiency near 25%. The high heat rejection temperature of the cycle (640K) would yield a small radiator. Thus, there are three advanced technology PCS's whose components, subsystems, and/or complete systems may be tested in the SDPTF on space station as follows:

- High temperature (1150 - 1400K) Brayton PCS with refractory or ceramic components.
- High temperature (1025 - 1400K) Stirling PCS with super alloy, refractory or ceramic components.
- High temperature (1100 - 1400K) Rankine PCS with an alkali metal (non-organic) working fluid.

As noted above, the advanced technology PCS's are critically dependent on advanced materials. The present state-of-the-art of ceramics and refractory materials are discussed as follows:

4.1.3 POWER CONVERSION SYSTEMS (PCS'S): (continued)

The Automotive Gas Turbine (AGT) Program is sponsored by the Department of Energy (DOE) and managed by NASA-LeRC. The present goal of the AGT program is to demonstrate the conceptual feasibility of an AGT with an all ceramic hot flow path (Ref. No. 6). In addition to a ceramic housing, ceramic nozzle, ceramic radial inflow turbine and ceramic recuperator, the rotating unit will demonstrate a foil bearing at its hot end. A 100 hour demonstration test simulating a typical automotive driving cycle will be conducted by the Garrett Pneumatic Systems Division. The AGT is an open cycle system and the silicon-nitride components must be capable of resisting an oxidizing environment. A closed cycle Brayton space power system would operate at a near constant power level and be exposed to a very low level oxidizing environment. The operating conditions of the Brayton space power system are more benign than for the terrestrial AGT. It is judged (Ref. No. 6) that the present AGT program, a follow-on ceramics development program, the commitment of the Garrett Corporation to ceramics and outstanding efforts of the Japanese will yield a ceramics technology readiness by 1992. This readiness will permit the testing of advanced Brayton systems on the ground and in space on the SDPTF.

Ceramic materials may have application to a high temperature Stirling PCS. However, there are no proposed designs using ceramics for the Stirling PCS. The Stirling free piston engine (FPSE) is being developed in the SP-100 program using super alloys for temperatures up to 1050K. Candidate designs of the FPSE using ceramics and/or refractory materials in order to permit operation at higher temperatures is required. Subsequent testing and development will lead to baseline designs of advanced FPSE's. A niobium-1 Zirconium alloy reinforced with Tungsten wires is being evaluated by the NASA-LeRC Materials Division for the SP-100 Program as a possible high strength refractory material for use in the FPSE.

The high temperature advanced Rankine power system will utilize an alkali metal (Potassium/Lithium) as the working fluid and a suitable containment material which is typically a refractory alloy. There is a wealth of refractory materials technology which was developed in the 1950's and 1960's as part of the Space Nuclear Power Programs. A summary of the refractory alloy technology is given in Reference No. 7. One of the most ambitious undertakings of the NASA-LeRC program at General Electric was the development, construction, and operation of a 3 MW potassium turbine and the associated boiler and condenser system. The turbine rotor and rotor blades were constructed of molybdenum alloys, Mo-TZM and Mo-TZC. This axial flow turbine technology is probably not applicable to a 5-20 KW potassium turbine, since a radial inflow type turbine is likely. However, the materials compatible with the alkali metals have been established and the technology to design potassium turbines exists. The fabrication process for small radial flow refractory metal turbines will require development.

The high temperature PCS technologies available in the 1992 + time frame for testing in the SDPTF are listed on the following page. The peak cycle temperature of each PCS is varied to achieve comparable performance and size.

4.1.3 POWER CONVERSION SYSTEMS (PCS'S): (continued)

PARAMETER	HIGH TEMP. BRAYTON	HIGH TEMP. STIRLING	HIGH TEMP. RANKINE
Peak cycle temperature	1175K	1050K	1120K
Efficiency, pcs*	.32	.30	.34
Overall system Efficiency**	.24	.24	.25
Specific weight Kg/KWe of PCS	1.4	2.7	-
Recuperator Kg/KWe	2.3	-	-

* Ratio of electric power out to thermal power in.

** Ratio of electric power out to solar insolation on mirror.

4.1.4 RADIATOR:

The NASA conducted a substantial effort on radiators in the 1960's, developing analytical tools, shielding against micro-meteoroid puncture, coatings, etc. A substantial amount of ground testing was conducted on radiators, radiator segments and coatings. There is little or no flight experience since solar dynamic power systems have not been utilized in space. The only flight radiator associated with a power system which flew is a small (500 We) zirconium-hydride reactor/thermo-electric power system. The radiator was a pumped NaK loop with stainless steel tubing and aluminum fins and armor. After only a short time (40 hours), an electrical instrument malfunction shut the reactor down. The major thrust of the NASA effort in the 60's was on pumped loop type radiators.

Since that time, cooling systems in space have been used on the shuttle, spacelab, LEM, etc. Heat pipe technology is moving to the forefront as an efficient method for transferring waste heat from the working fluid to the radiator and is being developed in the SP-100 Program. Tailoring the two-phase fluid of the heat pipe to the source temperature results in a near constant temperature for radiation of heat. Use of many parallel and redundant heat pipes could lead to a lightweight, efficient, reliable radiator for a space power system.

An alternate approach for an efficient heat transfer system is a pumped two phase flow (utilizes heat of vaporization and condensation to effect heat transfer) system. Tailoring the heat transfer fluid to vaporize at the various temperatures of the heat rejection portion of the PCS working cycle would lead to an efficient radiator system. Development of such systems is required.

4.1.4 RADIATOR: (continued)

Current technology is such that a heat pipe radiator design coupled with sufficient ground testing will provide a lightweight radiator which will perform thermally as designed. Zero-g testing of heat pipes on the shuttle will enhance the confidence level of the baseline design. Shutdown and restart in zero-g will further enhance the credibility of these heat transfer devices. However, all radiating surfaces will utilize coatings to enhance their emissivity. The life and performance of radiator coatings may be degraded by the combined environment of LEO. The capability to predict radiator performance for a lifetime of 5-10 years does not exist at this time.

The radiator technology available in the 1992 + time frame for the SDPTF on space station is projected to be as follows:

- Utilize a heat pipe radiator of advanced design to radiate heat. This concept will require a separate or multiple heat exchangers to transfer reject heat from the PCS working fluid to the various heat pipes/modules.
- A planar radiator radiating from both surfaces will be utilized.
- The weight goal for the radiator is 4.9 Kg/M^2 of radiator area.

There are other radiator technologies such as the advanced liquid droplet concept and the liquid belt concept which have the potential to substantially reduce radiator weights. These concepts are just emerging, and if developed, will eventually be tested on a space station test bed as a radiator experiment. It is judged that the advanced radiator technology will not be ready until the late 1990's and would not be utilized until second generation solar dynamic power systems are planned.

4.1.5 STRUCTURE:

Each system will require structure to locate the various components in a proper configuration in space. The structure for SDPS's above 5 KWe will probably require folding or collapsing to stow in the shuttle bay. There are two options available in the design of the structure; a deployable approach, which will require no EVA, and an erectable approach, which will require EVA. Deployable structures are an emerging technology and are expected to achieve substantial advances by the 1992 + time frame.

The weight goal for structures will be influenced by the system configuration chosen for the SDPTF. The options available are all components located symmetrically on the concentrator center line and on the sun side of the concentrator or an offset design.

The weight of structures may vary from 3 to 7 Kg./KWe depending on approach. The approach will be selected in Task II and an overall system weight determined.

The structures technology available in the 1992 + time frame for the SDPTF on space station is projected to be a lightweight deployable truss type structure, requiring a minimum of EVA for attaching the various modules of the power system and locking mirror facets in place.

4.1.6 MISCELLANEOUS COMPONENTS:

There are a number of components which are common to each PCS, but may vary in size and weight as a function of the PCS design requirements. These include the speed or frequency control of the PCS power output, pointing system, piping or ducting, data acquisition and transmittal, and power management and distribution. The PCS may require certain specialized components peculiar to that PCS, such as a gas storage/supply for Brayton and Stirling, and a condensing heat exchanger for the Rankine PCS. The Rankine system may require special components for fluid management. Both the Rankine and Stirling systems require regenerators which are integrated into the PCS's.

The capability and weight goals for these components are projected as follows:

COMPONENT	CAPABILITY	WEIGHT GOAL (Kg./KWe)
Pointing System	$\pm 0.1^{o}$	1
Speed Control^{B,R}	$\pm 0.1\%$	1
Piping, Ducting	-	1 - 2
Data Acquisition and Transmittal	TBD	
Condensing HX^{R}		2
Gas Storage^{B,S}	-	1.5

(NOTE: B, R, or S indicates Brayton, Rankine, or Stirling systems only. No letter indicates applicability to all PCS's.)

4.2 CRITICAL TECHNOLOGIES:

An assessment of the current SOA in Solar Dynamic Power Systems indicates that the critical technologies which must be developed prior to testing of advanced SDPS's on the SDPTF are as follows:

1. The heat receiver/thermal storage technology is very immature. Candidate designs do not exist. Candidate materials and their compatibility must be established. Test hardware of candidate designs must be fabricated and tested for functional operation and 40,000 melt/freeze cycles. Operational credibility of candidate design in zero-g must be established via shuttle experiments. Development of this technology must have a high priority and is essential to SDPS's.

2. The concentrator technology is mixed; the capability to design a concentrator and meet a performance goal exists; the capability to design a deployable concentrator having a weight of 1.5 $Kg./M^2$ and a life of 5-10 years in LEO does not exist at present. Candidate conceptual designs have been proposed. Baseline designs must be established via development. (It is assumed that small power systems will utilize fixed structures, and large systems will require deployable structures). Development of this technology is essential to SDPS'S.

3. The heat pipe radiator technology status is similar to that of the concentrator. There is a design capability for heat pipe radiators. Candidate designs do not exist. Candidate designs, development of these designs through test hardware, and extensive ground testing are required. Heat pipe radiator technology is critical to maintaining the area and weight advantages of SDPS's.

4.2 CRITICAL TECHNOLOGIES: (continued)

Pumped loop technology will probably be available as an alternate. However, lack of heat pipe radiator technology will result in a weight penalty for the SDPS.

4. The PCS technology base for high temperature systems is relatively immature. The development of high temperature materials (ceramics, refractory materials) is critical to advanced PCS`s.

5. There are systems and safety considerations which must be resolved for an SDPS on space station. Systems considerations include startup, shutdown, and restart. Safety considerations include elimination of any hazard associated with walk-on or walk-off of the concentrated solar insolation, hunting by the pointing system, etc. Other systems considerations include management (fill, control, etc.) of the working fluid of the PCS, assembly of major components into the system, impact of docking loads (accelerations) on management of two phase flows or thermal storage subsystem, etc. This area is considered critical for operation of a SDPS on space station.

The critical technologies for advanced SDPS's, their relative priorities, and the specific questions are summarized as follows:

- Heat receiver/thermal storage
  Highest priority
  - Demonstrate behavior of thermal storage material in zero-g.
  - Determine life capability (40,000 melt/freeze cycles) in zero-g.
  - Determine performance and life of coatings in LEO.

4.2 CRITICAL TECHNOLOGIES: (continued)

- Lightweight, high accuracy, deployable concentrators
  High priority
  - Demonstrate deployability, rigidity, and dynamics of large, deployable concentrator/structure.
  - Minimize impact of thermal distortion of concentrator in space.
  - Determine life and performance capabilities of concentrator and coatings in combined environment of LEO (UV, Atomic Oxygen, micro-meteoroids, interaction with plasma).

- Systems and Safety
  High Priority
  Demonstrate capability to handle:
  - Walk off or walk on.
  - Pointing system failure.
  - Startup, shutdown, restart.
  - pointing control dynamics.
  - Evaluation of control mechanisms in vacuum and zero-g.

- Heat Pipe Radiator
  High Priority
  - Determine performance and life of coatings in LEO.
  - Demonstrate performance, life, and reliability of heat pipe in LEO.

- Power Conversion System
  High Priority
  - Demonstrate high temperature materials capabilities.
  - Demonstrate zero leakage systems.
  - Demonstrate bearing operation.

4.3 WHY SDPTF?

The purpose of the SDPTF on space station is to provide a capability for evaluating advanced SDPS's and major components in the combined space environment of LEO over long periods of time under operational conditions. One may question the need for testing SDPS's in LEO. This suggests that the required technologies can be completely developed on earth and expect it to work perfectly in space. Although most of the technology development will be accomplished via ground testing and critical zero-g experiments on the shuttle, there are issues which can only be resolved by testing on space station. A summary of these issues follows:

- Will the heat receiver/thermal storage system withstand 40,000 + melt/freeze cycles in zero-g?
- Will the concentrator perform in the LEO environment for 5 to 10 years without degradation? Although some insight can be gained from ground tests with a simulated LEO environment, the impact of the combined effects of atomic oxygen, UV and micro-meteoroids on films, coatings, and materials can only be determined in LEO over long periods of time.
- Coatings will play an important role for SDPS's as protection against the environment or in tailoring the absorptive or emissive characteristics of various surfaces. Again, only the LEO environment exposes the coating to the combined effects of atomic oxygen, UV, plasma, and micro-meteoroids. The effects of contamination from Space Station will also be evaluated.

It is, therefore, concluded that realistic life and degradation data on advanced SDPS's can be best obtained by testing in the actual LEO environment.

4.4 CONCEPTUAL DEFINITION OF SDPTF

The SDPTF is intended to be a versatile test bed capable of testing advanced technology, components, subsystems, or total systems over a power range of 5-20 KWe. The capability to test over such a power range must be designed into the test facility at the beginning.

The concentrator reflects and concentrates the solar insolation for the SDPS. It must, therefore, be designed to provide the power flexibility required of the SDPTF. A possible approach to the concentrator concept is shown in Figure 4-4. A deployable support structure and pedestal mount will be designed to provide approximately 60 M^2 of parabolic reflecting surface using 19 hexagonal facets. This total surface will provide approximately 80 KWt or 20KWe for a 25% efficient system. The initial launch of the support structure would include only 7 hexagonal facets providing approximately 22 M^2 of mirror and 7 KWe of generated power. The use of sun shades at the outer periphery of the six facets or defocusing certain facets would lead to further reductions in power.

The concentrator support structure will provide for the support and proper orientation of two panels, a concentrator sample panel, and a radiator sample panel. The concentrator sample panel will be pointed at the sun and expose advanced technology concentrator samples to the LEO environment. The radiator sample panel will be oriented edgewise to the sun, heated to various temperatures and exposed to the LEO environment. Concentrator and radiator samples will be periodically removed, returned to earth, and evaluated for performance degradation, etc. Thus, life and degradation characteristics of advanced concentrator and radiator technologies will be evaluated.

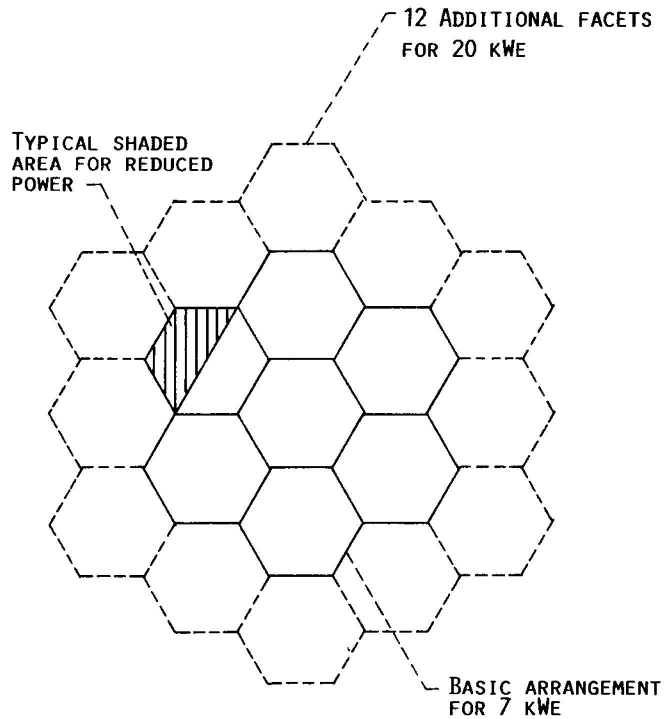


FIGURE 4-4. - FACET ARRANGEMENT FOR SDPTF.

4.4 CONCEPTUAL DEFINITION OF SDPTF: (continued)

With a basic heat source available (sun and concentrator), any SDPS component operating at a particular heat load and temperature can be tested as follows:

- Heat receiver using a high temperature radiator to reject the heat to space.
- High temperature heat pipe heat transfer experiment, using a heat receiver and radiator to accept and reject heat.
- Heat pipe radiator using low temperature heat receiver.
- PCS using heat receiver and radiator.

It may not be cost effective to test anything but complete systems in the SDPTF. When testing complete systems, the heat receiver, PCS, and radiator will be launched as a deployable assembly or as modules which will be assembled in space. It is assumed that all the electric power generated will be dissipated as heat to space. The SDPTF will, therefore, have a resistance heated radiator capable of dissipating up to 20 KWe. The pedestal mount must provide two degrees of freedom (similar to the α and β joints on the space station power boom which provide the required pointing for the IOC power systems) for pointing the concentrator. The pointing system will be built into the concentrator support structure and will be available regardless of the test being conducted in the SDPTF.

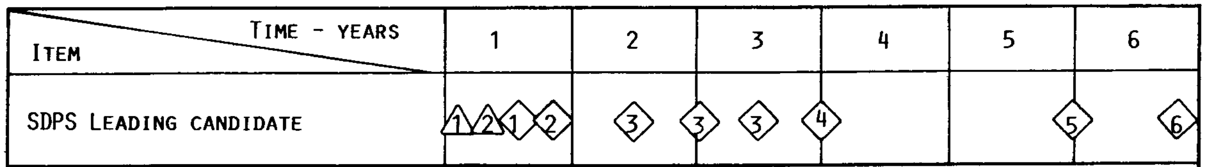
The SDPTF requires a clear, unobstructed view of the sun. Because of its mass and drag, it should be located on the center line (earth pointing) of the space station. To assure an unobstructed view of the sun, it should be located on the crossbeam used for experiments requiring an unobstructed view of space.

4.5 TEST PLAN FOR SDPTF:

The test plan is strongly dependent on the component, subsystem, or system technology which is under development. As noted in Section 4.3, the SDPTF is capable of testing components, subsystems, or complete SDPS's. However, if testing a high temperature ceramic receiver as a component, some means of dissipating the heat to space is required. This could be accomplished with a small, high temperature, pumped loop radiator, a high temperature heat pipe radiator, or a thermal resistance with a low temperature radiator. Any of these options would require additional resources to accomplish the component test in the SDPTF. It is the writer's opinion that testing of components on the SDPTF will not be cost effective. The test plan for the SDPTF is based on testing complete systems. The systems under consideration are as follows:

- The free piston Stirling engine (FPSE) using conventional materials (1050K max.).
- The advanced Brayton system using ceramics.
- The advanced FPSE using ceramics and/or refractory materials.
- The advanced Rankine system using potassium as the working fluid and compatible refractory alloys.

The test plan for testing advanced SDPS's is shown as Figure No. 4-5. The plan is success oriented, assuming that sufficient precursor development work has been completed. It is also assumed that the precursor development work will lead to the selection of a power system as the leading candidate. It is the leading candidate which will be life tested on the SDPTF. A backup candidate will also be available for testing should an irreparable problem occur with the leading power system. The advanced systems will be scaled in power to the lowest level practical.



△ - CONCENTRATOR/TRUSS STRUCTURE

1 - LAUNCH, DEPLOY, ERECT, CHECKOUT OF POINTING SYSTEM

2 - SURVEY OF MIRROR PERFORMANCE

◇ - TESTING OF LEADING CANDIDATE SDPS

1 - LAUNCH, DEPLOY, ATTACH TO CONCENTRATOR

2 - SYSTEM STARTUP AND TESTING

3 - PLANNED SHUTDOWN AND RESTART

4 - SHUTDOWN, TIE TO STATION POWER

5 - COMPLETE TESTING. SHUTDOWN, REMOVE, AND RETURN

6 - COMPLETE EVALUATION

ADVANCED TECHNOLOGY SYSTEMS:

FPSE WITH CONVENTIONAL MATERIALS
BRAYTON WITH CERAMIC MATERIALS
FPSE WITH CERAMIC OR REFRACTORY METALS
RANKINE WITH REFRACTORY METALS

} PRECURSOR TESTING WILL PERMIT SELECTION OF LEADING AND BACKUP CANDIDATES

FIGURE 4-5. - TEST PLAN FOR SDPTF ON SPACE STATION.

4.5 TEST PLAN FOR SDPTF: (continued)

The objectives of the test program are:

- Conduct tests to evaluate performance of advanced system technology.
- Conduct life testing of advanced SDPS's for performance and life capability projections.
- Demonstrate systems safety and reliability via planned shutdowns and restarts.
- Demonstrate the capability to maintain and repair advanced SDPS's via modular replacements.

4.6 MEASUREMENTS REQUIRED:

As noted earlier, the SDPS in the space station test facility will be instrumented in such a manner as to monitor performance, performance degradation, and possibly impending failure of a component. The instrumentation will include operational and diagnostic instrumentation. The desired measurements are located by station in the flow schematic, Figure No. 4-6, and are tabulated on page 38.

The rate at which the listed data is scanned is a function of what phase of testing we are in. During the initial startup, the data would be under a continuous scan mode. After system startup and steady state operation, the total data set may be scanned once each 30 minutes, with certain critical measurements being scanned continuously.

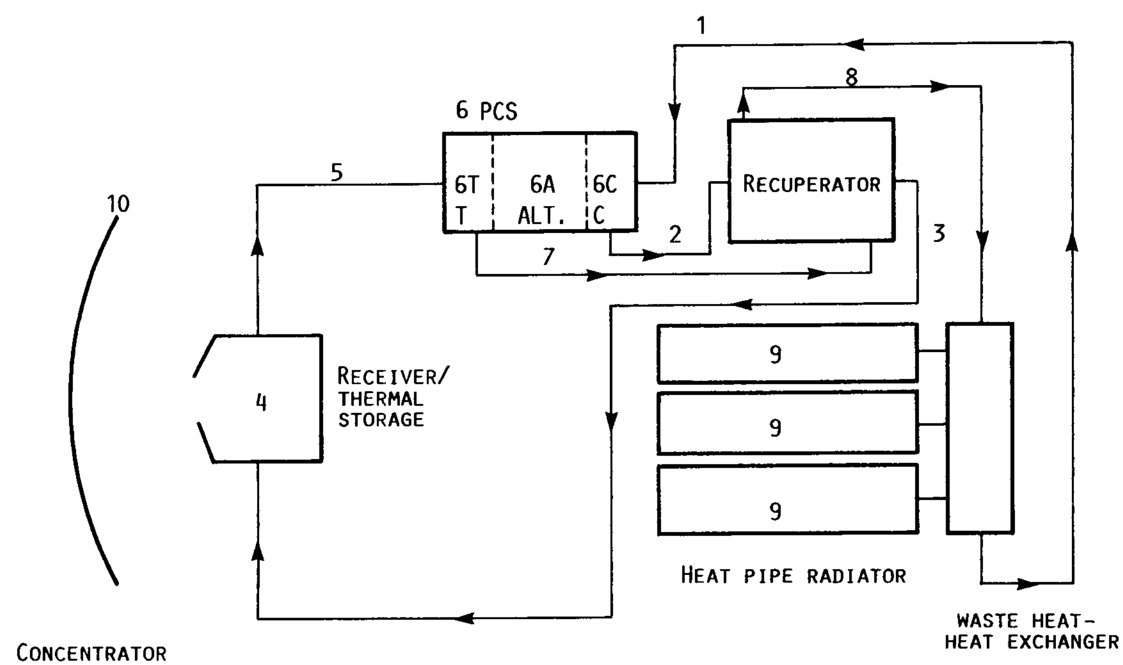


FIGURE 4-6. - FLOW SCHEMATIC - STATIONS.

STATION*	MEASUREMENT	NO. REQUIRED
1	Compressor Inlet	
	Temperature	3
	Pressure	3
	P-Flow	3
2	Compressor Outlet	
	Temperature	3
	Pressure	3
3	Receiver Inlet	
	Temperature	3
	Pressure	3
4	Thermal Storage	
	Temperature distribution, including aperture.	6
5	Turbine Inlet	
	Temperature	3
	Pressure	3
6	PCS	
6T	Turbine Bearing Temp.	3
	Turbine Speed	3
6A	Power (KWe), I, V	3,3,3
6C	Compressor Bearing Temp.	3
7	Turbine Outlet	
	Temperature	3
	Pressure	3
8	Recuperator Outlet	
	Temperature	3
	Pressure	3
9	Radiator (coating eff.)	
	Temperature	9
	Accelerometers	9
10	Concentrator	
	Back Side Temperature	9
	Accelerometers	6
11	Structure	
	Accelerometers	9
	TOTAL	105

*See Figure No. 4-6, page 37.

5.0 EXPERIMENTAL REQUIREMENTS:

The objective of Task II is to develop a conceptual design of the solar dynamic power test facility (SDPTF) on space station, and to define the requirements for such experiments. The requirements defined shall include items such as orbit, viewing, power, thermal, data, crew, servicing, contamination sensitivities, experiment setup and assembly, operation, changeout, teardown, stow, physical mass and size, equipment list and a system sketch. Prior to development of a concept and sketch, it is necessary to size each of the major components of the SDPTF.

As noted in Task I, the SDPTF should be a versatile test facility capable of testing SDPS's over a range of 5 - 20 KWe. The capability to test over this range of power must be designed into the concentrator support structure and facet mounts. An approach to providing this capability was discussed in Section 4.4 of this report. However, for purposes of sizing and determining the requirements of this facility, a 20 KWe power level will be assumed.

5.1 SIZING OF COMPONENTS:

The objective of this section is to determine the approximate size and weight of the advanced solar dynamic power systems under consideration. As shown on page 22, the temperatures of the three PCS's have been varied to yield similar performance levels and sizes for all three systems. The actual system to be flight tested may have a higher or lower overall system efficiency. The impact of such a deviation will be a higher or lower net power for the system.

5.1.1 CONCENTRATOR:

The area of the concentrator is a function of the electric power to be generated by the PCS, the overall efficiency of the SDPS (Solar Insolation to Bus Bar) and the level of solar insolation at LEO. Thus;

5.0 EXPERIMENTAL REQUIREMENTS: (continued)

$$A_c = \frac{Po}{\eta_o S} \qquad Po = 20 \text{ KWe}$$

Where, A_c = Area of concentrator $-M^2$

η_o = Overall system efficiency

See Task I, page 22 for projections

$S = 1.4 \frac{KW}{M^2}$ in LEO. (444 $\frac{BTU}{HR\ Ft^2}$ Ref: NASA TM82585)

	ADVANCED BRAYTON OR STIRLING
η_o	0.25
$A_c(M^2)$	60
A_c+10% Blockage	66
D_c (M)	~9.0
W_c (Kg)	99

Concentration of the solar insolation will be accomplished with a parabolic or faceted concentrator. The physical configuration of the concentrator and other major components depends on the focal point of the parabola which, in turn, depends on the rim angle. The equation for a parabola and relationship of rim slope and focal length are given below and illustrated in Figure No. 5-1.

$$Y^2 = 4\ ax \qquad \left(\frac{dy}{dx}\right)_c = \frac{2a}{Y_c}$$

Where, a = Focal point

$(dy/dx)_c$ = Slope at rim

Y_c = Radius of rim

θ = Rim angle

$\alpha = (90-\frac{\theta}{2})$ = Rim slope angle

$$(dy/dx)_c = \text{Tan}\ (90-\frac{\theta}{2})$$

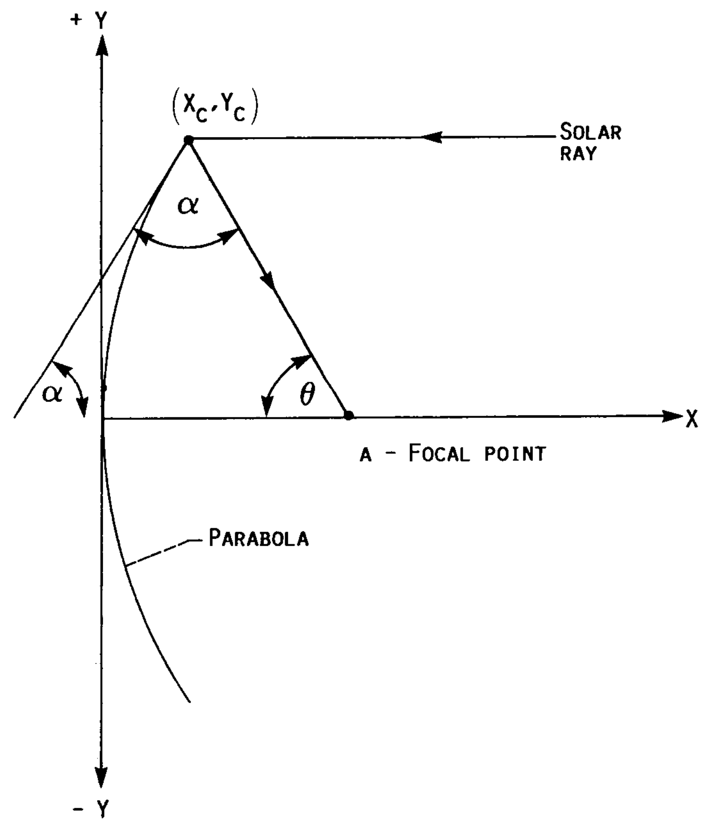


FIGURE 5-1. - GEOMETRY OF A PARABOLA.

5.1.1 CONCENTRATOR: (continued)

The rim angle of the concentrator can be selected to optimize collection efficiency. Such an optimization was performed in Reference No. 8. The reference study has determined collection efficiency as a function of rim angle for various receiver temperatures and surface errors. These results are included as Figure No. 5-2. It is seen that the maximum collection efficiency occurs at rim angles of 50 to 65^{o} at the 1100K receiver temperature. A rim angle of 60^{o} will be selected for sizing the test bed. The focal length of the concentrator for the assumed rim angle is:

	Advanced Brayton or Stirling
θ=Rim Angle	60^{o}
$(90-\theta/2)$	60^{o}
Tan $(90-\frac{\theta}{2})$	1.73
Y_C (M)	4.5
$a = Y_C \text{Tan } (90-\frac{\theta}{2}) \div 2$	3.89M

The focal length of the concentrator for a 20 KWe power system is 3.9M. A larger power system could have a larger focal length than shown above. The structure which positions the heat receiver at the focal point of the concentrator may be an individualized tripod type structure mounted from the rim of the concentrator or a truss type structure which supports the concentrator trussed backside and the heat receiver thru an appropriate intermediate structure. The power system must be mounted on the space station test bed structure and provide for accurate α'and β' pointing of the concentrator. Use of a truss structure would also permit mounting at the fore and aft C.G of the entire power system.

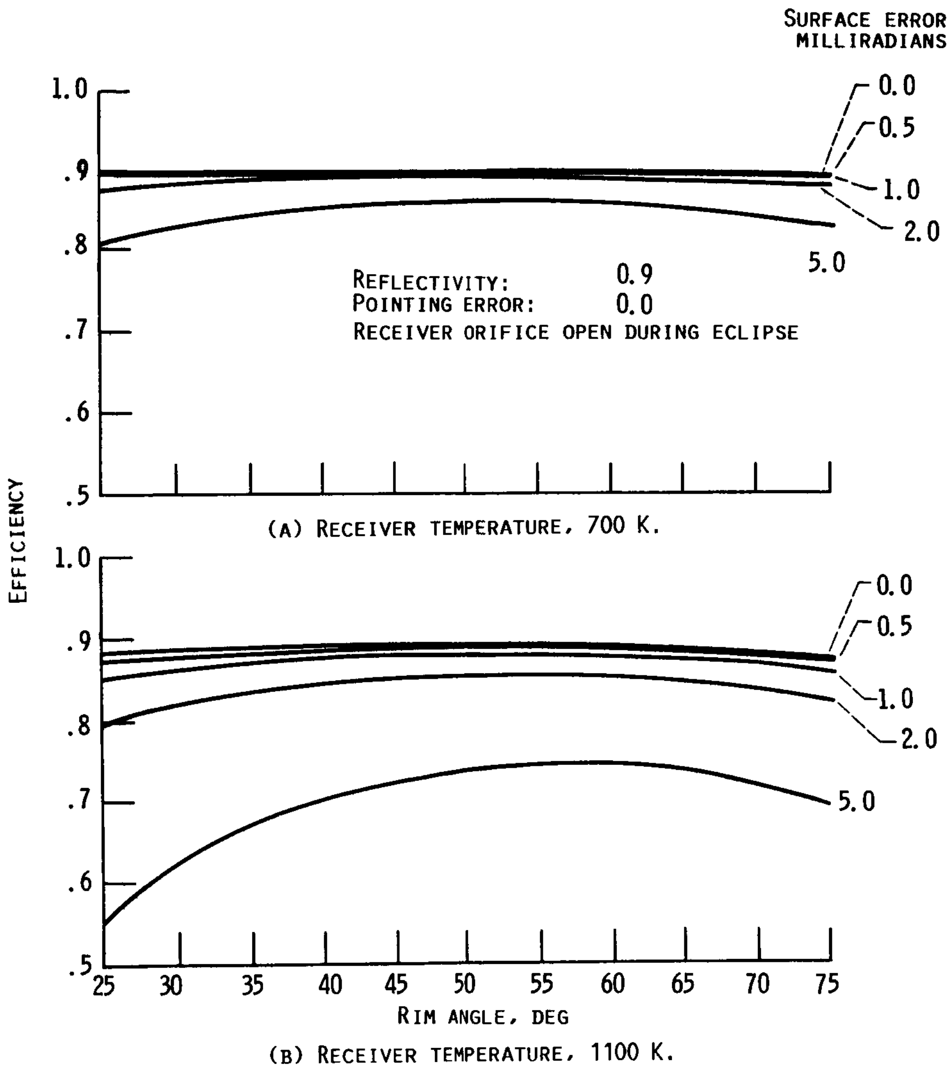


FIGURE 5-2. - COLLECTION EFFICIENCY AS A FUNCTION OF RIM ANGLE AT VARIOUS RECEIVER TEMPERATURES.

5.1.2 HEAT RECEIVER/THERMAL STORAGE:

The mass of storage material required is readily calculated from the power generation rate and heat receiver to bus efficiency (approximately overall system efficiency divided by 0.9). For LEO, the sun portion of the orbit is approximately 60 minutes and the shade portion is 34 minutes. For a power generation rate of 20 KW, the total energy generated during the shade is:

$$E_{shade} = 20 \text{ KW} \times \frac{34}{60} \text{ Hr.} = 11.33 \text{ KW Hr.} \quad (38,810 \text{ BTU})$$

$$= 40,800 \text{ KJ}$$

The energy required from thermal storage is:

$$E_{ts} = \frac{E \text{ (Shade)}}{\eta_o/\eta_c}$$

$$E_{ts} \text{ (Stirling)} = \frac{40,800}{0.24/.87} = 147,000 \text{ KJ}$$

LiF is the candidate thermal storage material and provides approximate results for all systems for the peak cycle temperatures chosen. Its thermal storage characteristics are:

Heat of Fusion = 6,474 Cal./Mol. (Ref. PIR #103)
1044 KJ/Kg

$$W \text{ (LiF)} = \frac{E_{ts}}{\text{H. of F.}} = \frac{147,000 \text{ KJ}}{1044 \text{ KJ/Kg}}$$

$$W = 141 \text{ Kg}$$

5.1.2 HEAT RECEIVER/THERMAL STORAGE: (continued)

$$V\ (LiF) = \frac{W}{\rho} = \frac{141{,}000\ gm.}{2.64\ gm/cm^3} = 53{,}410\ cm^3\ @\ 25^oC$$

$$V\ (LiF) = 1.45 \times 53{,}410 = 77{,}500\ cm^3 \text{ in molten state.}$$

The sizing of the heat receiver is considerably more difficult since one must know the heat flux distribution within the receiver, the heat transfer characteristics of the receiver and working fluid, peak flux, hot spot temperature, etc. An approximate size of the heat receiver will be determined using one-dimensional heat transfer analysis.

The approach to sizing the heat receiver will be to provide the required thermal storage material and check the average heat flux for acceptability of peak temperatures of containment tubing.

The volume of LiF in the molten state is 77,500 cm^3. (See above). Assuming a geometry, as shown in Figure 5-3, the size of the heat receiver required to provide the proper thermal storage volume can be calculated.

This configuration is considered because of the potential problem associated with the large volume change ($\sim$ 30%) of the LiF solid/liquid phase change. When completely solid (at the end of the shade period) and in zero-g, the void will be centralized in the circumferential direction and is expected to be elongated in the radial direction. This elongation is expected because on entering the shade, the freeze planes (contours) will tend to move in the circumferential direction. On entering the sun portion of the orbit, initial melting will occur as marked and communication with the void will occur early on because of the thermal finger. Repetitive melt/freeze cycles should not be a problem.

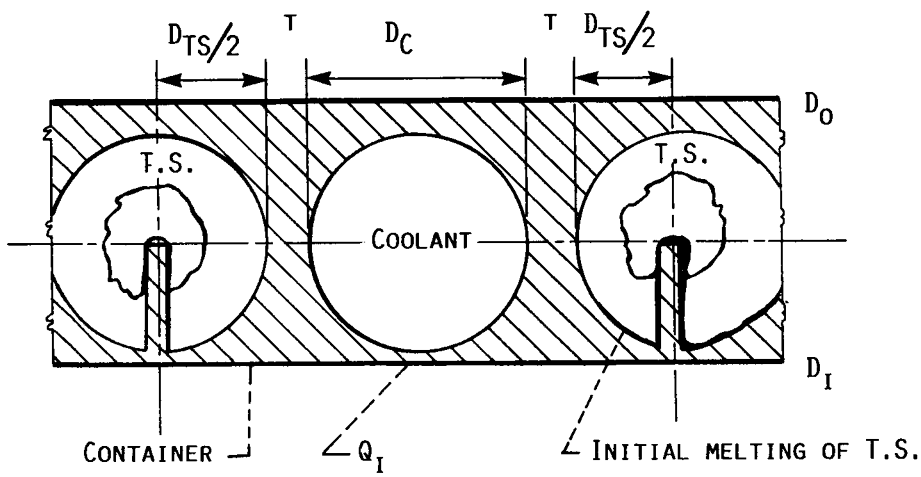


FIGURE 5-3. - GEOMETRY OF HEAT RECEIVER.

$s = D_c + D_{ts} + 2t$

For $D_c = D_{ts} = 3.8$ cm = 1.5" & t = .05 in.

s = 7.9 cm = 3.1 In.

$Ns = \pi D_m$

$D_m = 2.5N$ (cm.) = .987 N (in.)

The volume of thermal storage material is given by:

$$V_{ts} = NAL = N \frac{\pi \times 3.8^2}{4} \times 1.2Dm = 77{,}500 \text{ cm}^3$$

$$13.6 \text{ N } D_m = 77{,}500 \text{ but } D_m = 2.5 \text{ N}$$

$$34.1 \text{ N}^2 = 77{,}500$$

$$N^2 = 2272$$

$$N = 47.7 \simeq 48$$

Select N = 50 Sectors

$$D_m = 2.5 \text{ N} = 125 \text{ cm.} = 49.2 \text{ in.}$$

$$L = 1.2 D_m = 150 \text{ cm.} = 59.1 \text{ in.}$$

$$D_o = D_m + \frac{Dts}{2} + t = 125 + 1.9 + .13$$

$$D_o = 127 \text{ cm.}$$

$$D_i = 123 \text{ cm.} = 48.4 \text{ in.}$$

The internal area of the cylinder not including the endwall is:

$$A = \pi D_i L = \pi \times 123 \times 150 = 57{,}930 \text{ cm}^2$$

$$= 62.4 \text{ Ft.}^2$$

The total heat supplied to the heat receiver is:

$$Q_{H.R.} = \frac{Pout + Pts}{\eta_o / \eta_c} = \frac{20 + 11.33}{.25/.9} \text{ KW Hr.}$$

$$Q_{H.R.} = 113 \text{ KW Hr./Hr.}$$

$$= 384{,}900 \text{ BTU/Hr.}$$

The average heat flux on the cylindrical surface is:

$$\frac{Q_{ave}}{A} = \frac{113 \text{ KW}}{63.5} = 19.5 \frac{\text{KW}}{\text{M}^2}$$

The peak heat flux is estimated at:

$$\frac{Q_{peak}}{A} = 2.2 \times 19.5 \frac{\text{KW}}{\text{M}^2} = 42.9 \frac{\text{KW}}{\text{M}^2}$$

The peak to average heat flux ratio of 2.2 in the receiver is based on experimental data shown in Figure No. 5-4, Ref. No. 9. Using a linear approximation to the heat flux distribution, the average heat flux is 32,300 BTU/Hr. Ft^2, resulting in the peak to average ratio of 2.2. This ratio may be a function of the concentration ratio and may be higher for the high temperature advanced systems.

The average temperature of the gas in the receiver is:

$$T_{ave} = \frac{T_{in} + T_{out}}{2} = \frac{827 + 1090}{2} = 959\text{K}$$

The temperature drop from molten LiF at 1121K to the average gas temperature is:

$$\Delta T = 1121 - 956 = 165\text{K}$$

If 80% of the ΔT is allotted to the film coefficient, the average film coefficient is:

$$h_{ave} = \frac{Q/A \text{ ave}}{(\Delta T)\text{x}.8} = \frac{19.5}{165\text{x}.8} = .148 \frac{\text{KW}}{\text{M}^2\text{K}}$$

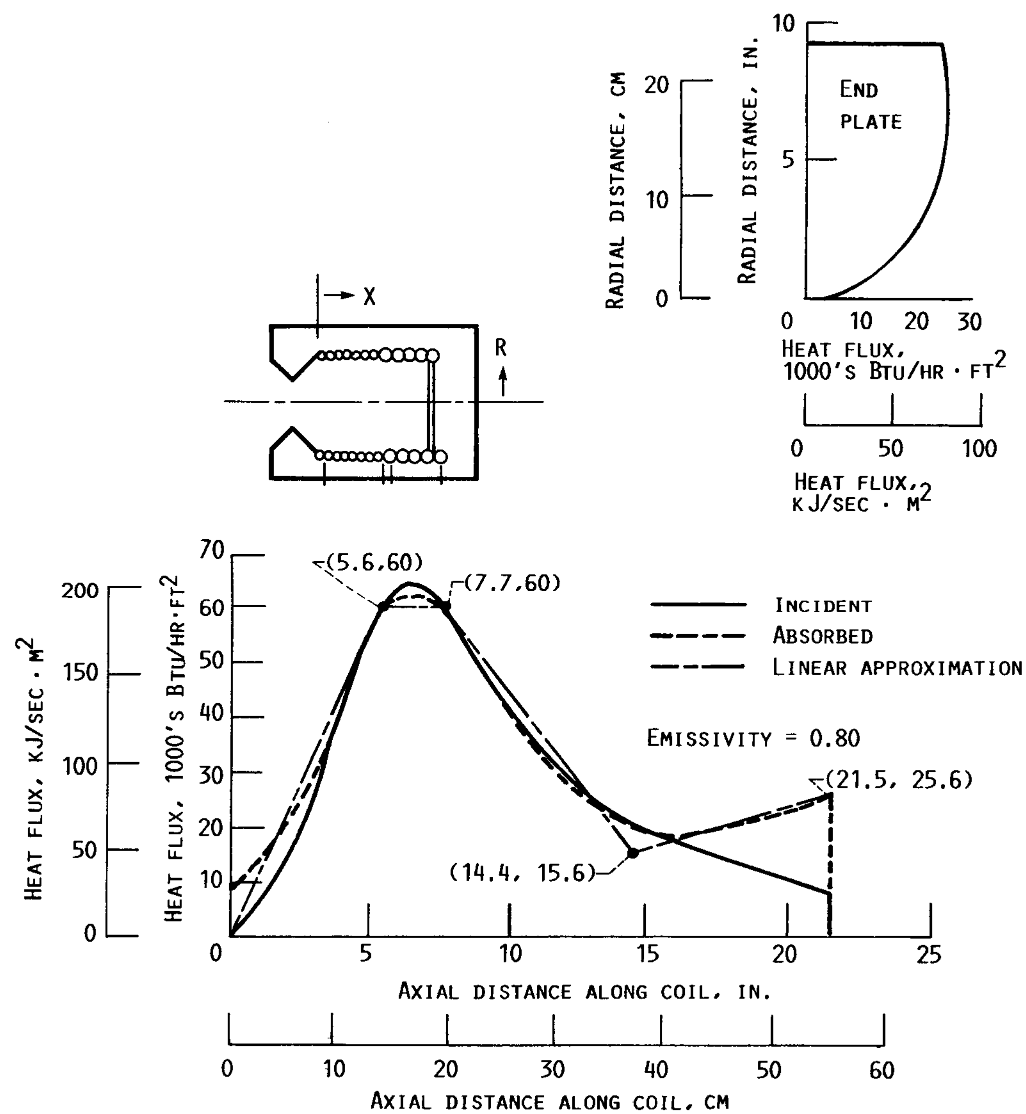


FIGURE 5-4. - HEAT FLUX DISTRIBUTION IN AN EXPERIMENTAL CYLINDRICAL RECEIVER.

The peak heat flux occurs at approximately 30% of the receiver length. The gas temperature at this point assuming a linear variation is:

$$T_{ave}\Big|_{.3} = .3\,(T_{out}-T_{in}) + T_{in}$$

$$= .3\,(1090-827) + 827 = 906K$$

$$T\Big|_{.3} = 1121 - 906 = 215K$$

$$h_{peak} = \frac{Q/A\ peak}{.8x\ \ T_{.3}} = \frac{42.9}{.8 \times 215} = .25\ \frac{KW}{M^2\ {}^oK}$$

These film coefficients compare with a value of less than .113 $\frac{KW}{M^2\ {}^oK}$ (20 BTU/HR Ft.^{2} ^oF) used in the preliminary design done by NASA and reported in NASA TM X-2552. (Ref. No. 5). A film coefficient of .23 $\frac{KW}{M^2\ {}^oK}$ is feasible but will result in a substantially larger pressure drop. The need for a detail design in this area is evident.

This estimate of receiver size is at best pre-conceptual in nature. It is not representative of heat pipe technology nor does it address the specific requirements of the FPSE where the thermal energy must be delivered to the heater head of the engine. Thus, the receiver is a function of the technology to be utilized, the approach to TES and the PCS to be used.

CONCLUSION: Candidate designs of receivers for each of the PCS's are required.

5.1.3 DIMENSIONS AND WEIGHTS:

The dimensions of the various components which make up the system are listed below for a 20 KWe Brayton SDPS. The dimensions of the concentrator and receiver have been estimated earlier. The dimensions of the PCS are estimated from presentation material of Garrett Pneumatic Systems Divisions. Radiator areas are taken from the preliminary data shown in Figure 5-5.

BRAYTON

Concentrator Diameter:

D = 9.0M
a = 3.9M

Receiver:

$\sim$ 1.3M x 1.5M

Power Conversion System:

.8M Dia. x 1.5M Lg.
Recuperator: .6M x.9M x 1.2M

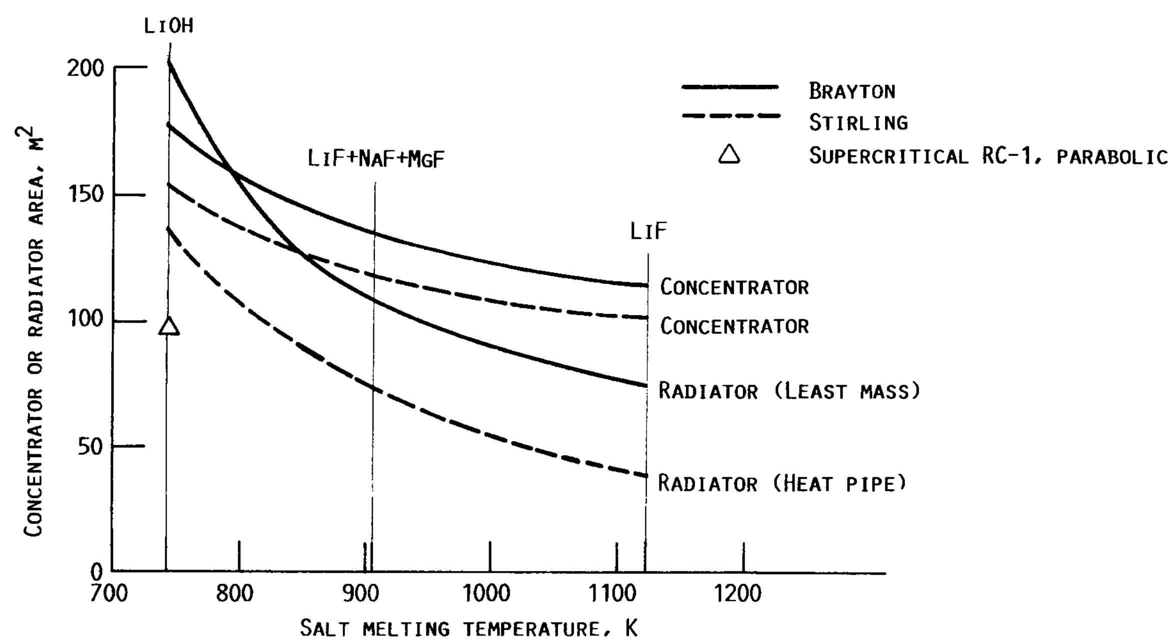


FIGURE 5-5. - PRELIMINARY DATA ON CONCENTRATOR AND RADIATOR AREA FOR BRAYTON, ORCS AND STIRLING POWER SYSTEMS FOR VARIOUS RECEIVER TEMPERATURES - 20 KWE SYSTEM.

5.1.3 DIMENSIONS AND WEIGHTS: (continued)

Radiator:

$$A = 75\ M^2$$

$$A = 807\ Ft.^2$$

In estimating the width of the radiator, it is assumed that the effective width is the diameter of the concentrator less the diameter of the PCS.

$$\text{Width} = D_c - .6M$$

$$= 9.0 - .6 = 8.4M$$

$$\text{Length} = \frac{A}{W} = \frac{75}{8.4} = 8.9M$$

Envelope Volume:

$$V = \frac{\pi D^2}{4} \times L + L \times W \times H \text{ (Pedestal)}$$

$$= \frac{\pi \times 9^2}{4} \times 14.6 + 7.3 \times 1 \times 1$$

$$V = 929 + 7.3 = 936\ M^3$$

A sketch and overall dimensions of an advanced Brayton SDPS on test in the SDPTF is shown in Figure No. 5-6. The envelope volume of the SDPTF is assumed to be a cylinder with a diameter equal to the concentrator and overall length from Figure No. 5-6 plus the volume of the pedestal mount.

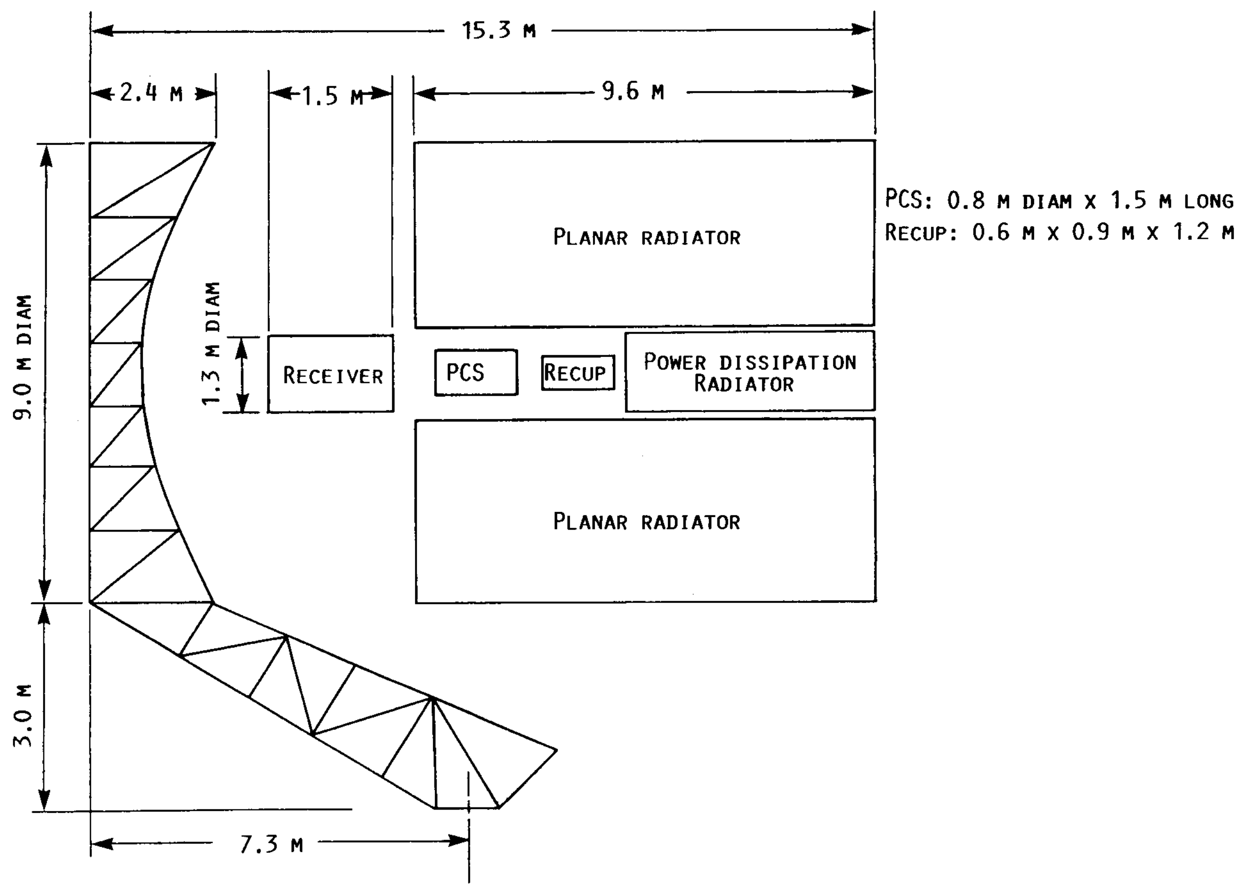


FIGURE 5-6. - BRAYTON SOLAR DYNAMIC POWER SYSTEM.

5.1.3 DIMENSIONS AND WEIGHTS: (continued)

The total mass of the advanced Brayton SDPS is based on the preliminary data shown in Figure No. 5-7. The component masses and total system mass for a 20 KWe Brayton SDPS projected to the 1990 + time period is estimated as follows:

COMPONENT	WEIGHT KG
Collector & Truss Structure	136
Receiver & Thermal Storage	318
Power Conversion System	82
Recuperator	159
Radiator	367
Structure	64
Power Dissipation Radiator	50
Pointing System, Controls, Piping, Data, etc.	64
TOTAL	*1240 KG

*The total system weight may be reduced by advanced materials such as ceramics or advance heat pipe technology.

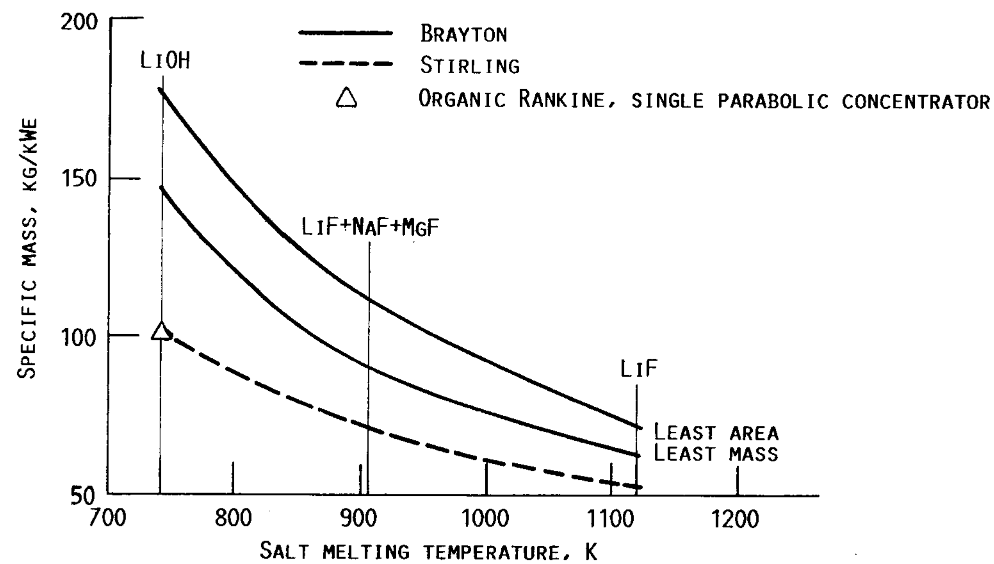


FIGURE 5-7. - PRELIMINARY DATA ON SPECIFIC MASS OF BRAYTON, ORCS, AND STIRLING SOLAR POWER SYSTEMS FOR VARIOUS RECEIVER TEMPERATURES - 20 KWE SYSTEM.

5.2 SPACE STATION POWER:

It is planned to utilize space station power for the control and operation of the power test facility. An estimate of the power required for one SDPTF follows:

ITEM	POWER
Data Communications	250 W
Controls	250 W
Pointing Drives (two 1/4" HP Motors)	400 W
Valves (4)	100 W

Continuous power 1.0 KWe.
Intermittent power 500 W.

Additional power will be required for startup of the power system. The Brayton system could circulate the working fluid (alternator used as a motor) and transfer the incident solar heat to the other components. To assure a fast startup, it is assumed that the receiver will be preheated electrically to 1090K, the turbine housing to 1090K and the recuperator to 533K. The total amount of heat required is estimated as:

COMPONENT	WEIGHT(Kg.)	T(K)	Cp W T(KW Hr.)
Receiver	363	1090	53
Turbine	14	1090	1.9
Recuperator	181	533	8.8
		TOTAL ≅	64 KW. HR.

5.2 SPACE STATION POWER: (continued)

Assuming that these components are heated up over a 24 hour period:

$$P = \frac{64}{24}\frac{\text{KW HR.}}{\text{HR.}} = 2.66$$

$$\cong 3.0 \text{ KW.}$$

An alternate approach to startup of the system is to run the alternator as a motor to circulate the working fluid. The solar heat incident on the receiver would heat the receiver and be transferred to other portions of the system. Component and working fluid temperatures would rise to a point when the turbine becomes self-sustaining and then rise to steady state conditions. An analysis of the transient startup conditions is required to determine best startup approach.

The power required to drive the compressor at 1/4 speed is estimated using the speed cubed relationship as follows:

$$P = P_{out} \times 2 \times \left(\frac{N_1}{N_2}\right)^3 = 20 \times 2 \times \left(\frac{1}{4}\right)^3$$

$$P = .625 \simeq .75 \text{ KW.}$$

$$P_{total} = P_{facility} + P_{comp.} = 1.0 + .75 = 1.75 \text{ KWe}$$

5.3 DATA/COMMUNICATIONS:

There are 105 data words identified on page 38 and Figure 4-6 which are required to provide an understanding of the operation of the power system. To assure complete coverage of data, the number of words are tripled. Assuming 8 bits per word, the total bits are:

$$N_{bits} = 3 \times 105 \times 8 = 2520$$

If transmitted in 5 seconds, the generation rate is:

$$R = \frac{N_{bits}}{\text{Time}} = \frac{2520}{5} = 504 \simeq 0.5 \text{ KBPS}$$

Round upward to 1.0 KBPS.

5.3 DATA/COMMUNICATIONS: (continued)

Additionally, it is estimated that 20 critical words (160 bits) will be scanned once per minute whereas the entire data set will be scanned every 30 minutes.

If we wished to store one day's data, this would represent:

$$
\begin{aligned}
N_{stored} &= (24 \times 2 \times 315 + 24 \times 60 \times 20)8 \\
&= (15{,}120 + 28{,}800)8 \\
&= 351{,}400 \text{ Bits}
\end{aligned}
$$

A storage capability of 1 megabit gives:

$$N_{days} = \frac{1000000}{351{,}400} = 2.85 \text{ days of data storage}$$

Seems Adequate

5.4 STOWED DIMENSIONS:

The package or stowed dimensions for a 20 KWe system is estimated as follows:

1. It is assumed that the concentrator truss can be folded into a volume 10.4M long by 2.75M wide by 2.5M high.

2. Radiator

   4 Sections 2.6M x 10.4M x .6M

3. Overall

   Installed volume 3.7M Dia. by 12.2M Lg.

WEIGHT:

$$\text{Brayton } W = 62 \frac{KG}{KWe} \times 20KWe = 1240 \text{ KG.}$$

5.5 EVA:

It is expected that all components for a complete power system will be transported in a single shuttle flight. In view of the size of a 20 KWe SDPS, it will be necessary to package or stow in as small a volume as possible. The maximum payload envelope of the shuttle is 4.57M Dia. x 18.3M Lg. with a weight limit of 29,470 Kg. when located at the C.G. of the shuttle. There are C.G. limitations which reduce the maximum payload weight depending on the cargo C.G. location. The 20 KWe power system is estimated at 1240 Kg. The power system is probably volume limited by shuttle.

The stowed power system will be moved from the cargo bay to the expected location on space station. The packaged components will require deployment and assembly into the power system. The following deployment and assembly activities which require EVA are anticipated. The EVA hours estimated are based on personal judgement.

NO.	ACTIVITY	EVA (Hrs.)
1.	Connect temporary electric power (1/2), deploy collector truss structure (1/2), lock in place (1) and attach to space station (3).	5
2.	Check out operational capability of pointing drives using temporary power.	2
3.	Deploy and lock facets in place on collector (20 facets x 1/2 Hr. Ea.).	10
4.	Deploy module consisting of heat receiver, PCS and attached piping and attach to collector truss via support structure.	8
5.	Deploy the four sections of radiator, attach piping and make final connections of piping.	8

5.5 EVA: (continued)

NO.	ACTIVITY	EVA (Hrs.)
6.	Attach gas management system to attachment point of piping, inject helium and check connections for leakage.	4
7.	Using repair kits, repair joints and recheck for leakage.	4
8.	Deploy and attach radiator for dissipating electric power.	4
9.	Make all electrical connections for power out, controls, instrumentation, station power in, pointing, etc. (12 connections x 1/2 ea.)	6
	SUBTOTAL	51
10.	CONTINGENCY 50%	25.5
	GRAND TOTAL	76

5.6 ELECTRICAL BLOCK DIAGRAM:

The electrical block diagram is shown in Figure No. 5-8. The block diagram shown relates to control functions, data acquisition and data storage. This diagram was prepared based on information from Ref. No. 10.

A similar diagram could be prepared for the power and management distribution system which will eventually be required. However, it is assumed that all the power generated by the SDPS will be dissipated via electrical resistors and radiated to space.

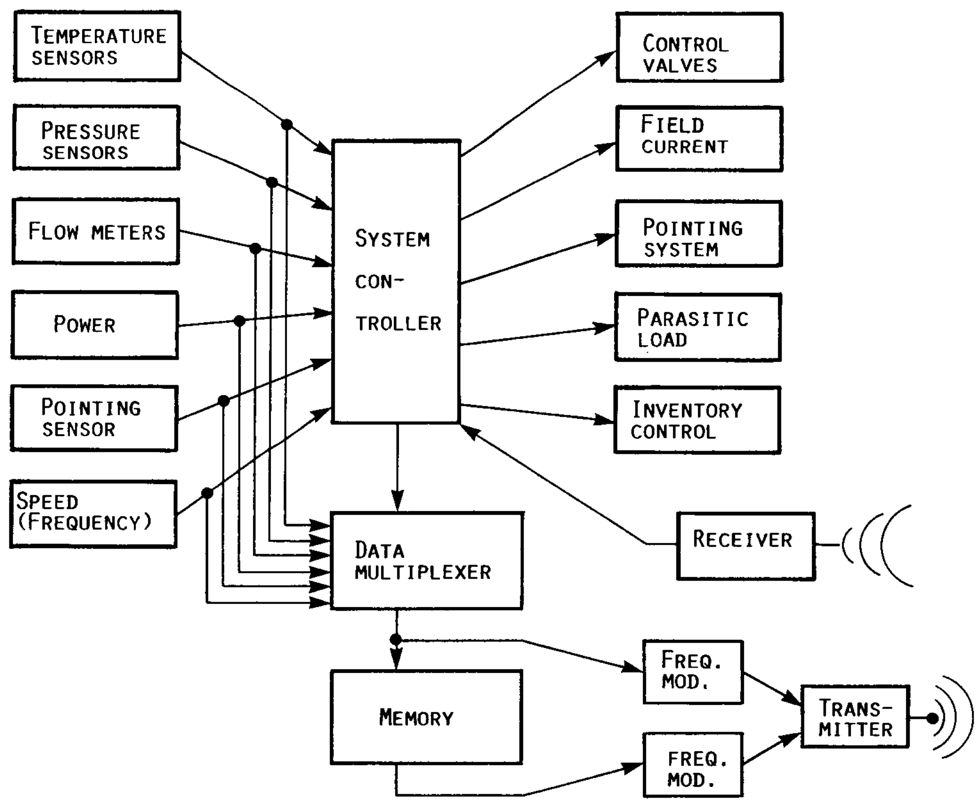


FIGURE 5-8. - SOLAR DYNAMIC POWER SYSTEM ELECTRICAL BLOCK DIAGRAM.

6.0 DOCUMENTATION OF EXPERIMENTAL REQUIREMENTS:

Task III - Documentation of the experimental requirements of the SDPTF consists of completing the information required by:

1. The NASA Mission Requirements Working Group (MRWG) Form.
2. The Technology Development Advocacy Group (TDAG) Form.

The information provided in these forms is based on the analyses, assumptions, etc., as listed in Task II. Copies of the MRWG and TDAG forms are included in the Appendix.

7.0 CONCEPTUAL EQUIPMENT DESIGN:

The purpose of this task is to prepare conceptual designs for each of the major components or subsystems of the SDPTF. The limited scope precludes any analysis on design concepts. This section discusses various design considerations and comments which have resulted from the work on other tasks.

7.1 CONCENTRATOR:

The concentrator is envisioned as an integrated assembly of a deployable truss structure which supports and provides for focusing the many lightweight hexagonal concentrator facets. It is anticipated that each facet will be focused during ground testing with a mechanism which will lock in place or be suitably indexed so that the required focus can be achieved after deployment. The flexibility to test at various power levels may be provided by defocusing as many facets as required, the use of sun shades or other approach. (Note: A concept for concentrator flexibility of power level is discussed in Section 4.4, Conceptual Definition of SDPTF, and illustrated in Figure 4-5.) The facet support and attachment to the truss structure should simplify removal by EVA. This latter feature is important since testing in the SDPTF will provide for periodic removal, replacement, and evaluation of mirror facets.

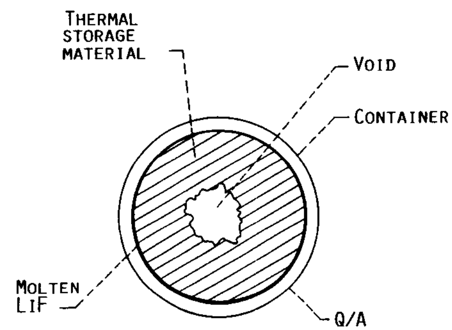
7.2 RECEIVER/THERMAL STORAGE:

An obvious requirement of the receiver/thermal storage design is close thermal coupling of the thermal storage material and the working fluid of the PCS. Close thermal coupling is required to minimize degradation of the quality of heat stored. A heat pipe design could provide the required thermal coupling.

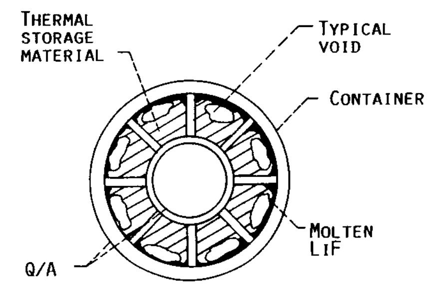
The heat flux incident on the cylindrical receiver wall can vary by a factor of 6 to 7 over the length of the receiver. There are three design options available to aid in the handling of this large variation in heat flux. They are:

- Use a heat pipe design to thermally couple the solar insolation and the working fluid.
- Tailor the absorptivity of the surface so that the heat flux absorbed is flattened out.
- Tailor the heat transfer coefficient on the gas side (Brayton only) so that pressure drop is minimized while preventing a hot spot from occurring

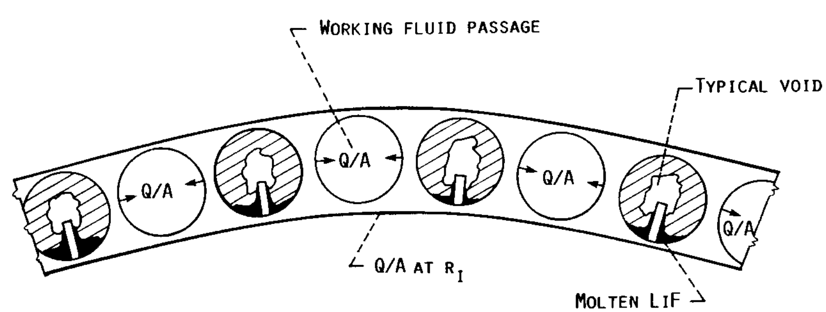
The containment of the thermal energy storage material is a critical design problem due to the large volume change during the melt/freeze cycle for LiF. The containment design appears to be a strong function of the direction of heat addition and heat removal. The configuration of LiF thermal storage material internal to a cylinder, Figure No. 7-1a, may result in plastic deformation of the container. Once frozen with uniformly distributed heat removal, the void in zero-g may be centrally located. Subsequent melting via uniformly distributed heat input will cause melting at the container's inner surface with a substantial increase in pressure. Non-communication with the central void will lead to plastic deformation of the container which will ratchet until failure occurs.



(A) UNIFORM HEAT ADDITION AND REMOVAL.



(B) EXTERNAL HEAT ADDITION, INTERNAL HEAT REMOVAL.



(C) RADIAL HEAT ADDITION, CIRCUMFERENTIAL HEAT REMOVAL.

FIGURE 7-1. - THERMAL STORAGE CONCEPTS.

7.2 RECEIVER/THERMAL STORAGE: (continued)

Locating the LiF external to the working fluid and in an annulus with many axial or circumferential fins may lead to a freeze pattern shown in Figure 7-1b for uniform heat removal via the inner diameter. In zero-g and internal heat removal, the void may be located near the outer containment wall. Subsequent external heating will create liquid molten salt at the outer containment. It is anticipated that moderate pressures will cause the thin layer of solid LiF to fracture and provide communication between the void and molten LiF.

A similar situation exists for configuration "C" which would have internal heat addition and circumferential heat removal. Because of symmetric, circumferential heat removal, the void in zero-g would be centrally located and elongated in the radial direction. A fin (thermal finger) will extend into the void. Subsequent heating internally will result in molten LiF along the finger with early communication between the void and molten LiF.

8.0 PRELIMINARY EVOLUTIONARY PLAN:

The critical technologies for SDPS's were identified in Section 4.2 of this report. All of the critical technologies must be developed in a timely and successful manner for testing of SDPS's on the space station test facility. The precursor activities required to permit space station testing and an overall program schedule are discussed in the following sections.

8.1 PRECURSOR ACTIVITIES:

The critical technologies identified in Section 4.2 are summarized below:

- Concentrator (Mirror)/Facets/Deployable Truss Structure
- Receiver/Thermal Storage/Heat Pipe
- Heat Pipe Radiators
- Systems and Safety
- Materials for advanced PCS's. (Ceramics for advanced Brayton and refractory metals for advanced Stirling.)

The activities required to develop the critical technologies and design the components from mature technologies are shown in Figure No. 8-1 and described as follows:

8.1.1 CONCENTRATOR:

The concentrator technology projected to the 1992 + time frame consists of a deployable truss structure with a multifaceted concentrator having a weight goal of 1.5 Kg. per square meter and a reflectivity of 0.9 maintained over its lifetime, and a high surface accuracy (0-2 milli-radians). The multifaceted deployable truss structure is a complex component which has yet to be designed. The design activity must be a systems type activity since the component must provide various capabilities and functions as follows:

8.1.1 CONCENTRATOR: (continued)

- The truss structure must provide attachment points and focusing capability for each concentrator facet.
- The truss structure must provide a gimbaling attach point to the space station.
- A pointing subsystem must be integrated with the structure to provide for α' and β' adjustments of attitude and needed accuracy in sun pointing.
- A control system integrated with pointing which will provide for safe startup (walk-on), shutdown (walk-off) and emergencies.

In parallel with the system design function is the development of lightweight concentrator facet technology. Known candidates include micro-sheet glass, reinforced graphite, thin metal or a honeycomb backup to a silvered or aluminized surface. Testing in a simulated LEO environment will lead to candidate facet designs. Testing candidate facets in LEO on a shuttle launched and recovered free flyer will permit final evaluation and selection of facet design.

Also in parallel with the above efforts is the coatings development. A long-life coating is required to protect the concentrator surface from tarnishing with a subsequent reduction in reflectivity.

Extensive testing of concentrator facets with coatings in a simulated LEO environment including micro-meteoroid damage will lead to candidate facet designs. As noted above, testing of candidate designs in the actual LEO environment via a free flyer launched from shuttle will lead to selection of the baseline design.

Systems testing of a complete concentrator will permit a characterization of performance and a demonstration of deployment and operational capability.

8.1.2 RECEIVER/THERMAL STORAGE:

The receiver/thermal storage technology projected to the 1992 + time frame consists of advanced heat receiver concepts including a heat pipe thermal storage subsystem integrated into the receiver for transfer of the concentrated solar insolation to the working fluid of the power conversion cycle. The candidate thermal storage materials for advanced solar dynamic power systems will be identified for the 1000K to 1400K range. There are potential problems with each of the salts and eutectics due to the volume change associated with the phase change (solid to liquid). These problems must be addressed in the design phase. The design must also provide for the satisfactory heat transfer of the solar insolation to the working fluid and thermal storage material during the sun portion of the orbit and from the thermal storage material to the working fluid during the shade.

A materials study will be conducted to establish or confirm properties of the candidate materials. The materials study will also seek out other thermal storage materials which may provide improved container compatibility or reduced volumetric changes during the phase change.

Extensive ground testing of candidate receiver/thermal storage designs will be conducted. These tests will demonstrate the satisfactory operation of the thermal storage subsystem, the life capability of the receiver/thermal storage subsystem and the capability of the heat pipe to operate with or against the gravity force. Early testing will be done with modules or sectors of the receiver. Selection of a baseline design will lead to full scale testing.

8.1.2 RECEIVER/THERMAL STORAGE: (continued)

The thermal storage materials undergo a volume increase when changing from solid to liquid and a volume reduction when freezing. Freezing in zero-g could lead to void formations which could drastically alter the heat transfer characteristics of the design and cause a fatigue failure of the thermal storage material container if subjected to repeated plastic deformations. Zero-g, thermal storage experiments on shuttle are required to demonstrate an understanding of the zero-g behavior of thermal storage materials in the liquid phase and predictability of the heat transfer characteristics.

A coatings effort may be required for the receiver. To facilitate walk-on and walk-off of the concentrated solar insolation, a highly reflective, high temperature coating or high temperature insulation may be required for the aperture area. It may also be desirable to tailor the absorptivity of the receiver's cylindrical wall to flatten the heat flux absorbed over the length of the receiver.

These activities will culminate in a baseline receiver/thermal storage design for each of the power conversion cycles. Systems analysis and evaluation will lead to selection of the SDPS to be flown on space station.

8.1.3 POWER CONVERSION SYSTEMS:

The technology for the low temperature Rankine and Brayton power conversion systems (PCS's) is mature and will require a minimum of development. The advanced technology PCS's include a high temperature Brayton, intermediate and high temperature Stirling and high temperature Rankine.

8.1.3 POWER CONVERSION SYSTEMS: (continued)

The high temperature Brayton PCS will operate in the 1100 - 1400K range and will utilize ceramic components. The ceramic components anticipated include the heat receiver, the turbine and housing, and the recuperator. Ceramics technology (SiC, SiN) is presently being developed via the automotive gas turbine program managed by NASA-LeRC for the Department of Energy. This technology will cover the turbine, turbine housing and recuperator. A ceramic receiver development effort will be required to complete the Brayton technology for SDPS's.

The basic Stirling PCS technology is being developed on the automotive Stirling engine program managed by the NASA-LeRC for the Department of Energy. The free piston Stirling engine (FPSE) with a linear alternator is being developed for operation up to 1350K as part of the SP-100 advanced technology program. The basic PCS technology for both moderate and high temperature FPSE's will be available for solar dynamic power applications. The SP-100 advanced Stirling development includes engine testing, space engine design, scaling studies, heat exchanger module, oscillating flow heat transfer analysis and experiments, high temperature magnet evaluation and linear alternator configuration analysis. A development effort on the receiver, thermal storage and heat pipe coupling to the heater head of both the moderate temperature and high temperature FPSE's is required.

The advanced Rankine system will consist of a potassium (K) working fluid operating in the range of 1100 - 1400K. The performance gains over the organic Rankine system make it competitive with Brayton and Stirling and radiator area is markedly reduced. The technology base for a potassium PCS is fair, NASA-LeRC having designed and tested a potassium turbine at the General Electric Company in the late 60's and early 70's. A development effort on the heat receiver/thermal storage component for an advanced Rankine system is required.

8.1.4 HEAT PIPE RADIATORS:

The radiator technology projected to the 1992 + time frame consists of a multi-panel, heat pipe radiator of the planar type. Early design activity will generate candidate design. Extensive ground testing of sub-modules of a radiator panel will lead to selection of a baseline design.

A coatings effort is also required. The coatings' objective will be to provide a highly emissive surface which remains stable over its lifetime while exposed to the LEO environment.

It is assumed herein that sufficient zero-g tests of heat pipes will have been conducted in other areas (i.e., thermal management) to preclude the need for additional zero-g tests here. However, if doubt or concerns still exist, zero-g testing may be required.

8.1.5 SYSTEMS AND SAFETY:

All of the precursor activities stem from an overall systems definition wherein the performance requirements for each major subsystem or component are also defined. The overall systems analysis function is an ongoing activity which requires periodic updating as the performance characteristics of the major subsystems evolve.

This activity will develop all analyses and procedures for the launch and safe operation of the SDPS on space station.

The complete systems test will demonstrate readiness for launch and testing on the space station.

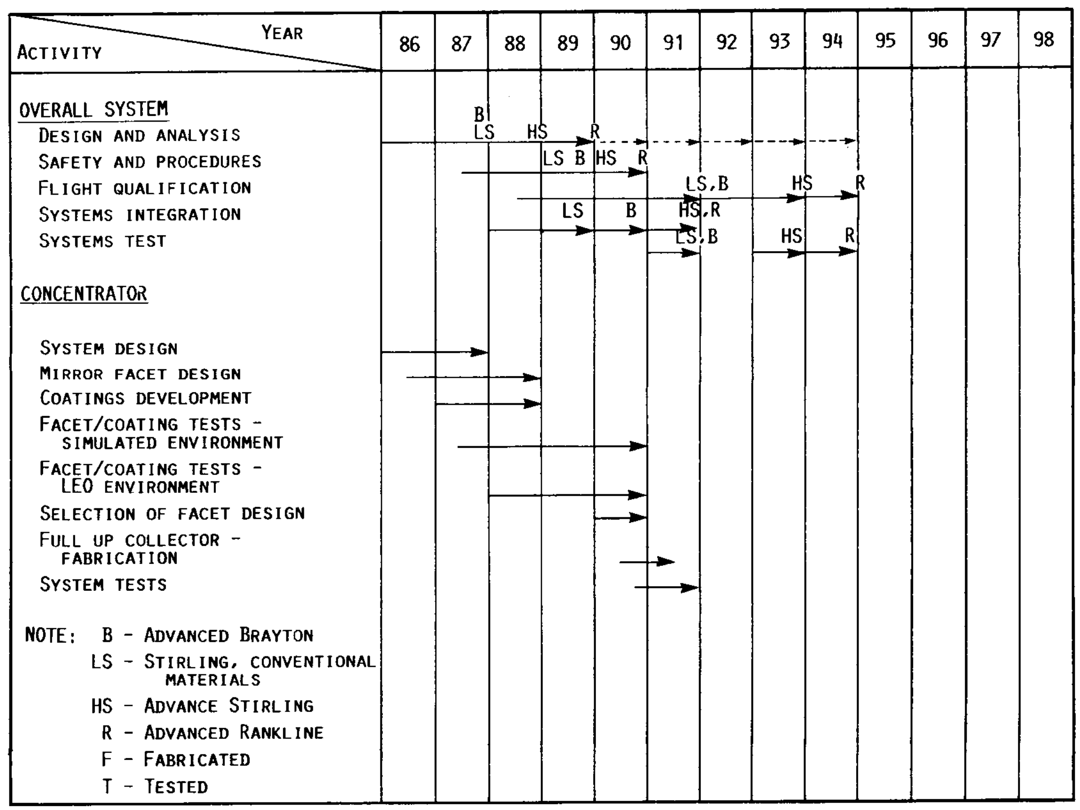


FIGURE 8-1. - SCHEDULE OF PRECURSOR ACTIVITIES.

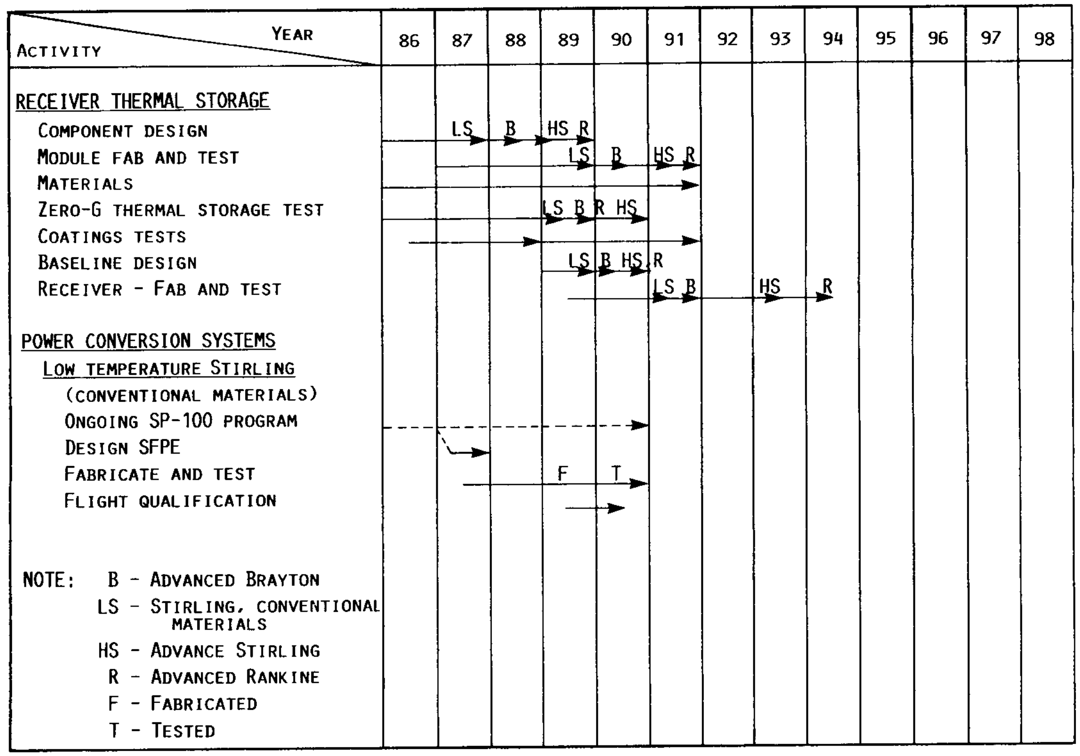


FIGURE 8-1. - CONTINUED.

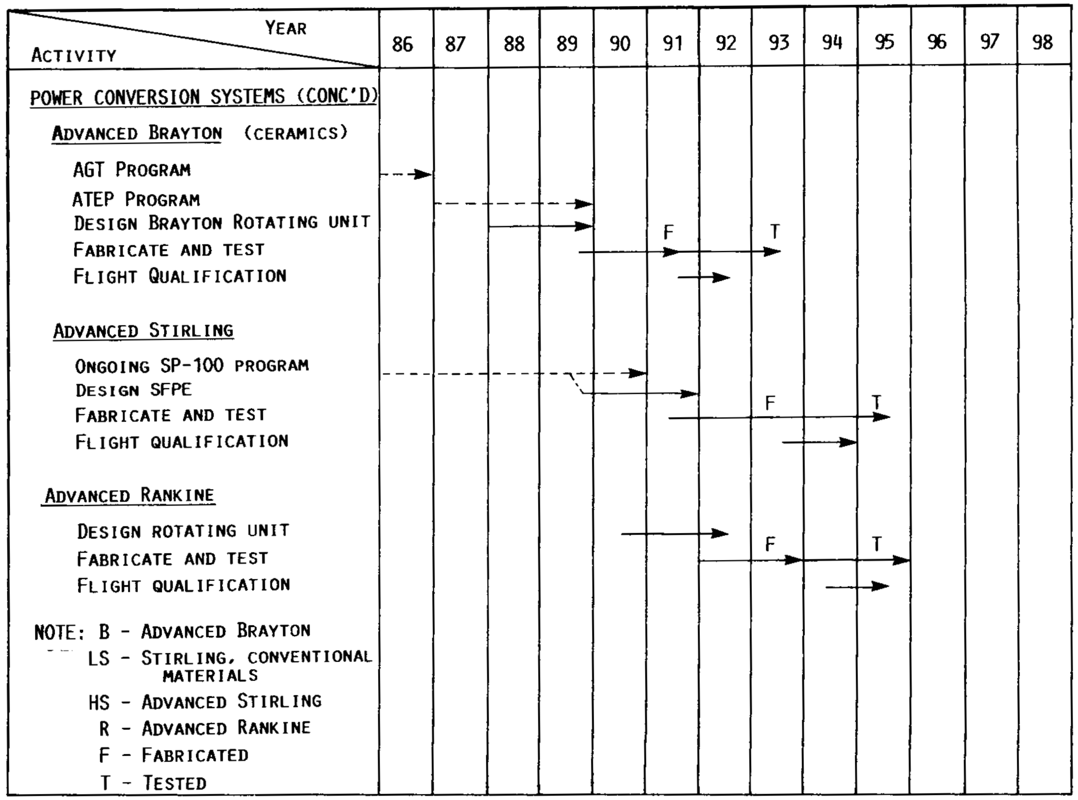


FIGURE 8-1. - CONTINUED.

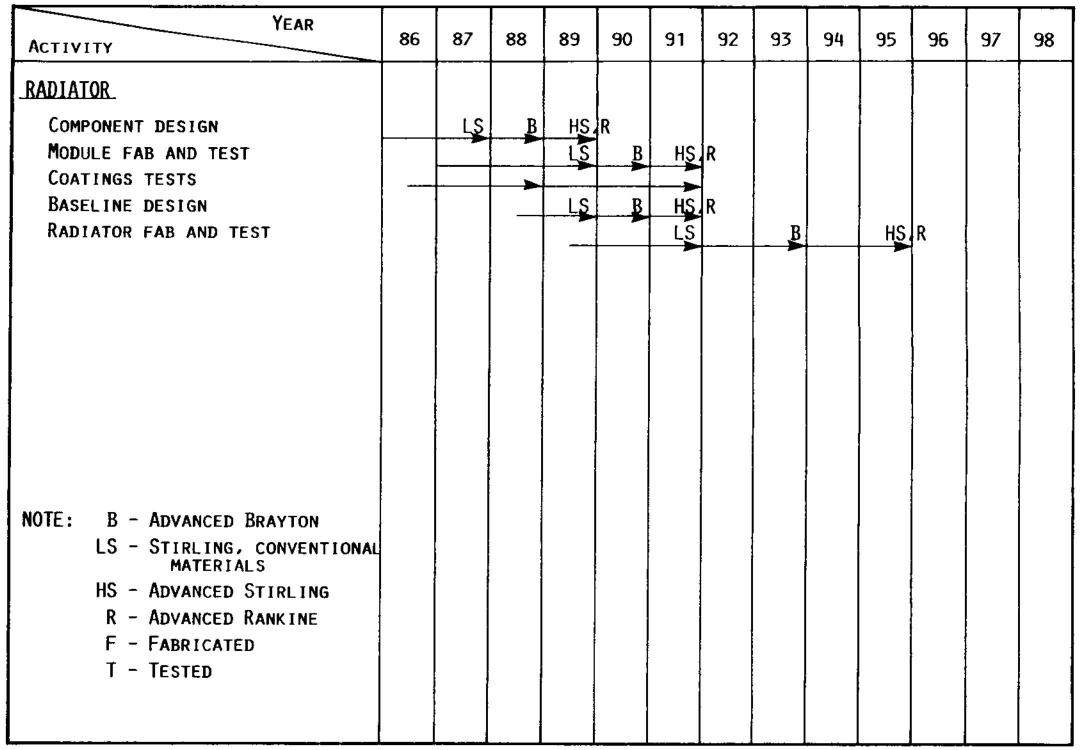


FIGURE 8-1.- CONCLUDED.

8.2 OVERALL PROGRAM SCHEDULE:

The overall program schedule is shown in Figure No. 8-2. Each of the major precursor activities is summarized and space station testing is taken from the test plan as shown in Figure No. 4-5.

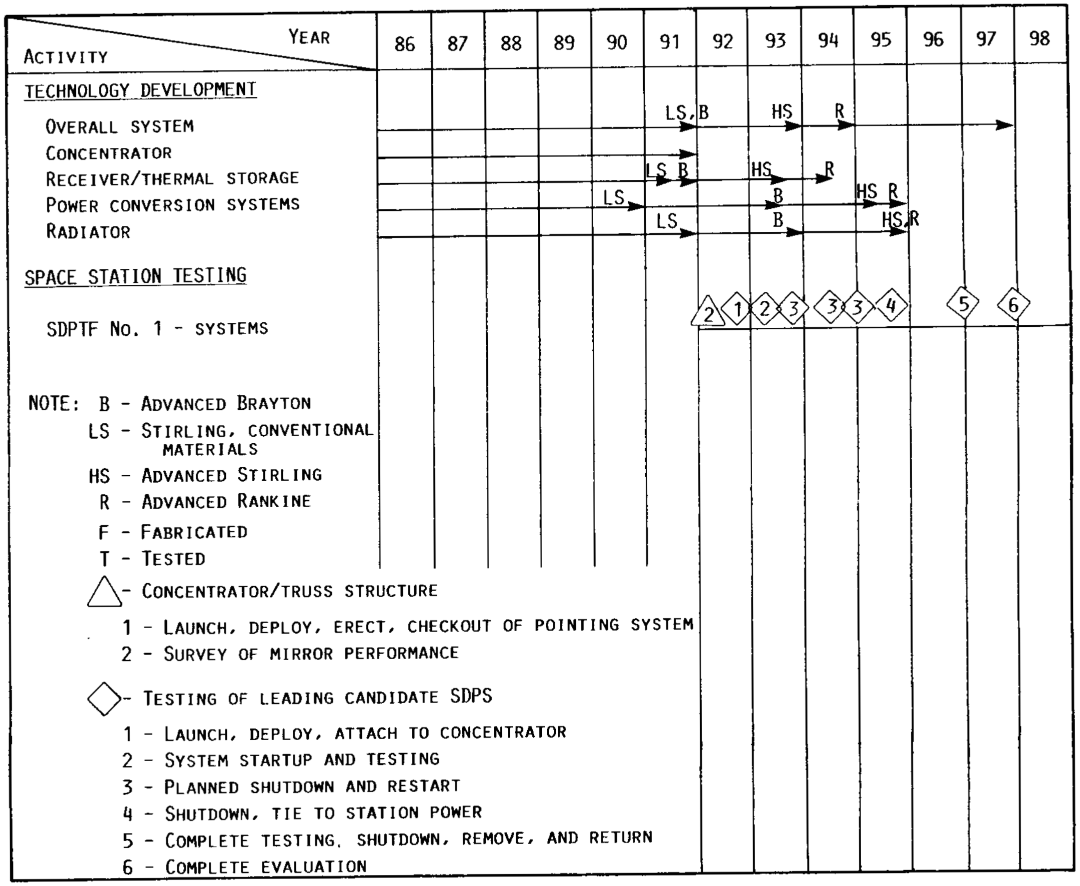


FIGURE 8-2. - OVERALL PROGRAM SCHEDULE.

9.0 CONCLUSION AND RECOMMENDATIONS:

The major conclusions resulting from this limited conceptual design effort are as follows:

- There is sufficient time to develop the critical technologies required for advanced SDPS's in the late 1990's time frame.
- Testing mirror samples in LEO, zero-g testing of thermal storage materials and container designs and two-phase flow related zero-g experiments are required to substantiate extensive ground testing.
- The present study is more of a planning exercise than a conceptual design.

The following recommendations result from the present study effort:

- A follow-on effort that stresses component design and definition of secondary components or subsystems such as pointing, control, piping, data acquisition and transmittal, etc. should be conducted.
- Use of a single SDPTF requires a location on the center line of the dual keel configuration and on the crossbeam for experiments requiring a clear view of space or the sun. An unsymmetric location of the SDPTF will require additional fuel for attitude corrections.

LIST OF REFERENCES

REF. NO.	DESCRIPTION
1.	Nainiger, Joseph J., and McKissock, David B.; "Mass, Area and Propellant Requirement Comparisons of Several Potential Growth Space Station Power Systems", PIR No. 71, October, 1984.
2.	Personal communications with the Garrett-Pneumatic Systems Division (Brayton) and LeRC (Stirling).
3.	Comparative performance of SDPS's based on preliminary analyses of J. Klann (Brayton), R. Johnson (Rankine), and R. Stochl (Stirling), of the LeRC.
4.	H. Cameron et al; "Preliminary Design of a Solar Heat Receiver for a Brayton - Cycle Space Power System", NASA TMX-2552.
5.	Personal communication: G. Yoder, Oak Ridge National Laboratory.
6.	Personal communication: R. C. Evans, NASA-LeRC.
7.	Proceedings of Symposium on "Refractory Alloy Technology for Space Nuclear Power Applications", CONF-8308130, dated January, 1984 and hosted by the Oak Ridge National Laboratory and the Department of Energy.
8.	Jeffries, Keut S.; "Optical Analysis of Parabolic Dish Concentrators for Solar Dynamic Power Systems in Space", NASA TN 87080, August, 1985.
9.	C. C. Wright and H. Bank; "The Development of an 85 KW Steam Rankine Solar Receiver".
10.	Personal communication: R. Abramczyk, Sverdrup Technology, Inc.

APPENDIX A.1

MRWG Form

NOTES:

The attached form is intended for use in input of new elements to the July 1984 version of the Space Station mission data bases. It may also be used to change the current data bases to the new format by employing the following:

- o Long narratives such as the OBJECTIVE and DESCRIPTION need not be filled in unless they are completely changed. If they remain "as is," write the word "SAME" across that field. If one or two sentences are changed, count down to the proper line on the form and fill in the changed sentences.
- o Fill in all (or as much as possible) of the sections that have been almost totally rewritten (e.g. FLIGHTS, DATA/COMMUNICATIONS, EQUIPMENT).
- o For sections with a few additional parameters, fill in those parameters (if possible) and write "SAME" across the rest of the section.
- o Please break SPECIAL CONSIDERATIONS into other narrative sections where applicable. Otherwise, use OTHER under SPECIAL NOTES.

MISSION CODE:

TDMX2153

PAYLOAD ELEMENT NAME:

SOLAR DYNAMIC POWER TESTS

COUNTRY:

USA

CONTACT:

THADDEUS S MROZ
NASA LERC
21000 BROOKPARK RD.
CLEVELAND, OHIO 44135

PHONE:

216-433-6168 (FTS-297-6168)

STATUS: 4

FLIGHTS:

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
EQUIPMENT UP (flights)	0	1	0	1	0	0	1	0	0	0
EQUIPMENT DOWN (no. of times)	0	0	0	1	0	0	1	0	0	
OPERATIONAL DAYS (per flight)	0	270	350	330	350	350	270	350	350	
OTV FLIGHTS	0	0	0	0	0	0	0	0	0	0

EARLY FLIGHT: ________

LATE RETURN: ________

OBJECTIVE:

LINE

1 PROVIDE A DEDICATED AREA ON SPACE STATION FOR TEST AND EVALUATION

2 OF CANDIDATE SOLAR DYNAMIC POWER SYSTEMS, SUB-SYSTEMS AND COMPONENTS.

3 THIS TESTING AND EVALUATION OF POWER SYSTEMS IS SEPARATE AND APART FROM

4 THE OPERATIONAL POWER SYSTEMS PROVIDING POWER TO THE STATION.

5

6

7

ORIGINAL PAGE IS
OF POOR QUALITY

DESCRIPTION:

ORIGINAL PAGE IS
OF POOR QUALITY

LINE

1 SOLAR DYNAMIC POWER SYSTEMS CONSIST OF
SOLAR COLLECTORS, HEAT RECEIVER

2 , THERMAL STORAGE CAPABILITY, DYNAMIC PO
WER CONVERSION SYSTEMS AND RAD-

3 IATORS. THE TEST FACILITIES ARE CAPABLE
OF TESTING COMPONENTS OR TOTAL

4 SYSTEMS AT POWER LEVELS OF 5 TO 20 KWe.
THE SOLAR COLLECTORS WILL HAVE

5 MANY FACETS, PERMITTING THE TESTING OF V
ARIOUS REFLECTIVE SURFACES,

6 COATINGS AND OPTICAL CONFIGURATIONS. INT
EGRATED HEAT RECEIVERS/THERMAL

7 STORAGE COMPONENTS WILL EVALUATE STORAGE
MATERIALS, TEMPERATURE AND

8 GEOMETRIES. THE LEADING POWER CONVERSION
SYSTEM WILL BE TESTED, EITHER A

9 RANKINE, BRAYTON OR STIRLING THERMODYNA
MIC CYCLE. RADIATOR TESTING

10 COULD INCLUDE TUBE AND FIN, HEAT PIPE, A
ND ADVANCED CONCEPTS. SPACE

11 STATION TESTING IS ABSOLUTELY REQUIRED S
INCE IT IS IN LEO WHERE THE

12 COMBINED EFFECT OF UV, ATOMIC OXYGEN, MI
CROMETEOROIDS, CHARGED PLASMA

13 PARTICLES AND ZERO-G ARE SYNERGISTACALLY
EVALUATED. SPACE STATION TESTS

14 WILL AID THE DEVELOPMENT AND SELECTION O
F SOLAR DYNAMIC POWER SYSTEMS.

TYPE NUMBER: 11

IMPORTANCE OF SPACE STATION: 10

NON-SERVICING OMV FLIGHTS (per year): 0

NASA Space Station Mission Data Base - Form 1 (concluded)

ORBIT

MISSION CODE:

7	0	M	X	2	1	5	3

ORBIT: 1 (If 1 is selected, skip remainder of Form 2)

APOGEE: ______ km + ______ km / - ______ km } TOLERANCE

PERIGEE: ______ km + ______ km / - ______ km } TOLERANCE

INCLINATION: ______ deg + ______ deg / - ______ deg } TOLERANCE

LOCAL TIME OF EQUATOR CROSSING NODE: ______ hr. ______ min

ASCENDING OR DESCENDING: ______

SPECIAL CONSIDERATIONS (ORBIT):

LINE

1

2

3

4

MISSION CODE: TDMX2153

POINTING/ORIENTATION: 2 (If 1 is selected, skip remainder of FORM 3)

VIEW DIRECTION: 2

If 4 selected, OTHER:

HOURS: 16

TRUTH SITES:

POINTING ACCURACY: 360 $\widehat{sec}$

POINTING KNOWLEDGE: 100 $\widehat{sec}$

FIELD OF VIEW: 90 deg

POINTING STABILITY RATE: 10 $\widehat{sec}$ per sec

POINTING STABILITY: 200 $\widehat{sec}$

PLACEMENT: 200 $\widehat{sec}$

SPECIAL CONSIDERATIONS:

LINE	
1	POINTING REQUIREMENTS ARE 16 HOURS OF FINE POINTING AND 8 HOURS OF
2	COARSE POINTING. THE TEST FACILITY WILL PROVIDE SELF-ORIENTATION VIA TWO
3	ROTARY JOINTS SIMILAR TO THE α AND β JOINTS USED TO PROVIDE POINTING
4	FOR THE IOC POWER SYSTEMS.

POWER

MISSION CODE: TDMX2153

POWER: 1

	AC	DC
OPERATING (KW):	1	
HOURS, PER DAY (OPERATING)	24	
VOLTAGE:	220/440	
FREQUENCY:	400 HZ	
PEAK (KW):	1.2	
HOURS PER DAY (PEAK)	2.5	
STANDBY POWER (KW)	1	

SPECIAL CONSIDERATIONS (POWER):

LINE	
1	ADDITIONAL POWER WILL BE REQUIRED FOR ST ARTUP. A MAXIMUM OF 3 KWe OVER A
2	24 HR STARTUP PERIOD IS REQUIRED TO PREH EAT CERTAIN SYSTEM COMPONENTS.
3	
4	

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MISSION CODE: TDMX2153

THERMAL: NONE

	ACTIVE		PASSIVE	
	OPERATIONAL	NON-OPERATIONAL	OPERATIONAL	NON-OPERATIONAL
MIN TEMP (°C)				
MAX TEMP (°C)				
MIN HEAT REJECTION (KW)				
MAX HEAT REJECTION (KW)				

SPECIAL CONSIDERATIONS:

LINE

1 THIS EXPERIMENT HAS ITS OWN RADIATOR TO REJECT WASTE HEAT FROM THE POWER

2 CYCLE. ALL POWER GENERATED WILL BE DISSI-PATED BY RESISTIVE LOADS AND

3 RADIATED TO SPACE. THIS EXPERIMENT PLACES NO THERMAL DEMANDS ON SPACE

4 STATION.

MISSION CODE: 7DMX2153

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ON-BOARD DATA PROCESSING REQUIRED: 0

If 1 (YES), this DESCRIPTION:

ON-BOARD STORAGE (MBIT): 1

STATION DATA REQUIRED:

LINE

1 A TOTAL OF 20 CRITICAL DATA POINTS SUCH AS TIME, ATTITUDE, RECEIVER T.,

2 APERTURE PLATE T., TURBINE T., TURBINE SPEED, ETC. TOTAL STORAGE-1 MBIT

COMMUNICATION LINKS:

1. **From:** Station **To:** Ground

	Digital Data	Video Data	Voice
a. Generation rate (kbps)	1.0/0.16	0	NA
b. Duration (hours)	.0014/.0003	0	
c. Frequency (per day)	48/1440	0	
d. Delivery time (hours)	0	0	0
e. Security (yes/no)	0	0	
f. Reliability (%)	90	0	
g. Interactive (yes/no)	1	0	Yes

2. **From:** Ground **To:** Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)	.15	0	NA
b. Duration (hours)	.0014	0	
c. Frequency (per day)	48	0	
d. Delivery time (hours)	0	0	0
e. Security (yes/no)	1	0	
f. Reliability (%)	99	0	
g. Interactive (yes/no)	1	0	Yes

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To: Free Flyer	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

4. From: Free Flyer
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

5. From: Station
To: Platform

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

6. From: Platform
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

7. From: Platform
To: Ground

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

NASA Space Station Mission Data Base - Form 6 (continued)

8. From: Ground
To: Platform

	Digital Data	:	Video Data	:	Voice
a. Generation rate (kbps)		:		:	NA
b. Duration (hours)		:		:	
c. Frequency (per day)		:		:	
d. Delivery time (hours)		:		:	0
e. Security (yes/no)		:		:	
f. Reliability (%)		:		:	
g. Interactive (yes/no)		:		:	Yes

9. From: Station
To: Shuttle

	Digital Data	:	Video Data	:	Voice
a. Generation rate (kbps)		:		:	NA
b. Duration (hours)		:		:	
c. Frequency (per day)		:		:	
d. Delivery time (hours)		:		:	0
e. Security (yes/no)		:		:	
f. Reliability (%)		:		:	
g. Interactive (yes/no)		:		:	Yes

10. From: Shuttle
To: Station

	Digital Data	:	Video Data	:	Voice
a. Generation rate (kbps)		:		:	NA
b. Duration (hours)		:		:	
c. Frequency (per day)		:		:	
d. Delivery time (hours)		:		:	0
e. Security (yes/no)		:		:	
f. Reliability (%)		:		:	
g. Interactive (yes/no)		:		:	Yes

COMMENTS:

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LINE	
1	VIDEO OBSERVATIONS WILL BE REQUIRED FOR
	ASSEMBLY, TEARDOWN AND REPAIRS.
2	ONBOARD DATA PROCESSING IS NOT REQUIRED.
	DATA STORAGE IS REQUIRED ONLY
3	IF DOWNLINK IS TEMPORARILY LOST. DATA WI
	LL BE CONTINOUSLY SCANNED AT 1
4	KBPS DURING STARTUP.

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EQUIPMENT

MISSION CODE: 1 D N X 2 1 5 3

MODULE CODE: 1

SHARED FACILITY CODE: 0

(If 1 is selected, list mission codes of sharing missions below:)

EQUIPMENT LOCATION:

If equipment location is:	1	2	3	4	5	6	7
	INTERNAL PRESSURIZED	EXTERNAL/ATTACHED PRESSURIZED	UNPRESSURIZED	FREE FLYER (REMOTE)	FREE FLYER (CO-ORBITING)	28.5 DEGREE PLATFORM	SUN SYNC/POLAR PLATFORM
DIMENSIONS (M)							
Length			15.3				
Width or Dia.			9.0 D				
Height (or blank)			12.0				
VOLUME (M^3)			1050.				
PKG DIMENSION (M)							
Length			12				
Width or Dia.			3.75				
Height (or blank)							
PKG VOLUME (M^3)			153				
LAUNCH MASS (KG)			1240				
ACCELERATION MAX (g)			[illegible]				

ATTACH POINTS: 1

SET UP CODE: 1 2

HARDWARE DESCRIPTION:

LINE	
1	THE DIMENSIONS AND MASS ARE FOR A 50 KWE POWER SYSTEM. THE ESTIMATED
2	VOLUMES ARE ASSOCIATED WITH ENVELOPE DIMENSIONS SUCH AS COLLECTOR
3	DIAMETER AND OVERALL LENGTH. THIS HARDWARE INCLUDES THE COLLECTOR, HEAT
4	RECEIVER, POWER CONVERSION SYSTEM, RADIATOR AND OTHER NECESSARY HARDWARE

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NASA Space Station Mission Data Base - Form 7 (concluded)

CREW

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MISSION CODE: 7DMX2123

INITIAL CONSTRUCTION/SET UP: 1 (If 0, skip to DAILY OPERATIONS)

TASK:

FINAL ASSEMBLY, ATTACHING AND ELECTRICAL
CONNECTIONS FOR POWER SYSTEM

PERIOD: 15 days

IVA TOTAL CREW TIME: 8 man-hrs

EVA PRODUCTIVE CREW TIME: 75 man-hrs

SKILLS: (See last page of Form 8 for example)

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1							
2	2						1
3					1		

DAILY OPERATIONS: 1 (If 0, skip to PERIODIC OPERATIONS)

TASK:

DAILY CHECK OF INSTRUMENT PANEL (4X).
LOG CRITICAL PARAMETERS

IVA CREW TIME PER DAY: 2 man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1							
2							1
3							

PERIODIC OPERATIONS: ____ (If 0, skip to TEARDOWN AND STOW)

TASK:

IVA OCCURRENCE INTERVAL: ________ days

CREW TIME/OCCURRENCE: ________ man-hrs

EVA OCCURRENCE INTERVAL: ________ days

PRODUCTIVE CREW TIME/OCCURRENCES: ________ man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1							
2							
3							

TEARDOWN AND STOW: 1 (If 0, skip this section)

TASK:

REMOVAL OF POWER SYSTEM AND STOWAGE FOR TRANSPORT TO EARTH

PERIOD: .5 days

IVA TOTAL CREW TIME: ________ man-hrs

EVA PRODUCTIVE CREW TIME: 38 man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1							
2	2						
3							

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COMMENTS:

LINE

1 THE POWER SYSTEM IS DESIGNED FOR AUTOMAT
ED UNATTENDED OPERATION. REPAIR

2 AND/OR SERVICING IS NOT A SCHEDULED OPER
ATION. EVA IS REQUIRED FOR

3 INSTALLATION, REMOVAL OR COMPONENT CHANG
EOVER.

4

Typical example of skill type/level matrix input:

Skill Types

1. No Special Skill Required
2. Medical/Biological
3. Physical Sciences
4. Earth and Ocean Sciences
5. Engineering
6. Astronomy
7. Spacecraft Systems

Skill Levels

1. Task Trainable
2. Technician
3. Professional

If two medical/biological professionals are required, put 2 in second column, third row. No more than 6 skill types can be used for a given task.

NASA Space Station Mission Data Base - Form 8 (concluded)

SERVICING

MISSION CODE: TDNX2153

SERVICING: 2 (If 1 is selected, skip remainder of Form 9)

SERVICE INTERVAL (days): UNSCHEDULED

CONSUMABLES

TYPE:

HELIUM AND XENON FOR GAS MANAGEMENT SYSTEM.

WEIGHT: 100 kg

RETURN: 50 kg

VOLUME UP: 0.3 m^3

VOLUME DOWN: 0.3 m^3

POWER: 0 kw

HOURS FOR POWER: 0 hrs

EVA HOURS PER SERVICE: 2 hrs

TYPICAL TASKS (EVA):

REPLACE GAS BOTTLES.

IVA HOURS PER SERVICE: ______ hrs

LOCATION OF SERVICING: ______

TYPICAL TASKS (IVA):

SPECIAL CONSIDERATIONS:

LINE

1 THE ABOVE SERVICING IS FOR A BRAYTON OR STIRLING SYSTEM TEST. A RANKINE

2 TEST MAY REQUIRE SERVICING OF A LIQUID METAL PURIFICATION SYSTEM.

3

4

CONFIGURATION CHANGES

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MISSION CODE: TCMX2153

CONFIGURATION CHANGES: 2 (If 1 selected, skip the remainder of Form 10)

INTERVAL: 500/2000 days

CHANGE-OUT EQUIPMENT

TYPE:

THERE ARE TWO TYPES OF CHANGEOUT, COMPON-
ENTS AND COMPLETE SYSTEMS.

WEIGHT: 500/2000 kg

RETURN: 500/2000 kg

VOLUME UP: 400/1250 m^3

VOLUME DOWN: 400/1250 m^3

POWER: 2 kw

HOURS FOR POWER: 24 hrs

EVA HOURS PER CHANGE: 20/60 hrs

TYPICAL TASKS (EVA):

REMOVE AND REPLACE COMPONENTS OR REMOVE
AND REPLACE SYSTEM.

IVA HOURS PER CHANGE: ________ hrs

LOCATION: ________

TYPICAL TASKS (IVA):

SPECIAL CONSIDERATIONS:

LINE

1

2

3

4

SPECIAL NOTES

MISSION CODE: TCM-2153

CONTAMINATION:

LINE	
1	CONTAMINATION OF COLLECTOR AND RADIATOR SURFACES WITH HYDROCARBONS,
2	WATER, ETC. COULD AFFECT THE PERFORMANCE OF THESE COMPONENTS.

STRUCTURES:

LINE	
1	THE DYNAMIC CHARACTERISTICS OF SPACE STATION MAIN STRUCTURE SHALL BE LOW
2	ENOUGH AS NOT TO INTERACT WITH POWER SYSTEM POINTING CAPABILITY

MATERIALS:

LINE	
1	MATERIALS WILL BE DESIGNED FOR THE LEO ENVIRONMENT.
2	

RADIATION:

LINE	
1	EFFECT OF RADIATION IS PART OF TEST ASSESSMENT.
2	

LINE SAFETY:

1 THE PROCEDURES FOR STARTUP AND SHUTDOWN WILL HAVE BEEN DEVELOPED AND

2 EARTH TESTED TO DEMONSTRATE SAFETY.

LINE STORAGE:

1 NO SPECIAL REQUIREMENTS.

2

LINE OPTICAL WINDOW:

1 NOT REQUIRED.

2

LINE SCIENTIFIC AIRLOCK:

1 NOT REQUIRED.

2

NASA Space Station Mission Data Base - Form 11 (continued)

LINE TETHER:

1

2

LINE VACUUM VENTING:

1 SMALL AMOUNTS OF HELIUM OR XENON MAY BE RELEASED TO SPACE.

2

LINE OTHER:

1

2

3

4

NASA Space Station Mission Data Base - Form 11 (concluded)

APPENDIX A.2

TDAG Form

SOLAR DYNAMIC POWER TEST FACILITY

TECHNOLOGY EXPERIMENT DESCRIPTION

PROPOSER: NAME: Thaddeus S. Mroz

ADDRESS: Mail Stop 301-5
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

PHONE: (216) 433-6168

TDAG CONTACT: NAME: Dr. Robert M. Stubbs

ADDRESS: Mail Stop 501-15
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

PHONE: (216) 433-6303

TDM CATEGORY: TECHNOLOGY DEVELOPMENT

MRWG NO.: TDMX 2153

GENERAL

1. Briefly describe the mission objective.

The overall objective of this technology development mission (TDM) is to provide a dedicated area on space station for test and evaluation of advanced solar dynamic power systems, sub-systems and components. The test facility shall be capable of testing complete systems or components in the power range of 3 to 20 kWe output. The mission goal is to develop solar dynamic power systems in the 3 to 300 kWe power range for NASA missions beyond the 1992 time frame.

2. What are the potential benefits?

Solar dynamic power systems (SDPS) offer significant advantages over photovoltaic (PV) power systems because of higher overall system efficiency. The potential benefits of the SDPS are as follows:

(1) Collection areas are reduced by a factor of 4-5
(2) The system mass is reduced by a factor of 2
(3) Orbit life in LEO is increased over missions using PV systems or reduced fuel requirements for orbit maintenance
(4) Reduced cost of power system

3. Why is Space Station necessary for accomplishment of the objectives? Specifically, what Space Station characteristics are essential or highly beneficial?

The Space Station is necessary to provide long duration operation of SDPS's in the combined environment of LEO. It is only on Space Station where the synergistic effects of ultraviolet radiation, atomic oxygen, charged plasma particles, micrometeoroids and zero-g can be evaluated. Space Station testing of SDPS's will provide for their final development and demonstration of their advantages.

4. How is the experiment related to ongoing or planned programs?

The OAST is supporting a planned program to develop the advanced technology for solar dynamic power systems over the power range of 3 to 300 kWe for NASA missions beyond 1992. The Space Station program is planning a focused technology program on solar dynamic power systems in the 20-40 kWe range for growth Space Station. Both R & T programs on solar dynamic power systems are being conducted at LeRC. Close coordination will prevent any duplication of effort. The solar dynamic power test facility will provide a dedicated test area to both programs.

5. Describe the experiment. What do you propose to do, how, and when? (Include suggested flight dates and time phasing rationale.)

A schematic drawing of the Solar Dynamic Power Test Facility (SDPWT) is shown under Item 6. The dimensions shown are representative of a 20 kWe advanced Brayton power system. The SDPTF's will be designed to test components, sub-systems or complete SDPS's over a power range of 3 to 20 kWe. Shown in Item 6 are the major components of a SDPS and include the concentrator, heat receiver and thermal storage, dynamic power conversion system, regenerator and radiator. Other components or sub-systems not shown but essential to a SDPS include structure, pointing system, control system for the power conversion system (PCS), power management and distribution system (PMAD), inventory control system for the working fluid, piping or ducting, data acquisition and transmittal and data storage. It is planned to utilize Space Station power for operation and control of all SDPS tests. All power generated by SDPS will be dissipated in (Resistance) and radiated by a high temperature radiator.

The primary structure of the SDPTF is the deployable collector truss structure and pedestal attachment to the Space Station. The parabolic collector surface will be made up of many hexagonal facets of the proper contour. Each facet will have been focused on earth prior to launch and will be located into position by EVA. The power range will be achieved by shading or defocusing a suitable number of facets.

Major components of a SDPS will be replaceable by designing suitable mechanical joints into the system. The proper orientation of the components will require secondary structure tieing the components to the primary structure.

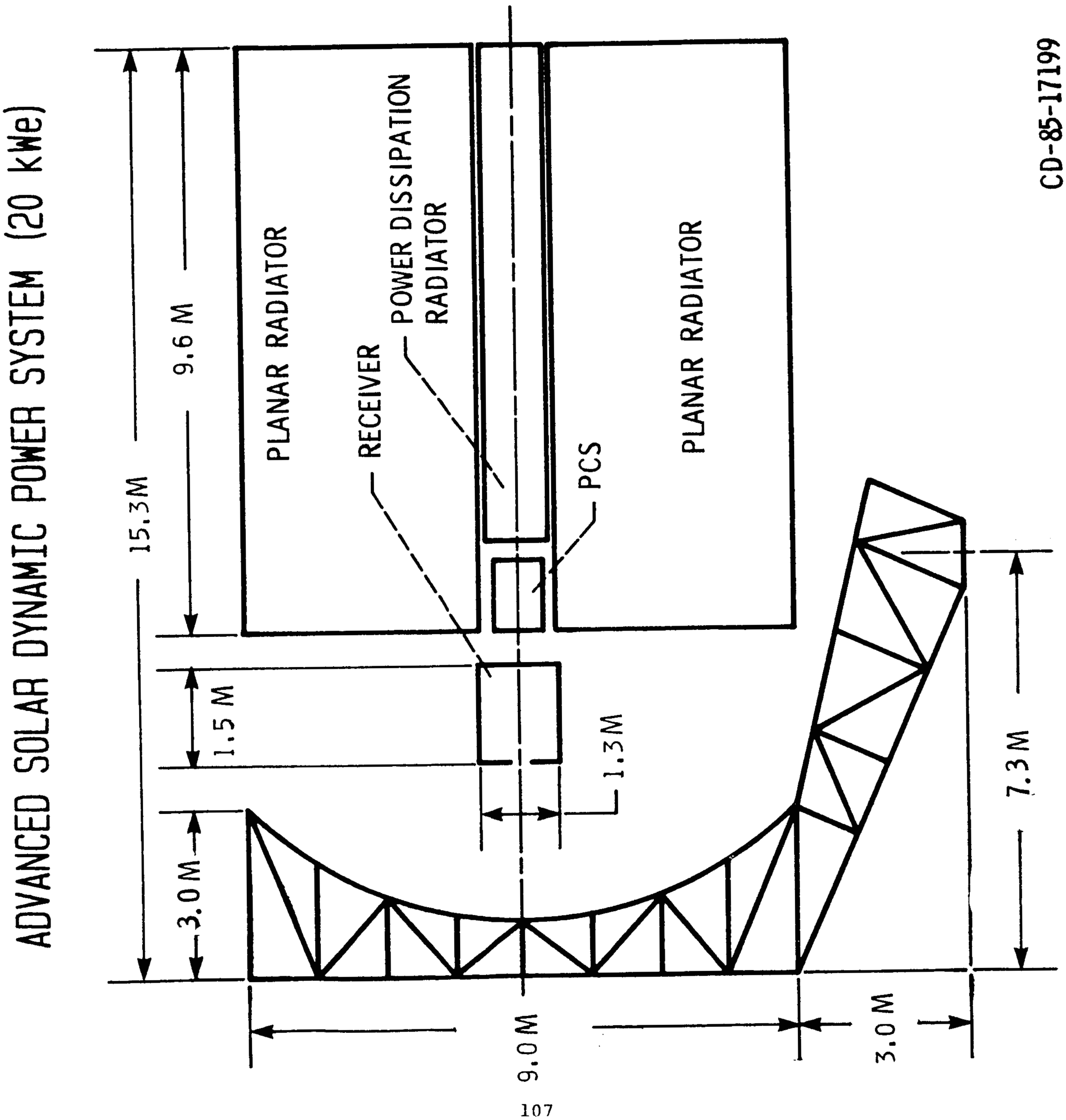
The location of the SDPTF on Space Station must meet certain minimum requirements. The SDPTF must be capable of the following:

- Must have a clear unobstructed view of the sun.
- Must be capable of accurate pointing at the sun ($\pm$ 0.1^{o}). Two degrees of pointing freedom are required similar to that provided by the α and β joints for the IOC power systems.
- Must provide a non-contaminating environment.
- Since the SDPTF has a substantial mass and drag, it should be located on a line of symmetry such as the earth pointing centerline of the space station.

The ideal location for the SDPTF appears to be the crossboom, which provides experiments an unobstructed view of space and at the above described centerline.

There are three advanced power conversion systems which may be developed for future applications; the Free Piston Stirling Engine (FPSE), the closed cycle Brayton, and the liquid metal Rankine, all operating in the 1100 to 1400K temperature range. The PCS with the most potential (maximum efficiency, least weight) will be selected for long time endurance testing of the SDPS. A backup PCS will be developed and be available in the event of unsolvable technology problems. The SDPTF will also expose small concentrator and radiator samples to the LEO environment. Samples will be periodically removed and returned to earth for evaluation.

6. PROVIDE A SKETCH OF THE EXPERIMENT INCLUDING APPROXIMATE DIMENSIONS.



7. Provide an equipment list including approximate dimension and weights as available.

Equipment	Length (m.)	Width or Dia. (m.)	Height (m.)	Weight (kg)
Collector & Truss Structure	7.3	9.0	12.0	136
Receiver & Thermal Storage	1.5	1.3	---	318
Power Conversion System	1.5	0.8	---	82
Radiator	9.6	8.0	---	367
Structure	TBD	TBD	---	64
Power Dissipation Radiator	6.0	1.2	---	50
Recuperator	1.2	0.6	0.9	159
Pointing system Controls Piping Data Acquisition, Storage & Transmission	TBD			64
			TOTAL	1240

ORBIT CHARACTERISTICS

8. What properties of the orbit are especially important to your mission and why? (Plasma density, earth distance, etc.)

The synergistic effect of UV, atomic oxygen, micrometeoroids, charged plasma particles and zero-g is required to determine the performance and life characteristics of solar dynamic power systems. Of particular concern is the collector and radiator and the combined effect of UV, atomic oxygen and micrometeoroids on reflectivity and emissivity of surfaces and coatings. The impact of microgravity on thermal storage materials and two phase working fluids is also of concern.

POINTING/ORIENTATION

9. Why have you chosen a particular view direction? Is it a requirement?

Pointing the collector at the sun is an absolute requirement. The operation of a solar dynamic power system depends on accurate pointing of the collector at the sun during the sun portion of the orbit.

10. Is the experiment capable of providing self-orientation? Describe equipment and procedures.

It is planned to locate the solar dynamic power test facility at the centerline of the space station attached to the boom which provides an unobstructed view of space for various experiments. The attachment will provide for pointing in the α' and β' planes, similar to the α and β joints provided for the IOC power systems.

11. If Space Station were oriented in a direction other than your desired orientation, how would your experiment be affected?

The solar dynamic power test facility provides for self-orientation within design limits. Small misorientations of Space Station (0-5^{o}) should not affect the experiment at all. Large misorientations of the Space Station which cannot be corrected by the experiment's pointing system will result in a shutdown of the experiment.

12. List components requiring electrical power and the desired operating levels of power and voltage.

Item	Voltage (V)	Power (W)	AC/DC
Data Communications	NC	250	NC
Control System	NC	250	NC
Pointing Drives (two 1/4 HP motors)	NC	400	NC
Valves	NC	100	NC
Auxilliary Equipment	NC	200	NC
TOTAL	1 SYS	1200	---

a NC - Not Critical. Design will conform to power availability on Space Station

b Auxilliary Equipment includes valve actuators, instrumentation, pointing system, and electronic components

STARTUP: Resistance heating heat receiver, turbine housing, regenerator and intervening ducting requires 3 KW for 24 hours.

Motoring of Alternator - .75 KW for 1/2 hour

13. Could you use power distributed in the following conditioned forms? Why or why not?

YES	NO		Circle Preference
___	✓	High frequency AC	20 KHz, Other ________
✓	___	Low frequency AC	60 Hz, 400 Hz
✓	___	DC	28V 120V 270V

There are no electrical components used in the power system which could utilize the high frequency AC power.

14. What special power conditioning requirements do you have?

Filtering and regulation will be required for electronic components (i.e., microprocessor, data/communications system) for precision control of voltage levels.

15. Sketch typical load profiles for power usage:

STARTUP:

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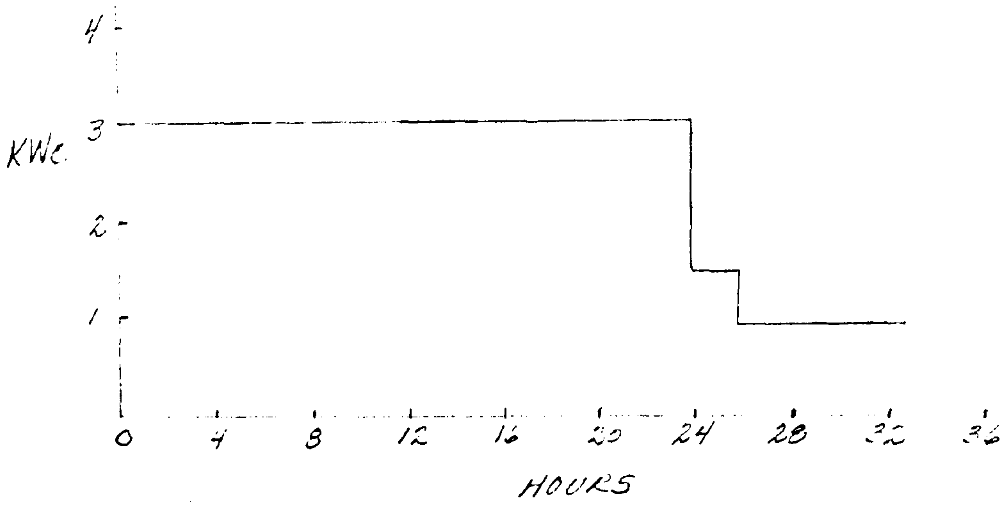
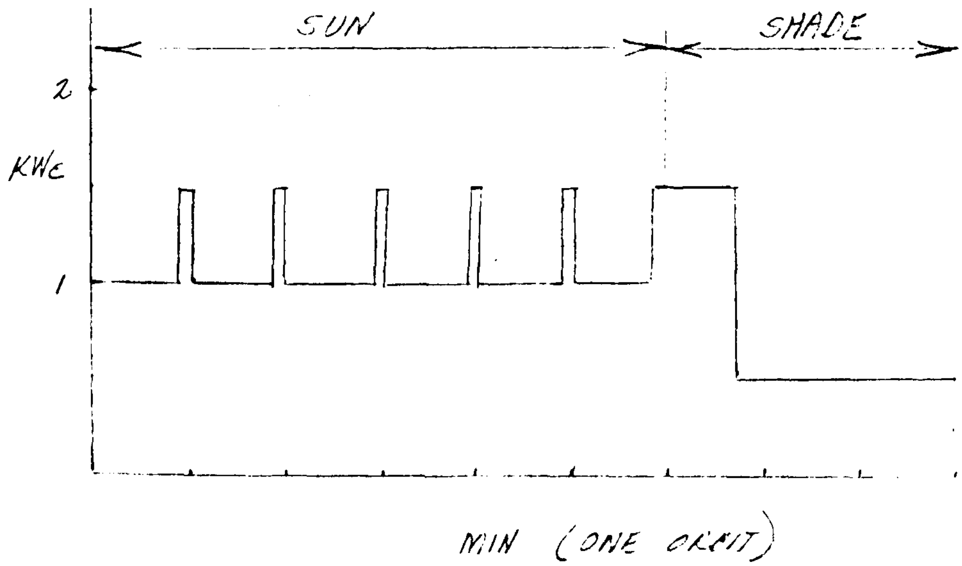


CONTINOUS OPERATION



16. Describe standby operations. What are the consequences of an interruption of electrical power?

During standby, approximately 1.0 KW is required to provide for an emergency shutdown of the power system. Emergency shutdown consists of placing the collector into a safe attitude relative to the sun so that any reflection of the solar insolation will be directed back into space without intercept by any part of the Space Station.

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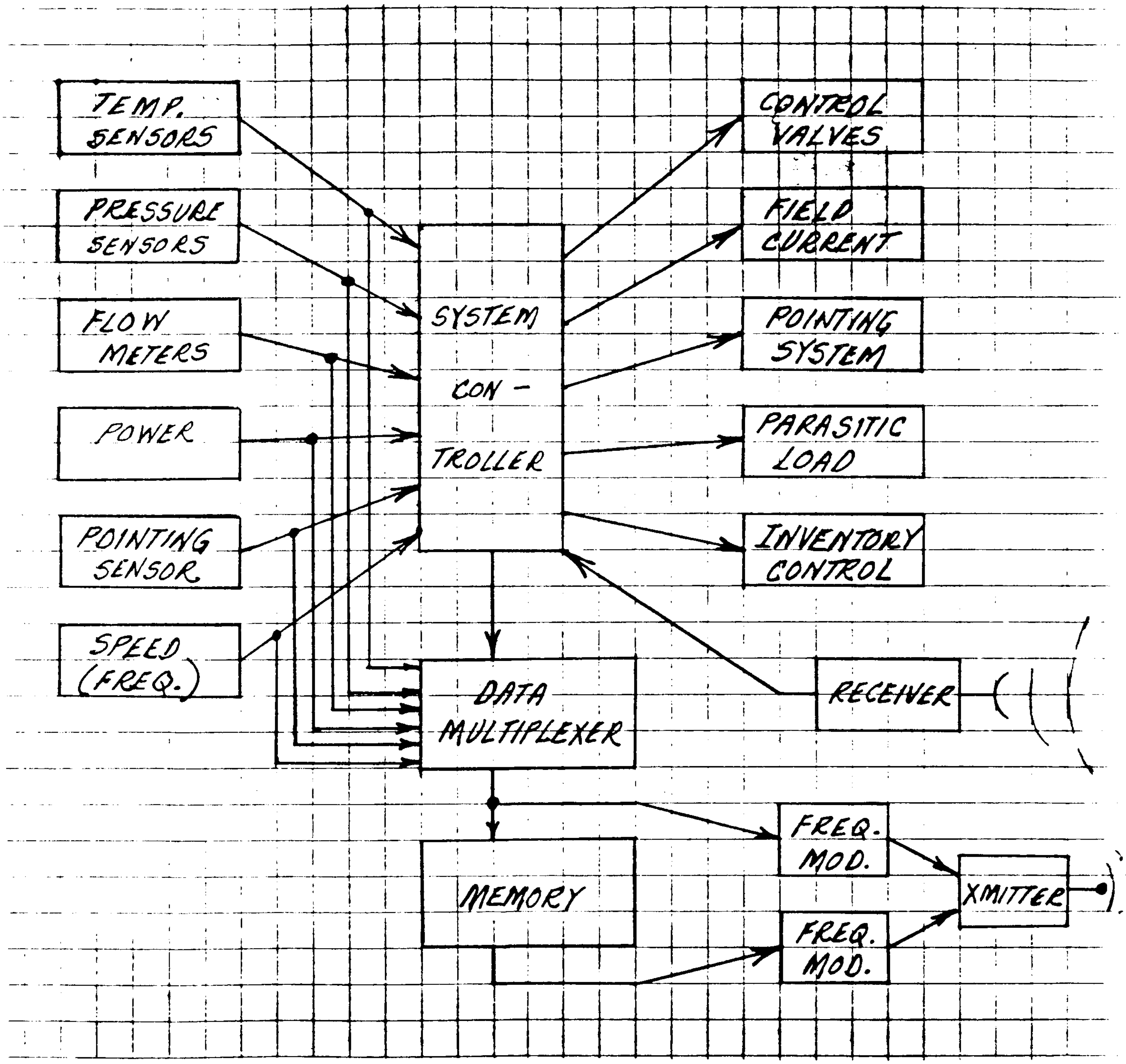
17. Sketch the experiment electrical system in block diagram form.



SOLAR DYNAMIC POWER SYSTEM
ELECTRICAL BLOCK DIAGRAM

DATA/COMMUNICATIONS

18. Describe what you want to do with the uplink and the downlink.

Uplink is required to perform the following tasks:

(1) command for startup and shutdown of experiment,
(2) command for manual override of microprocessor,
(3) control to adjust power levels, and
(4) command for Data Dump of Stored Data.

Downlink is required to perform the following tasks:

(1) real time data monitoring,
(2) Data Dump of Stored Data, and
(3) feedback of Command and Control instructions.

19. Describe specific monitoring needs, both on-board and ground based. (i.e., visual observation of deployment by shuttle crew, monitoring of experiment peformance parameters by ground crew, etc.)

Monitoring of the experiment may be implemented by means of:

(1) digital data from instruments (i.e., thermocouples, pressure transducers, flowmeters, and radiometers), and controls (i.e., valve positions, linear actuator positions, component power inputs,
(2) video observation of initial buildup and startup, and
(3) voice communication between ground station and Space Station experiment operating crews.

Duplicate monitoring of critical data by ground station and Space Station is desirable.

20. Describe data transmission and storage needs, including the nature of the information and rationale for on-board storage.

Both real time and stored data are desirable. Real time data is necessary for remote manual control of experiment (i.e., to adjust power levels speed, etc.). Stored digital data will be needed to cover the portion of the orbit in which communication blackout occurs or should data transmission to earth be interrupted.

THERMAL

21. Identify major sources of heat and describe heat rejection provisions. (Include operating temperatures of specific components and estimated loads.)

The solar dynamic power system is based on various thermodynamic cycles (Brayton, Rankine and Stirling) which utilize high temperature to achieve high efficiency. The approximate temperatures and heat loads on various components of the Brayton and Rankine SDPS's are summarized as follows:

COMPONENT		BRAYTON
Heat Receiver:		
	TMAX - ^{o} F	1600^{o} F
	Q -	113 KW Hr.
	HEAT TRANSFER COOLED BY WORKING FLUID.	
Turbine:		
	TMAX - ^{o} F	1500^{o} F
	Q -	25 KW OF MECHANICAL ENERGY IS CONVERTED TO 20 kWe.
Recuperator:		
	TMAX -	1070^{o} F
	Q -	25 KW Hr.
Radiator:		
	TMAX	390^{o} F
	Q	60 KW Hr.

22. What special interfaces with Space Station will be required for adequate thermal control? (i.e., low temperature requirements, extremely uniform temperature, etc.)

No special interfaces with the Space Station for thermal control are anticipated at this time; however, a detailed thermal analysis will be performed to substantiate this premise.

23. Identify problems that may occur with:

(a) Overheating

Significant overheating of the heat receiver could only occur if the mass flow of the working fluid was significantly below the design value. Overheating of the Rankine working fluid could result in overpressurization of the loop and excessive temperatures on various components. However, safety controls will prevent any pressure and temperature excursions via automatic shutdown of the SDPS.

(b) Overcooling

Overcooling could result in freezing of the Rankine working fluid, a liquid metal. However, it will be possible to restore the fluid to its original state since it is planned to pre-heat the SDPS for startup using Space Station electric power.

EQUIPMENT PHYSICAL CHARACTERISTICS

24. Describe critical aspects of location on or within Space Station related to:

(a) Viewing angle

The concentrator must have a clear view of and be accurately pointed at the sun at all times. Fine pointing will be self-contained within the SDPS experiment.

(b) G-level

The experiment will be designed for a zero-g environment.

(c) Thermal control

The experiment will have a self-contained thermal control system. No special interfaces with the Space Station for thermal control are currently anticipated.

(d) Contamination

A remote location on the Space Station where contamination of the SDPS experiment is minimized is recommended.

(e) Servicing and Resupply

No special servicing or resupply requirements are anticipated.

(f) Accessibility

The area should be readily accessible for EVA.

(g) Other

None

25. Describe requirements to go from shuttle stowed to Space Station operational. (i.e., self-contained, self-deployed, located in lab module, etc.)

The steps required to go from shuttle stowed to Space Station operational are:

(1) Move all components from the shuttle cargo bay to a staging area near the attachment point.
(2) Deploy the collector truss structure, lock and attach to the Space Station.
(3) Complete the electrical connection to Space Station.
(4) Deploy and attach facets to collector truss structure.
(5) Deploy heat receiver, power conversion system and piping and attach to collector truss via suitable structure.
(6) Deploy radiator and make final connections of piping.
(7) Complete all remaining electrical connections.

26. Describe Space Station integration requirements such as attachments, ports, supply lines and storage, etc.

SDPS/Space Station integration requirements will include:

(1) a structural attachment point for the truss structure of the concentrator pedestal,
(2) a source of electrical power for the experiment,
(3) digital data transmission lines, and
(4) a control room to monitor the experiment and record data.

No special storage requirements are anticipated.

27. If a remote location is desired, explain why.

A remote location is required because of the size of the SDPS experiment, the need for continuous pointing toward the sun, and the need to be contaminant free.

28. Describe special environmental requirements. (i.e., pressurization, temperature, etc.)

It is anticipated that all environmental requirements for the SDPS experiment will be self-contained, and will only require a source of electrical power from the Space Station.

CREW REQUIREMENTS

29. Describe the nature of crew assignments during operation and standby.

During standby, crew assignments will probably be limited to:

(1) correcting any component malfunctions identified during the operation of the experimental system, and
(2) taking necessary action to put system back in a startup readiness mode in the event of an interruption in electrical power.

During operation, the Space Station crew would provide assistance to the Ground research crew in monitoring startup, operation, and shutdown to insure proper operation of the SDPS experiment.

30. Describe specific tasks related to deployment and retrieval.

During deployment, crew EVA tasks will be limited to implementing structural and electrical attachments of the SDPTF to the Space Station, and final installation of plumbing connections between major components. The anticipated EVA's are as follows:

- Deploy collector truss structure, lock and attach to Space Station.
- Deploy and lock facets in place on collector structure.
- Check operational capability of pointing drives.
- Deploy Heat Receiver and PCS module; position with secondary structure.
- Deploy radiator sections; make final piping connections.
- Inject working fluid and check connections for leakage.
- Deploy and attach radiator for dissipating electric power.
- Make all electrical connections.

Checkout of system will be programmed from earth. Shutdown and removal will involve a reverse procedure.

31. Describe crew activities that would be performed on a routine basis for maintaining operational status.

Routine crew activities would be limited to periodic calibration of instrumentation, maintenance of electronic systems, and repair or replacement of faulty components.

SERVICING

32. Describe the nature of consumables and returnables desired, and the frequency resupply and return.

There are no planned consumables in any of the solar dynamic power systems. However, the working fluid of each system is pressurized and should leaks occur would require replacement after repair of leaks.

33. What special attachments or spatial allocations will be necessary for storage of consumables?

None

CONTAMINATION

34. What contaminants may be released by the experiments? (i.e., gaseous products, particulates, etc.)

Contaminants may be released from either the Brayton, Rankine or Stirling solar dynamic power systems due to leakage, as part of a startup procedure or required because of thermal degradation. Release of contaminants due to leakage is not anticipated. It is expected that the Brayton power system may release small amounts of He and Xe as part of a startup procedure.

35. What contaminants would detrimentally affect the experiment? (i.e., from thruster effluent, ECLS waste, etc.)

Any contaminant emanating from the Space Station including thruster effluents or environmental control and life support system wastes that might coat the surfaces of the collector and radiator and affect the performance of these components. The collector is designed to provide high reflectivity and will be coated to protect the surface from attack by atomic oxygen and UV. Hydrocarbon deposits or other contaminants could affect the coating and alter the reflectivity. Similarly, deposits could affect the emissivity of the radiator surface and coating. It is essential that the solar dynamic power test facility be placed on Space Station where contamination is at a minimum.

SAFETY

36. Are there any specific safety requirements or hazards?

In an emergency shutdown or a normal startup of the SDPS, there is a transition from pointing the collector at the sun to pointing away from the sun or vice versa. During this transition, the concentrated solar insolation must walk across the face of the heat receiver and any other components until a safe attitude is reached. Walk-on and walk-off will be designed for and demonstrated as a safe operation. However, failure to move to a safe attitude could result in failure of the power system and extensive contamination of the test area.

SPECIAL CONSIDERATIONS

37. Identify other unique features of the experiment that are important for Space Station design and operation.

None

FLIGHT PROCURSORS

38. Identify ground, shuttle, or other flight precursors which might be performed prior to Space Station implementation.

Current R & T plans include technology development of lightweight, deployable concentrators, heat receiver/thermal storage components and heat pipe radiators. PCS technology is at a mature state except for Stirling which is being developed on the SP-100 program. Technology development in each area will include design, fabrication of candidate designs, testing, modification and evolution of candidate components.

In parallel with the above developments will be certain critical zero-g experiments on the shuttle or as free flyers to get early confirmation of design approaches. One major concern is the control of void formation in thermal storage materials during the melt/freeze cycle in zero-g. A second concern deals with the synergistic effect of UV, atomic oxygen, micrometeoroids and charged plasma particles on the thermal performance of coatings, reflective surfaces and radiating surfaces.

Ground and zero-g testing of components will lead to ground testing of systems, definition of all procedures and selection of candidate systems for Space Station testing.

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15. Supplementary Notes

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16. Abstract

This study provides an initial conceptual definition of a technology development mission for advanced solar dynamic power systems, utilizing space station to provide a dedicated test facility. The advanced power systems considered included Brayton, Stirling, and liquid metal Rankine operating in the temperature range of 1040 to 1400 K. The critical technologies for advanced systems were identified by reviewing the current state of the art of solar dynamic power systems. The experimental requirements were determined by planning a system test of a 20 kWe solar dynamic power system on the space station test facility. These requirements were documented via the Mission Requirements Working Group (MRWG) and Technology Development Advocacy Group (TDAG) forms. Various concepts or considerations of advanced concepts are discussed. A preliminary evolutionary plan for this technology development mission was prepared.

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