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ELECTRICAL POWER SYSTEM DESIGN FOR THE U.S. SPACE STATION

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SUMMARY

The multipurpose, manned, permanent Space Station will be our next step toward utilization of space. A multikilowatt electrical power system will be critical to its success. The power systems for the Space Station manned core and platforms that have been selected in definition studies are described in this paper. The selected system for the platforms uses silicon arrays and $Ni-H_2$ batteries. The power system for the manned core is a hybrid employing arrays and batteries identical to those on the platform along with solar dynamic modules using either Brayton or organic Rankine engines. The power system requirements, candidate technologies, and configurations that were considered, and the basis for selection, are discussed.

BACKGROUND

The Space Station Phase B Program was initiated in 1984. Since then, NASA and its contractors have been involved in the definition and preliminary design of the Space Station in order to establish with confidence the cost, schedule, and performance before proceeding to hardware development. The Space Station Program involves the Space Station itself, which is the manned core, a polar orbiting unmanned platform, and a co-orbiting unmanned platform. Lewis has the responsibility for the electrical power system (EPS), and, along with its two contractors - Rocketdyne and TRW, conducted extensive technical and cost trade studies to arrive at an EPS design definition for the station manned core and platforms. This paper addresses the resulting baseline EPS design, as of the time of writing. Continuing trade studies and the preliminary design activity will, of course, provide updates to this design.

Figure 1 shows the station manned core concept. The EPS physical size makes it a principal feature of the station manned core geometry and a significant factor in mass, stability and control, and cost. The large, multipurpose, evolutionary nature of the Space Station program imposes requirements on the EPS that are unique among space power systems. It must be userfriendly and adaptable to a changing and evolving set of requirements. Thus, it must be more like a terrestrial utility power system rather than the typical fixed-purpose, dedicated, spacecraft power system. The general power requirements for the EPS are shown in table I. (Note: Power levels on this table, and throughout this paper, are given in kWe to the user, after distribution losses.)

To meet these requirements, a variety of options for the power generation subsystem, electrical storage subsystem, and power management and distribution (PMAD) subsystem were evaluated against a set of programmatic and technical considerations. Some of these considerations are shown in table II.

Numerous technology options were available in each subsystem area. Evaluation of these options was difficult, as might be imagined, because of variations in technology status and experience. A primary driver in the evaluation was the need to have low initial cost for the EPS. The technology had to be mature enough to have hardware available on schedule for launch, without, however, becoming rapidly obsolescent or suffering high life-cycle costs. Weight was of extreme importance for the platform EPS. This influenced the commonality trades between the station manned core and platforms. During the design definition phase, the requirements of the program were also being refined and changed, hence the considerations of table II were changing. An important part of the design and cost definition effort was the evaluation of the interactions between requirements and specific designs, and the resulting impact on Initial Operating Capability (IOC) costs.

Photovoltaic subsystems with electrochemical storage, solar dynamic subsystems with thermal energy storage, or a combination of both -- a hybrid -- were the major options considered for power generation and storage. The constraints of schedule (IOC date of 1994), necessity to minimize IOC costs, development risk, and level of power requirements precluded the use of nuclear power systems. Frequency, voltage, and architecture for the PMAD subsystem were also important options requiring careful evaluation. Some of the technology trades for these options are described below.

PHOTOVOLTAIC TECHNOLOGY TRADES

Solar Cell

For rigid planar and flexible planar-type arrays, detailed solar cell trades were performed. Development status and achieved performance levels were carefully evaluated to insure that selected technology would be mature by 1988 to 1989, the time at which fabrication of the IOC arrays would start. The full range of options for silicon cells was considered with sizes up to 10 by 10 cm; thickness up to 12 mil; back surface fields and reflectors; IR reflectors; IR transparent; and fused silica, ceria-doped, and microsheet coverglass. Based primarily on costs (evaluated at the cell, array, and total program level, including IOC and end-of-life), the selection was: silicon wrap-through cell, 8 by 8 cm size, 8 mil thick, IR transparent BSF (for flexible arrays), with 6 mil ceria-doped coverglass. The wrap-through contacts reduce array assembly and cost, and the gridded back (which allows IR to be transmitted through the cell and Kapton substrate) yields lower temperature and higher efficiency. There is, of course, extensive experience with silicon cells on spacecraft and an established capability to manufacture cells with efficiencies of 14 percent. Cells of 8 by 8 cm size are currently in pilot production. Gallium arsenide cells do offer higher efficiencies, but after early evaluation were not considered cost effective for planar arrays when compared to silicon cells (i.e., current and projected practical efficiencies and production costs did not yield a favorable trade to silicon).

Solar Array

A number of different array structural concepts were evaluated. After early screening, two types were considered prime candidates: (1) erectable or deployable rigid planar and (2) deployable flexible planar.

The most attractive concept for the solar array is the accordion-folded flexible blanket supported by a deployable mast. A high degree of confidence was established in this concept by the OAST-1 experiment (fig. 2) flown in 1984 on orbiter flight STS-41D. The 13-ft wide, 105-ft long array, built by Lockheed Missiles and Space Company, consisted of 84 hinged panels. The panel substrate was a double layer of Kapton, with the cells welded to a printed circuit on the Kapton. In the experiment, only three panels contained solar cells, and the other panels contained dummy cells for mass simulation. The successful four extension and retraction cycles showed the array was generally predictable, well behaved dynamically, and the solar cells were not damaged.

The flexible array has several important advantages over rigid arrays. It is lighter in weight than a rigid array (of vital concern to the platform), has convenient deployability and retractability, and the Kapton substrate is transparent, hence permitting use of solar cells that transmit infrared radiation (thus increasing their efficiency). Kapton, however, has been found to have a very limited life, if unprotected, in the atomic oxygen environment found in low Earth orbits. For this reason, protective coatings for Kapton are now under development in the Space Station Advanced Development Program, and a number of promising coatings have been identified, several of which are in commercial production. Rigid arrays would be the backup concept if Kapton cannot be made sufficiently insensitive to atomic oxygen or if increased array stiffness for the station were required. Currently, however, the flexible array design meets the stiffness requirements imposed by present overall Space Station structural dynamic design characteristics.

The final selected array wing design for both the station manned core and platform has two flexible blankets (using coated Kapton) that are supported by a deployable/retractable center mast. Each blanket would be stored in a container/cover assembly.

Electrochemical Storage

Energy storage is required for eclipse. It is also required for contingency purposes to provide power in the event of a station manned core malfunction that precludes power generation for one orbit (e.g., loss of station orientation). Two levels of contingency on the station manned core were examined. In one case, 37.5 kWe for one full orbit was assumed. In the second case, the inherent energy capability residing in the energy storage system was defined as the contingency capability. It was this later case which was finally baselined, since it provided sufficient power for expected contingencies. Options examined included regenerative fuel cells, nickel-cadmium batteries, and nickel-hydrogen batteries.

The RFC concept is shown schematically in figure 3. Excess electrical energy from the solar array is stored chemically by generating hydrogen and oxygen from water in the electrolyzer. Electricity is generated by recombining the stored hydrogen and oxygen. A high degree of flexibility is inherent in this approach. Changes in energy storage requirements (input and/or output) are easily accommodated by changes in the size of the storage tanks. The RFC system is significantly lighter than battery systems, but is not as efficient nor as reliable. The fuel cell module shown in figure 3 is based on NASA-sponsored improvements to the International Fuel Cells Corporation technology currently in use on the STS orbiter. The electrolysis module is based on the alkaline static-feed technology under development by Life Systems, Inc. with support from NASA. Reliability of the complex RFC system was considered a major problem in the platform trades (with the requirement of 3 yr on orbit before replacement or servicing) and was the primary reason for concentrating on batteries for platform use. For the station manned core, the RFC design was modularized into a number of orbital replacement units (ORU's) and redundancy was incorporated (weight not being as critical as on the platform) to achieve the required reliability.

Nickel-cadmium batteries were considered a prime candidate for energy storage. Their technology is well-established and mature. They currently provide energy storage for the majority of spacecraft, and they are produced in sizes up to 100 Ah in aerospace cell configurations. They have a long history of successful performance, although at low depth-of-discharge (DOD) levels, thus have a correspondingly high mass penalty. Development risk for the nickel-cadmium battery assembly, however, was considered very low.

Two nickel-hydrogen battery options were considered: (1) the Individual Pressure Vessel (IPV) nickel-hydrogen battery type and (2) the bipolar nickel-hydrogen battery type. The IPV nickel-hydrogen system is currently in use in spacecraft in geosynchronous Earth orbit (GEO). Space-qualified cells are available in cell sizes up to 50 Ah cell capacity and diameters of 3.5 in. Figure 4 shows the Intelsat V battery composed of 30 Ah nickel-hydrogen cells made by Eagle Picher Corporation. For station manned core and platform use in low Earth orbit (LEO), there are considerably more charge/discharge cycles per year than in GEO. Endurance testing for the LEO regime has been initiated to verify five year life. Because higher cell capacity would reduce weight and cost, development effort is under way on increased capacity cells, using straight-forward extrapolation of existing components. Successful fabrication of single-stack 4.5-in. diameter cells has already been completed. The bipolar nickel-hydrogen system is also currently being developed. Demonstrations of subscale hardware and battery stacks have been accomplished. However, due to its low technical maturity, it was not carried into the final trade studies.

IPV nickel-hydrogen batteries were finally selected for the platform, based on considerations of weight, cost, reliability, and development risk/schedule. Their weight was about 50 percent of the nickel-cadmium battery weight and they were much lower in overall cost.

Based on inherent contingency for the station manned core, IPV nickel-hydrogen batteries were also selected. They yielded slightly lower costs than for the RFC system, at IOC, while only being slightly higher in 30-yr life cycle cost. Their use would permit commonality between the platform and station. The extent of commonality, whether at the technology, development, cell, battery, and/or thermal control level, will be determined in the preliminary design activity. Such commonality is considered extremely important to reducing development, logistic, and sparing costs.

SOLAR DYNAMIC TECHNOLOGY TRADES

While the photovoltaic technology is, in general, well-proven in space, solar dynamic (SD) technology offers advantages of efficiency and cost. The efficiency advantage derives from the higher efficiency of the engine (20 to 30 percent) as compared to silicon solar cell efficiency (about 14 percent), and the higher efficiency of thermal energy storage (over 90 percent) as compared to battery efficiencies of around 70 to 80 percent and regenerative fuel cell efficiencies of about 55 percent. The improved system efficiency of solar dynamic (SD) systems as compared to photovoltaic (PV) systems translates into less solar collection area, which results in reduced drag and less concern regarding station dynamics, approach corridors, and experiment viewing angles. The reduced drag is particularly important because it allows lower flight altitudes within given constraints of drag-makeup fuel and orbit decay time.

Two types of dynamic conversion cycles were considered: (1) the closed Brayton cycle (CBC) and (2) the organic Rankine cycle (ORC). The ORC system is shown schematically in figure 5. A parabolic mirror focuses the sun's rays through aperture of the heat receiver. Within the receiver, the concentrated solar flux vaporizes the organic working fluid (e.g., toluene). The hot vapor goes to the turboalternator at about 750 °F and after condensation is recycled by the pump. Within the receiver, there is a need for thermal energy storage to get through the eclipse period. Typically, salt (e.g., LiOH) is considered. This salt would melt during the sun period and would solidify during the shade period, heating the working fluid as it solidified.

In the CBC system, helium-xenon gas mixture is used as the working fluid in place of the organic fluid. Since the fluid remains a gas in all regions of the flow loop, the pump becomes a compressor, there is no condensation required, and there are no potential low-gravity problems as might be the case for the ORC system which has both gas and liquid in its flow loop. The inlet temperature, however, of the gas to the turbine is considerably higher for the CBC system (about 1300 °F).

Because solar dynamic systems have not been used in space, there is higher risk in assessing costs, schedules, and power availability than for PV systems. There is, nevertheless, a strong technology base for the engines from terrestrial and aeronautical applications. ORC units in sizes from a few kilowatts of power to several hundred kilowatts have been used in numerous terrestrial applications. Three kilowatt units with Dowtherm A as the working fluid have accumulated over 150 000 hr of operation. Units of various sizes using toluene have accumulated over 100 000 hr. The applicable experience base for Brayton units (not closed cycle) include the hundreds of millions of hours of operating experience with aircraft gas turbine engines. Aircraft environmental control system turbine expanders using gas lubricated foil bearings have accumulated millions of hours of operating experience. These are similar in size to the turbine and gas bearing units evaluated for the station solar dynamic subsystem. Of particular significance, the NASA space power program in the 1960's achieved over 50 000 hr of test time (38 000 hr on one unit) for a space-designed, closed-cycle Brayton system using helium-xenon working fluid and gas-lubricated bearings. This unit was also tested in a complete flow loop system under space-simulated thermal vacuum conditions.

Receivers

The receiver, including the thermal energy storage, is a critical unit in the solar dynamic system. Some relevant experience was gained in 1962 by fabrication of a complete receiver for the NASA-Brayton space power system. A successful test of three gas tubes with surrounding lithium fluoride thermal storage material was completed.

For the station, the receiver for a 25 kWe solar dynamic subsystem will be 2 to 3 m in diameter and length, depending on the type of system, salt, and particular design. Concepts from the definition studies are shown in figures 6 (CBC) and 7 (ORC). The primary difference between the two designs is the use of a heat pipe concept, in the ORC case, to protect the toluene working fluid from hot spots that would cause thermal decomposition and breakdown of the toluene.

The Brayton cycle receiver concept shown in figure 6 is a cylindrical cavity lined with a series of tubes, running the length of the cavity, through which the working fluid (He/Xe) flows. Thermal energy storage (TES) is provided by a melting/freezing salt enclosed in a series of annular shaped metallic containment rings surrounding the working fluid tubes. Currently, the salt selected is a eutectic mixture of lithium fluoride and calcium fluoride. The compartmentalization of the salt in the rings localizes the void formation on freezing so as to better maintain the desired heat transfer and reduce wall stresses due to salt expansion during melting. The cavity walls consist of high temperature insulation which reradiates the incoming energy to the back side of the tubes. Multifoil insulation surrounds this wall structure.

The organic Rankine cycle receiver shown in figure 7 utilizes axial heat pipes with integral TES. Heat pipes are used to provide heat flux leveling to accommodate solar flux maldistributions that could cause localized hot spots that would degrade the temperature sensitive organic working fluid (toluene). The heat pipes maintain a uniform, constant cavity temperature and a uniform temperature around the TES material (in this case, lithium hydroxide). The vaporizer consists of parallel flow tubes that run axially inside the heat pipes. They are manifolded together at the inlet and outlet of the heat pipes and contain an orifice at the inlet to impose a large pressure drop, relative to the vaporizing section, to preclude flow imbalances. Under normal insolation, the concentrated solar flux is distributed over the length of the heat pipes, with higher heat loads at the end nearest the aperture. The heat pipe working fluid, potassium, is vaporized and distributes uniform heat to the cooler vaporizer and TES modules by condensing at these surfaces. The TES modules remain at a relatively constant temperature as latent melting occurs. During eclipse, solidification of the salt becomes the energy source and heat is transported away from the TES modules to the vaporizer tubes by the potassium.

Currently, while preliminary design has been initiated on these two concepts, there is continuing effort to evaluate other promising concepts. And, under the Space Station Advanced Development Program, work is under way both analytically and experimentally to address critical areas of the receiver design.

Concentrator

The technology base for the mirror concentrator is also more limited than for engines. There has been experience in terrestrial programs sponsored by the Department of Energy, but the mirrors were much more heavily constructed since they had to withstand wind and gravity loads. The lightweight concentrating mirror for a space SD system can draw, however, upon the large space antenna technology.

During the definition studies, two basic concentrator concepts were selected for in-depth evaluation, after early screening of a variety of concepts: (1) single reflection (Newtonian) and (2) multiple reflection (Cassegrainian). The Newtonian concept has had the most attention for terrestrial applications due to its simplicity. The Cassegrainian has been fabricated and successfully used in terrestrial applications, also. Both types have been used in space rf antenna designs. The Cassegrainian optical configuration was ultimately dropped from consideration, however, because of the need for a second reflector surface with attendant optical reflectivity losses, possible shadowing losses, possibility of increased pointing errors (or need for increased stiffness), and need for secondary mirror cooling (increased complexity).

For the Newtonian system, a special case was examined and ultimately baselined. This was the offset reflector (fig. 8). It consists of a segment of the parent paraboloid, with a relatively short focal length, and mounted offset from the parent parabolic axis. The receiver is tilted with respect to the parent paraboloid axis to optimize the receiver cavity heat flux distribution. This concept has been successfully used in rf antenna applications and has significant reduced structural weight and moment of inertia advantages over other concepts. The major disadvantage of this concept appears to be unsymmetrical fluxes within the cavity of the receiver.

One critical area of the SD concentrator involved definition of the gimbaling system. The mirror must be pointed to the sun with an accuracy of 0.1°, a value much tighter than for PV arrays. Pointing and tracking control, structural dynamics, and gimbal system design all play a role in achieving the required accuracy. A number of gimbal concepts were evaluated. The one finally selected involved the use of linear actuators incorporated into two of the three concentrator surface support struts for fine pointing, along with use of alpha and beta gimbals.

The design definition for the concentrator structure and reflective surface also involved examination of a large number of concepts. The approach selected consisted of a graphite-epoxy truss framework configured as a hexagonal panel that comprises a section of the paraboloidal curve along its surface. This provides a support structure for a number of triangular graphite-epoxy facets which are configured with a spherical surface. The graphite-epoxy facesheet of each facet is coated with vapor-deposited silver or aluminum along with a protective coating. Seventeen (CBC) to nineteen (ORC) hexagonal panels comprise the total concentrator surface. The panels are stacked for delivery to orbit and deployed to form the parabolic surface. Panel alignment is achieved with latching mechanisms at each panel interface. A subscale model of this panel, deployment, and latching concept has been demonstrated.

Current Status

Both CBC and ORC power generating subsystems are being carried forward into preliminary design. Performance and cost of the two are very close. Only through a more detailed evaluation can a decision between the two be made.

The CBC subsystem concept includes the receiver as shown in figure 6, an offset concentrator of graphite epoxy construction composed of individual hexagon panels with mirror facets on each panel, a rotating unit with a radial flow turbine and compressor, gas lubricated foil bearings, and a Rice-Lundell-type alternator. At the time of writing this paper, both segmented pump loop and multiple heat pipes were candidates for the radiator, and further analysis will be required for selection. The working fluid is helium-xenon gas.

The ORC concept includes the receiver as shown in figure 7, an offset concentrator, an axial flow turbine driving a Rice-Lundell alternator and pitot pump, with tilted pad bearings lubricated by the toluene working fluid. The radiator is a heat pipe concept (aluminum with ammonia). After examination of a number of working fluids, toluene was selected. Within the engine, there is a Rotary Fluid Management Device (RFMD) which is basically a low-speed pitot pump. It must operate in low gravity to ensure NPSH at the feed pump inlet, to separate noncondensable gases, and to control working fluid inventory. The condenser is a shear-controlled design utilizing converging passages to maintain adequate velocity and operation in low gravity.

POWER MANAGEMENT AND DISTRIBUTION TRADES

The power management and distribution (PMAD) subsystem has the general characteristics of a terrestrial utility power system. It must be user-friendly and accommodate changes in load type and size. Also, it must be adaptable to growth. The high power level (75 kWe initially, with growth capability to 300 kWe) dictates a higher distribution voltage than the 28 V commonly used on spacecraft. Distribution voltages up to 440 V were considered in the definition studies. A range of frequencies were also studied. The principal candidates ended up as 20 kHz ac, 400 Hz ac, and dc. The dc approach has the advantage of familiarity, but ac offers greater flexibility (ease of providing different voltages) and is easier to switch than dc (the switching for ac can be accomplished at zero current). While 28 Vdc components do exist, such components at 150 Vdc and higher, designed for space (hence high efficiency), are lacking in technology.

400 Hz is commonly used on aircraft, thus systems-level technology exists. However, technology is lacking for space-type components, although this is not considered a major problem. But, 400 Hz has a potential problem with acoustic noise and electromagnetic interference (EMI), particularly with respect to plasma coupling which can impact a number of plasma experiments planned for the station.

The 20 kHz high power, sine wave system has never been flown, but this concept is extremely attractive. Due to the high frequency, components are small, lightweight, and highly efficient, particularly when using series resonant conversion in dc/ac, ac/dc, dc/dc, or ac/ac converters. Space-type components have been designed and tested. A breadboard system has been demonstrated. No problems with acoustic noise exist, and the EMI is considered a minor problem. At the time of writing this paper, the voltage and frequency selection has not been made, and both 400 Hz and 20 kHz are being further evaluated.

Electrical System Architecture

The electrical distribution architecture for the station manned core is shown in figure 9. A dual-ring bus system provides utility power to each of ten external load areas on the upper keel and boom, lower keel and boom, and transverse boom. Each bus is rated for 15 kW. Utility power to the ring distribution system is controlled by the Main Bus Switching Assembly (MBSA) and interfaces to the load through a Power Distribution and Control Assembly (PDCA). Each PDCA is rated at 10 kW and can support up to 20-load connections. Critical loads can be connected to multiple outlets for reliability.

The architecture for the electrical distribution system to the manned modules is shown in figure 10. Each of the four modules will be supplied through two penetrations. Transformers are used at the module penetration port to provide isolation for a single point ground. Presently, each bus is rated at 30 kW. The distribution within the modules is also by a dual ring architecture. Loads within each module will receive utility power from a PDCA (total of five PDCA's in each U.S. module to accommodate up to 50 kW of load).

The PMAD system will have a control system for sensing and command. In the event of a fault in the ring distribution system, Remote Bus Isolators (RBI's) located in the MBSA's and PDCA's will remove the faulted section and restore power through alternate connections. If faults occur in the loads, Remote Power Controllers (RPC's) within the PDCA's will sense the fault and act to protect the power system.

The electrical distribution architecture for the platforms is similar to the above described station manned core architecture, with the exception being the use of a radial bus architecture rather than a ring bus.

SYSTEM STUDIES

Six basic cases were studied for the station manned core, as indicated in figure 11. Both the 75 kWe IOC configuration and the 300 kWe growth configuration are shown. The cases range from all PV (Case 1) to a case with maximum SD (Case 6), with varying proportions of SD to PV for Cases 2, 3, 4, and 5. A number of variations were also evaluated for each case to evaluate commonality. For example, Cases 5 and 6 are shown with platform arrays, but Cases 3 and 4 were also evaluated with platform arrays in addition to the larger, more optimum arrays as shown. An all SD case, with no PV array system, was not considered practical. Power is needed during station manned core assembly when sun tracking is not easily accomplished (up to about the fourth launch). Only PV arrays can produce power (although at a reduced level) in such circumstances.

In the final evaluation, an attempt was made to identify all factors impacting cost and translate them into total cost of the program for the combined station manned core and platform. Both IOC cost and life cycle costs were evaluated. Included were power system hardware and software development, manufacturing, verification, overhead, and launch costs. The cost benefit to station manned core operation with increased shuttle capacity was also estimated for the SD systems, as would occur due to lower orbit altitude permissible with the SD systems which have lower drag. There was a considerable reduction in life-cycle costs credited to SD systems due to this effect.

The selected station manned core configuration was Case 5. The PV subsystem generates nominally 25 kWe using four platform wings and uses nickel-hydrogen batteries identical to those used on the platform. The SD subsystem generates nominally 50 kWe (the exact value depends on the preliminary design and the exact PMAD efficiencies). The SD power generation would be either a Brayton or Rankine system, dependent on results of the preliminary design effort. Either would use the off-set concentrator concept previously described.

CONCLUSION

The selected electrical power system meets the station and platform requirements for both IOC and growth. Indeed, it offers a balanced utility approach to the uncertainty associated with future loads. There will be more loads which are larger in power requirements and of different nature from those currently planned for the station and platform at IOC. The subsystem selections are based on a combination of minimum IOC costs and life cycle costs, along with low development and schedule risk. The selected hybrid system appears to best meet the programmatic and technical considerations driving the power system definition.

TABLE I. - POWER REQUIREMENTS

	Power to user, kWe	
	Average	Peak
Station manned core - IOC	75	100
Growth	300	350
Polar platform - IOC	8	16
Growth	15	24
Co-orbiting platform - IOC	6	6
Growth	23	23

TABLE II. - PROGRAMMATIC/TECHNICAL CONSIDERATIONS

Initial cost	Schedule
Life-cycle cost	Orbit altitude and decay
Development risk	Growth capability
Commonality	Contingency requirement
Weight	Load types and location
Maintainability	Logistics and sparing
Failure criteria	Orbital assembly & buildup
Safety	Interfaces
Verification	Lifetime

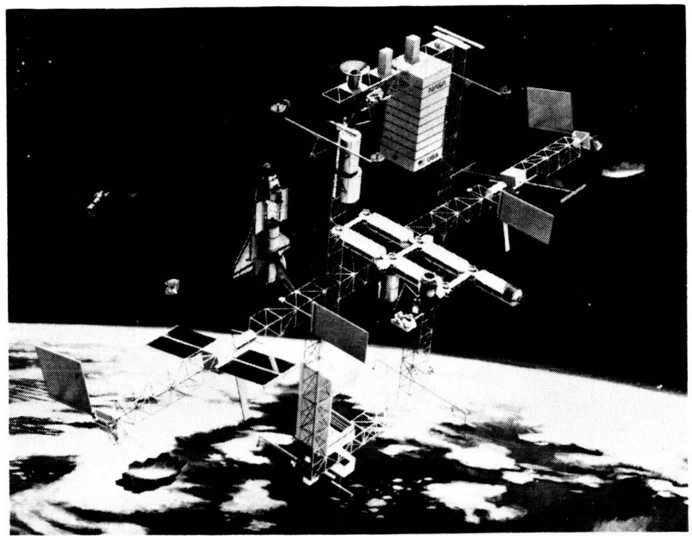

FIGURE 1. - DUAL-KEEL SPACE STATION CONCEPT.

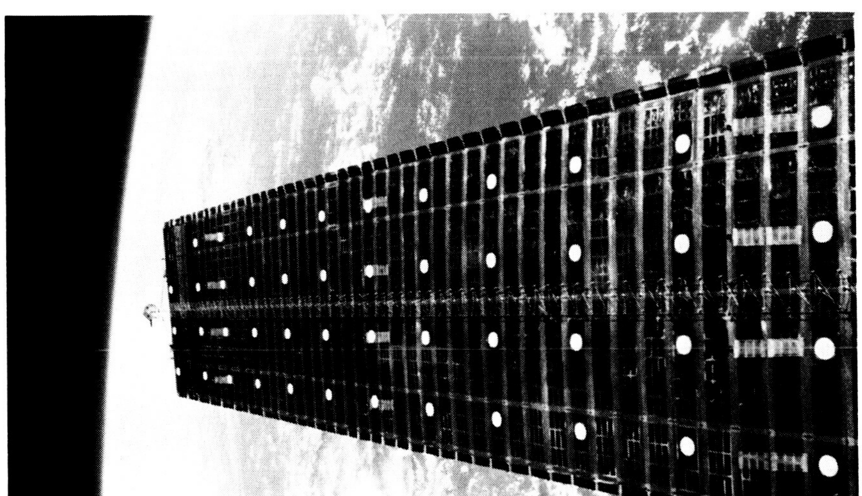

FIGURE 2. - OAST-1 ARRAY.

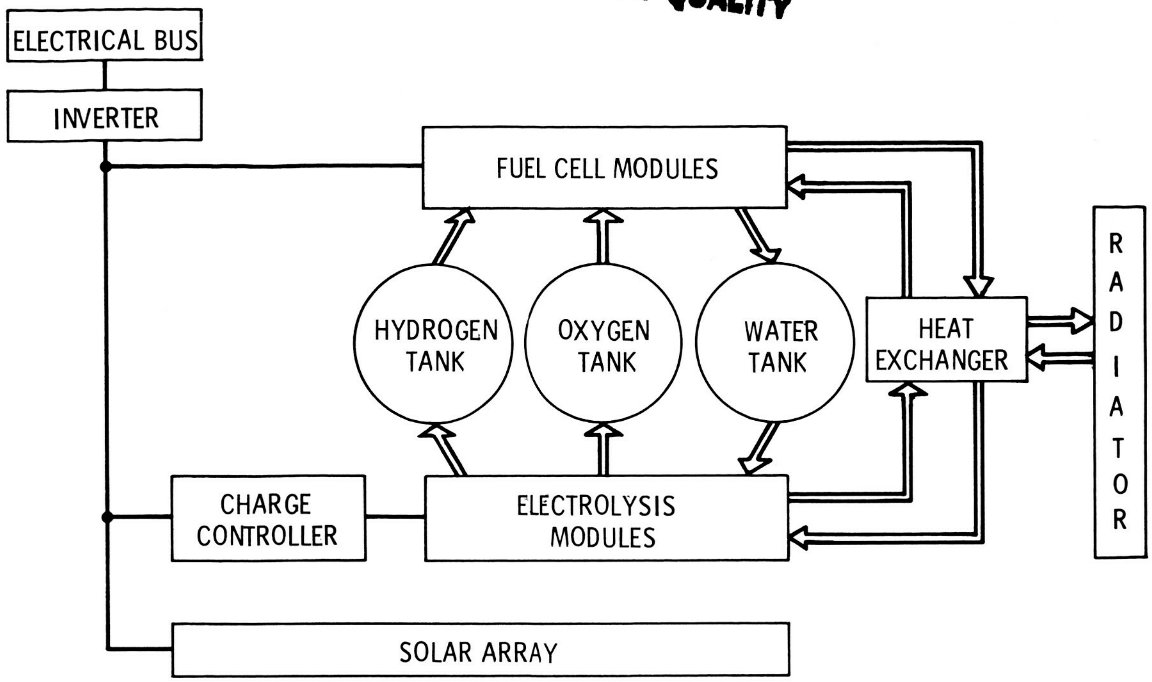

Figure 3. - Regenerative fuel cell schematic.

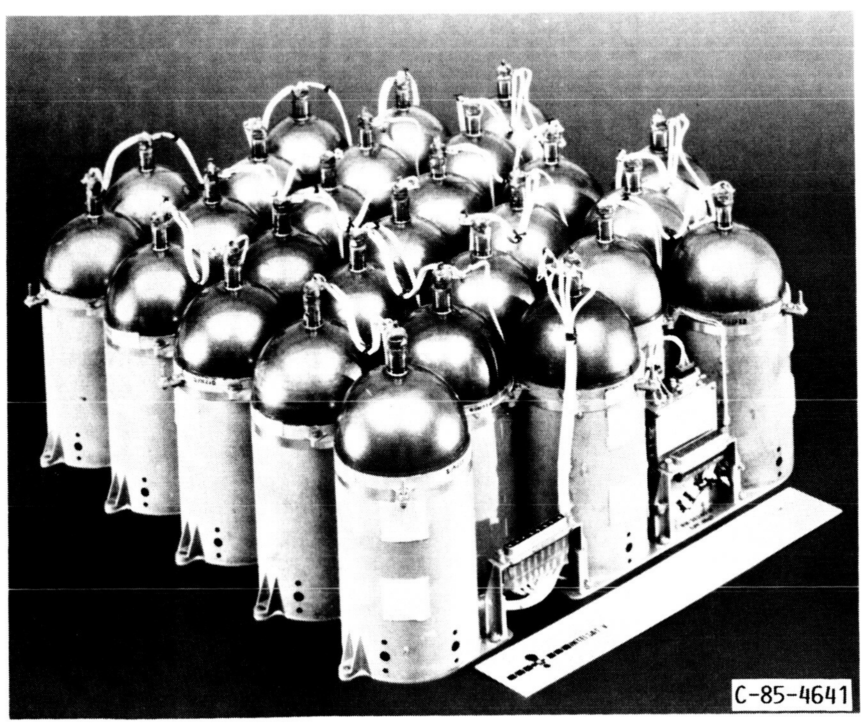

FIGURE 4. - INTELSAT V Ni-H_2 BATTERIES.

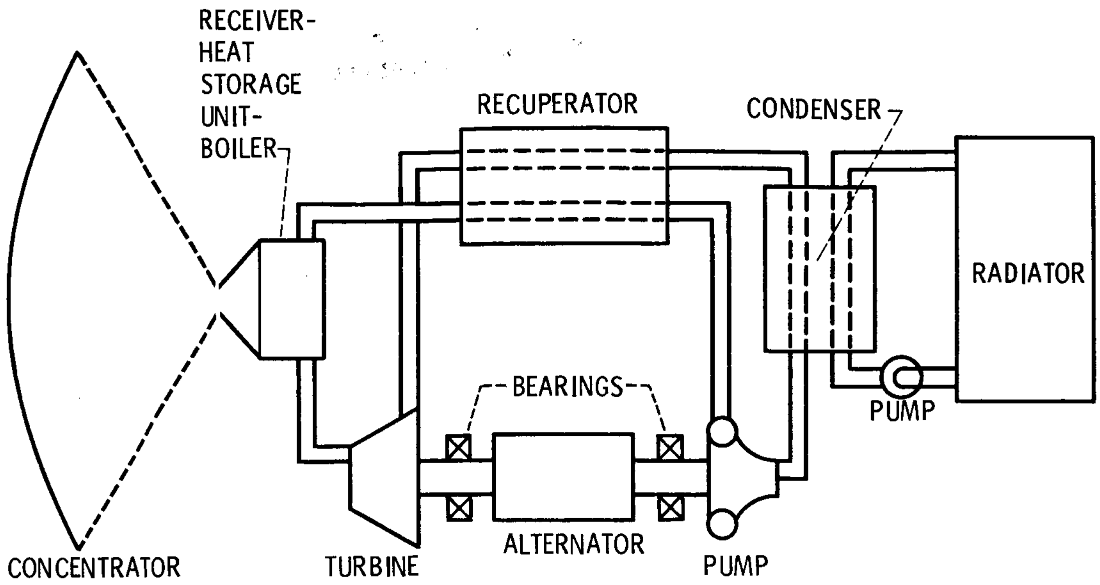

Figure 5. - Solar organic Rankine cycle system schematic.

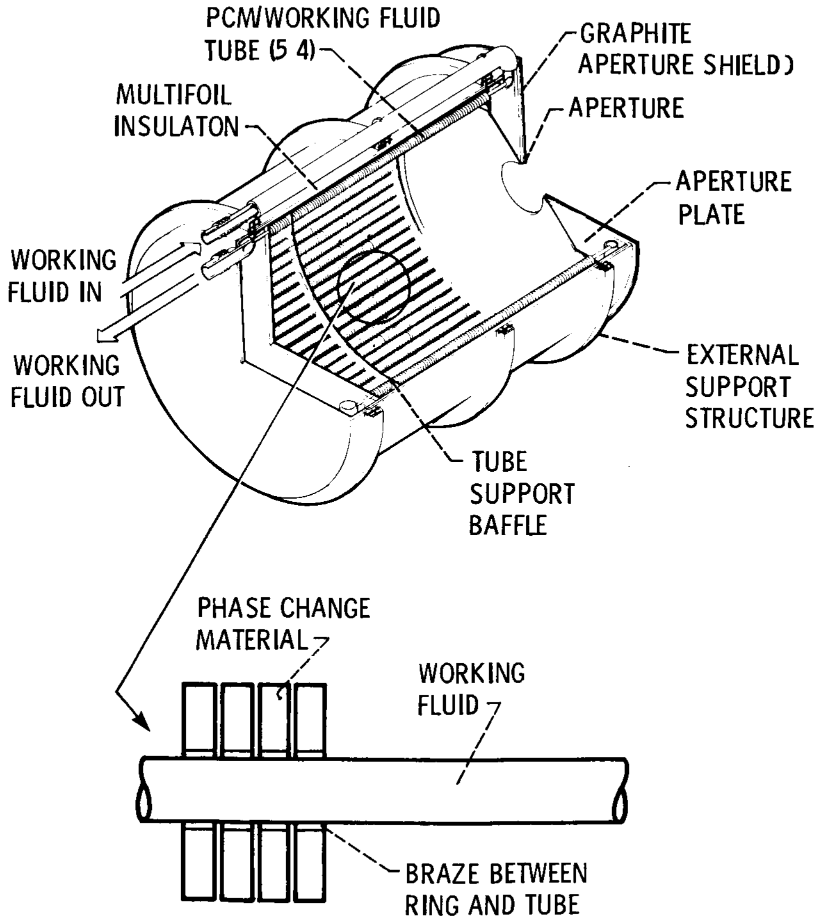

Figure 6. - Brayton receiver concept.

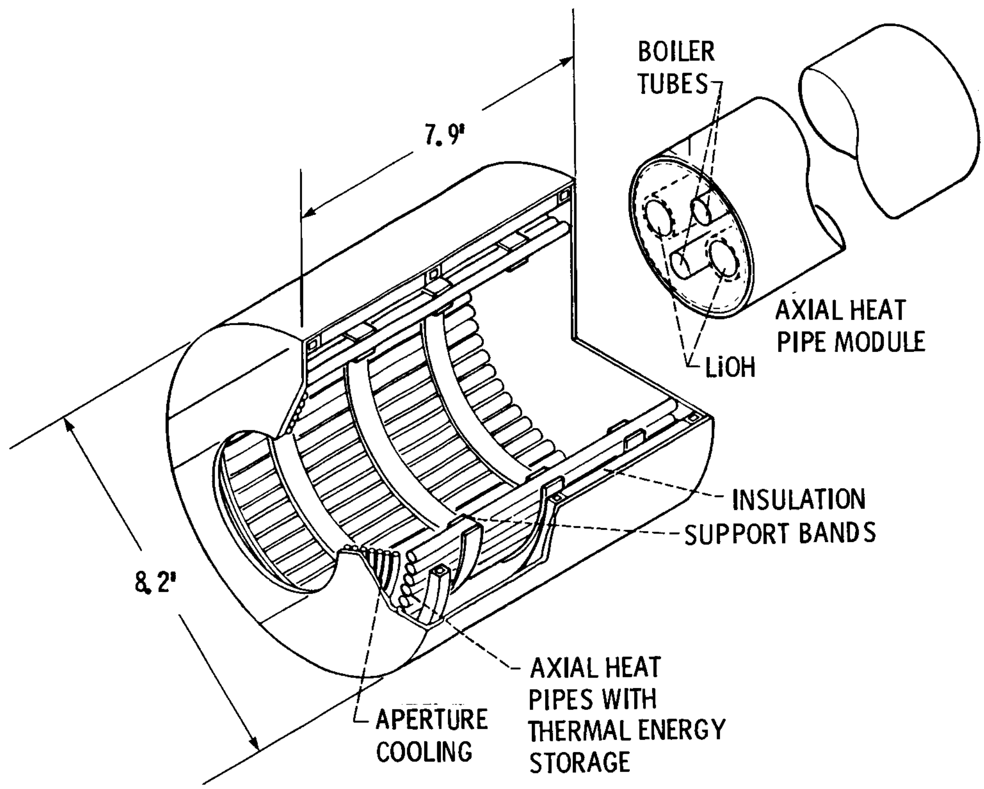

Figure 7. - ORC receiver concept.

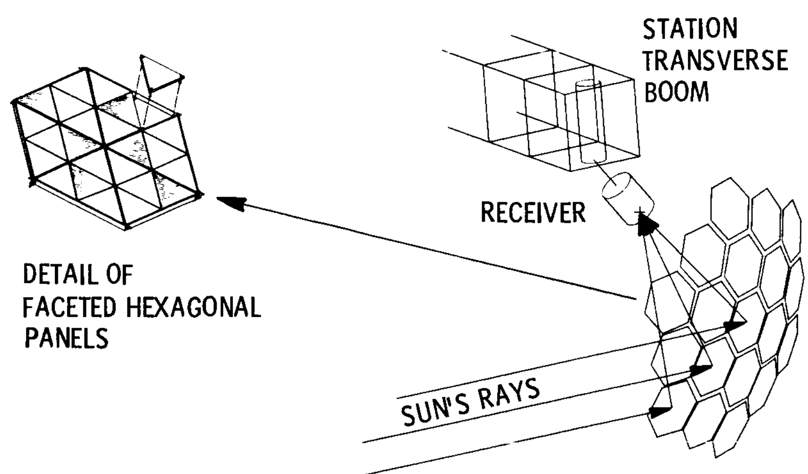

Figure 8. - Offset concentrator for solar dynamic power system.

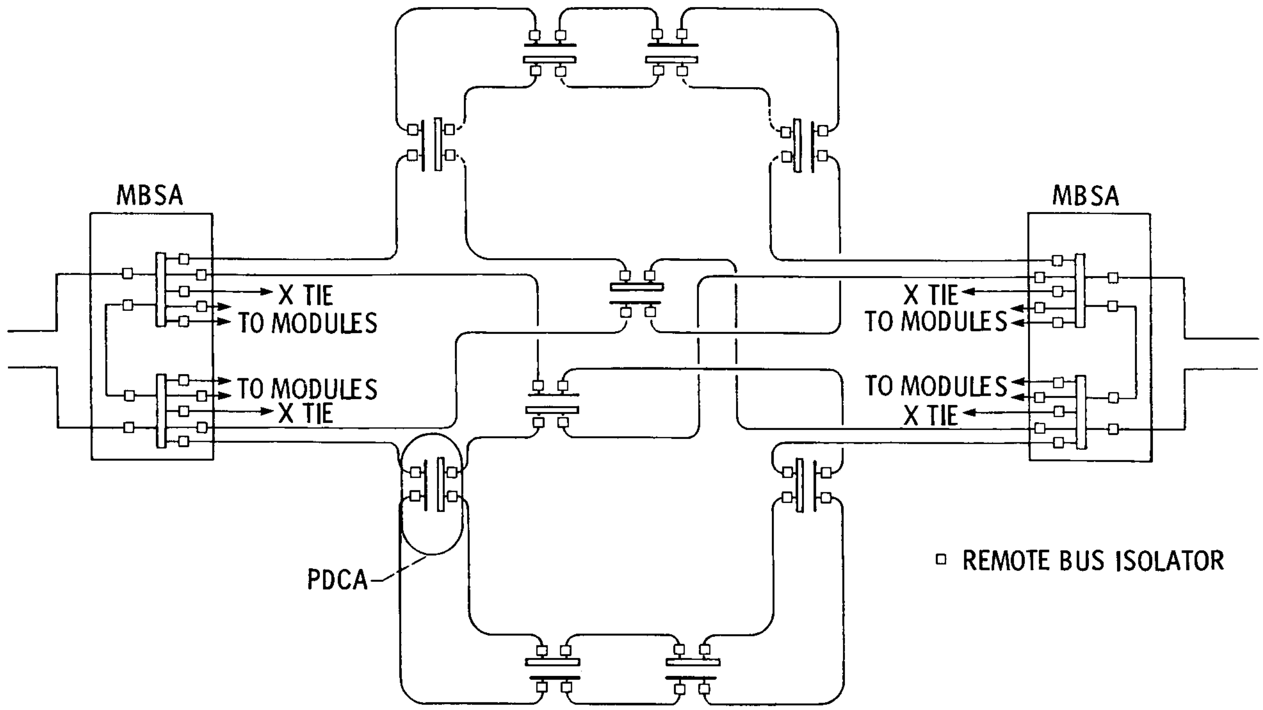

Figure 9. - Ring distribution architecture.

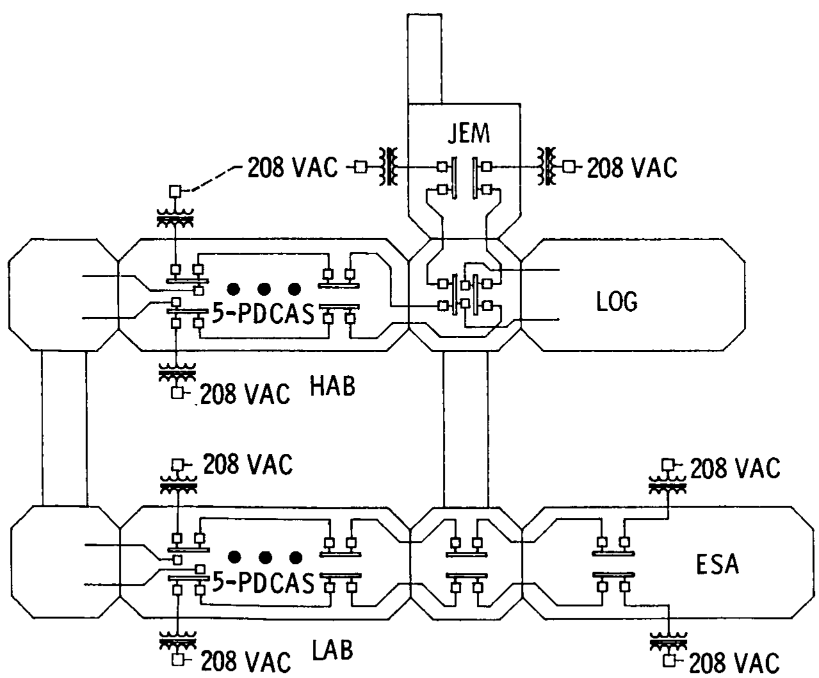

Figure 10. - Module architecture.

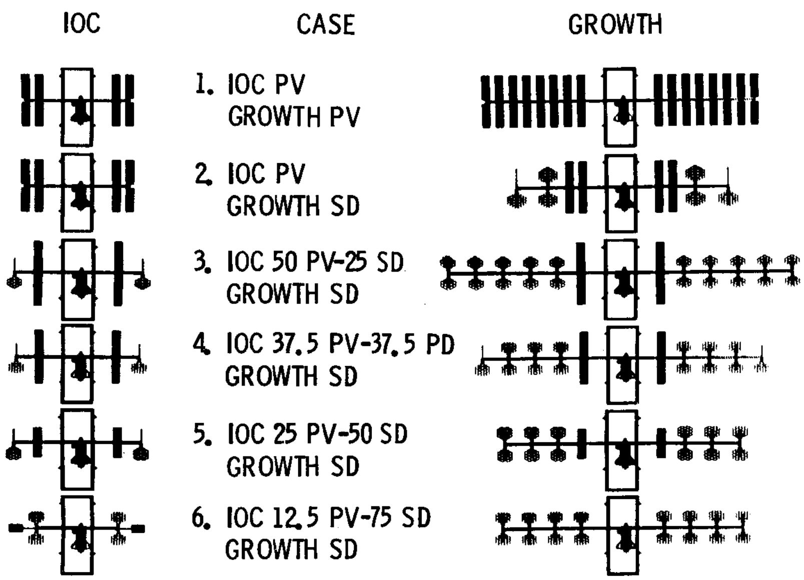

Figure 11. - Cases evaluated for Space Station power system.

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15. Supplementary Notes

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16. Abstract

The multipurpose, manned, permanent Space Station will be our next step toward utilization of space. A multikilowatt electrical power system will be critical to its success. The power systems for the Space Station manned core and platforms that have been selected in definition studies are described in this paper. The selected system for the platforms uses silicon arrays and Ni-H_2 batteries. The power system for the manned core is a hybrid employing arrays and batteries identical to those on the platform along with solar dynamic modules using either Brayton or organic Rankine engines. The power system requirements, candidate technologies, and configurations that were considered, and the basis for selection, are discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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