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Low Earth Orbit Environmental Effects on the Space Station Photovoltaic Power Generation Systems

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PHOTOVOLTAIC POWER GENERATION SYSTEMS

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SUMMARY

A summary of the Low Earth orbital Environment, its impact on the Photovoltaic Power systems of the Space Station and the solutions implemented to resolve the environmental concerns or issues are described in this paper. Low Earth Orbital environment (LEO), presents several concerns to the Photovoltaic Power systems of the Space Station. These concerns include atomic oxygen interaction with the polymeric substrate of the solar arrays, ionized environment effects on the array operating voltage, the effects of the meteoroids and debris impacts and penetration through the different layers of the solar cells and their circuits, and the high energy particle and radiation effects on the overall solar array performance.

Potential solutions to some of the degrading environmental interactions that will provide the photovoltaic power systems of the Space Station with the desired life are also summarized in this paper.

INTRODUCTION

Design of spacecraft for long duration missions for the low earth orbital environment presents new challenges that are the result of concerns over possible spacecraft systems interactions with the environment. The NASA Space Station design is an ultimate challenge because of the size, orbit, lifetime, and interface requirements imposed on the various system designers.

The Photovoltaic Power Generation system of the Space Station interacts with the environment in a variety of ways. Electrical interaction results from the power system moving through the LEO ionized environment whereas chemical interaction is primarily represented by the oxidation of the power system polymeric materials by atomic oxygen which represent the main chemical constituent of the LEO environment. Physical interaction results from the effect of atmospheric drag and impact of the meteoroids and orbital debris on the Space Station power system surfaces. The drag effect, which causes the orbital decay and which can be compensated for by the reboost plans and manouvers is beyond the scope of this paper and therefore will not be discussed. However, meteoroid and orbital debris interaction and effects on the PV power system are detailed in this paper.

This paper furnishes a brief description of the Photovoltaic (PV) power generation system, its chemical, electrical, and physical interactions with the environment, and the approaches taken to resolve or implement the environmental concerns in the power system design.

DEFINITION AND DESCRIPTION OF THE PV POWER MODULE

The Photovoltaic power system of the Space Station comprises two PV power modules that generate 37.5 KW to the users. The PV module as shown in figure 1, consists of two solar arrays for DC power generation, batteries for energy storage, a thermal control system for the thermal conditioning of batteries and frequency conversion devices, two rotational joints for solar pointing, and the truss for structural support. The Space Station (SS) solar array mechanical and structural design resembles the design of the flexible, deployable-retractable solar array flown on board of the Solar Array Flight Experiment (SAFE) (ref. 1). The solar array, as illustrated in figure 2, comprises two blankets which are made of hinged panels for power generation, a mast for deployment and retraction of the array, a canister, and a blanket box for mast and blanket stowage. The panel substrate is made of two prepunched polyimide Kapton[1] sheets that are laminated by a polyester adhesive. A copper circuit that is print etched on one of the Kapton sheets prior to lamination provides the electrical connection between cells. Solar cell/circuit contact is achieved by welding the wrap-through interconnect cells to the copper pads appearing through the Kapton prepunched holes. Figure 3 illustrates the cell-substrate structure.

DESCRIPTION OF THE LEO ENVIRONMENT

The LEO environment can be summarized to include the neutral and ionized gaseous environment, the radiation and meteoroids, and debris environment. These environments are not physically separated in space and time. They coexist and their effect can be synergistic in nature.

Atomic Oxygen

The neutral environment consists of residual gases ith concentration strongly dependent on altitude and solar activity. As depicted in figure 4, atomic oxygen is highest in concentration compared to other neutrals (ref. 2) in the LEO orbital altitudes. Atomic oxygen is construed to be created by photodissociation of molecular oxygen in the vacuum UV region ($100 < \lambda < 200$ nm) as given by (ref. 2)

$$O_2 + h\nu \rightarrow O. + O.$$

Atomic oxygen is a highly reactive species. Reaction of materials with atomic oxygen result in different reaction products. In general, metals develop layers of metal oxides whereas polymers experience mass loss and develop a textured surface.

Charged Particles

The ionized or plasma environment constituents are ions and electrons of concentrations dependent on the solar activity, position, and time. This environment in near equatorial orbits causes charges to collect on power surfaces

[1]Registered trademark of E.I. Dupont de Nemours and Co., Inc.

and form parasitic currents. Moreover, arcing between the solar array and the plasma represent another potential interaction that may occur depending on the operating voltage of the array (ref. 3).

High energy penetrating charged particles which exist in the geosynchronous and LEO polar orbits originate from the magnetosphere and cosmic rays. Magnetospheric particles consist primarily of electrons of 10's of KeV and protons of MeV's in energy which are trapped in the magnetosphere due to the magnetic field effect. The charged energetic particles oscillate between the two hemispheres and form the Van Allen belts which follow the magnetic field lines. Energetic proton and electron fluxes impacting the solar arrays degrade the solar cells and array performance (ref. 3). This degradation effect is included as an oversizing parameter in the design of the solar array.

Auroral energetic particle fluxes occur in the auroral zones due to the higher magnetic field fluxes. At LEO altitudes, auroral protons and electron fluxes, although not penetrating, induce charging of metallic and dielectric surfaces and thereby produce potential differences between those charged surfaces (ref. 3).

Cosmic rays, defined as protons, electrons, and nuclei of all elements, arise from galactic and solar origins and are considered isotropic outside the magnetosphere. Depending on their energy, cosmic rays are deflected by the magnetic field of the earth. Although the effect of cosmic rays on the power system materials is minimal, galactic cosmic rays may induce performance upset in microelectronic devices. Moreover, solar cosmic rays protons may enhance the charging effects of the magnetospheric auroral charged particles (ref. 3).

Radiation

Electromagnetic radiation environment consists of the solar spectrum (fig. 5) which peaks in the visible region, and from the radiation emitted from particles and field interactions. Even though the ultraviolet region of the spectrum of wavelength less than 200 nm possesses low intensity, photons from this region have sufficient energy to break polymeric bonds and degrade the backbone chain structure of the organic space polymer (ref. 4).

Meteoroids and Debris

Meteoroids and space debris represent the particulate environment in LEO. Meteoroid streams impact from deep space with an average velocity of 20 km/s and average density of 0.5 g/cm^3. Space debris, defined as man made particles orbit the earth with an average velocity of 10 km/s and an average density of 2.7 g/cm^3 (ref. 5).

Impact of a meteoroid or space debris can cause penetration in the surface. Penetration through a solar cell gives rise to local damaged area and reduces the power output of the cell. Penetration through the substrate may open a string circuit and disable the string of cells. Depending on its design and degree of redundancy, penetration through a radiator panel can degrade the performance of the radiator if the probability of impact was never taken into account in the design phase.

PHOTOVOLTAIC POWER MODULE CHEMICAL INTERACTION WITH LEO ENVIRONMENT

Solar arrays, truss members, lubricated surfaces, and thermal coatings are affected by the residual neutrals in the LEO environment; primarily atomic oxygen. Oxygen neutrals interaction with Kapton sheets of the space shuttle cameras was postulated to be the reason for loss of specularity and mass of Kapton. Two flight experiments were designed and carried out on board of STS-5 and STS-8 missions to verify the atomic oxygen - material interaction phenomenon (ref. 6). Atomic oxygen interacts with materials that have the thermodynamic tendency to undergo a chemical reaction. Organic polymers react with atomic oxygen to produce volatiles such as carbon oxides and lose mass whereas metals undergo a surface chemical conversion reaction to produce stable or unstable metal oxides. Certain metal oxides of no thermodynamic tendency to further react with atomic oxygen are thereby stable. Inorganic polymers and adhesives interact with oxygen neutrals differently. The reaction rate and mechanism are different from organic polymers because of the difference in the nature and energy of bonds. Composite materials such as graphite and fiber glass epoxy experience mass loss when exposed to atomic oxygen which attacks the resin binder and the graphite fibers in the composite (ref. 7).

Protection of the Solar Array

To protect the solar array substrate from atomic oxygen, one is faced with two options. The solar array substrate material can be substituted by another polymeric lightweight material that possesses the same or approches the mechanical, electrical, and physical properties of Kapton and does not oxidize by atomic oxygen. Such material does not exist. On the other hand, Kapton can be protected by a nonreactive or sacrificial coating that preserve its properties. Nonreactive coatings can be represented by the metal oxides thin film coatings that can be applied on the Kapton surface. Sacrificial coatings are those that interact at a slow rate with atomic oxygen and undergo a surface chemical conversion. They will eventually preserve the Kapton substrate if applied thick enough to prevent atomic oxygen attacks of the surface. Silicone coatings fall under this category.

Table 1 displays the rates of reactions of various polymeric materials relative to Kapton (ref. 7). These reaction rates, when multiplied by the flux and integrated over the mission time result in the total expected surface recession (assuming linear kinetics).

Thin film metal oxide coatings were fabricated and ground and space tested for atomic oxygen resistance. Fabrication of the coated samples was carried out in the ion beam sputter deposition facility at NASA Lewis Research Center (fig. 6). Ground and space atomic oxygen resistance testing was performed in air plasma ashers and on board of STS mission 8 respectively. Silicon oxide-Tetrafluoroethylene (SiOx-PTFE) coated Kapton showed negligible mass loss during the post flight analyses which translate into excellent protection (1/10000 of the uncoated Kapton mass loss) (ref. 8). Silicones exhibited mass loss rates comparable to SiOx coated Kapton. This is due to the oxygen-Silicon surface reaction which develop layers of silicon oxide which in turn provide Kapton protection (ref. 9).

Several NASA programs are designed to support manufacturing a durable solar array that survive the LEO environment. The in-house testing program at NASA Lewis is designed to screen potential coatings for oxidation resistance, flexibility, resistance to processing chemicals, and UV environment effects. After exposure to simulated atomic oxygen and UV environment, the coating durability is further evaluated using surface analysis techniques such as Rutherford backscattering spectrometry (RBS), Electron Spectroscopy and Chemical Analysis (ESCA), Auger Spectroscopy, and Scanning Electron and Transmission Microscopy.

The Space Station Protective Coatings Development program, managed by Marshall Space Center, is to develop protective coatings for the Space Station vulnerable surfaces. Considerable efforts were invested in inorganic coatings characterization and testing in atomic oxygen and UV environment for the solar array substrate. Silicone polymeric coatings, as result of the aforementioned testing, proved to be the most resistant to atomic oxygen (ref. 10).

The objective of the Photovoltaic Array Environmental Protection program (PAEP), as managed by NASA Lewis, is to implement the promising protective coatings such as metal oxides and silicones into the array manufacturing process. This program will produce protected and durable solar array panels that achieve the lifetime requirements of the solar array of 15 years in orbit (ref. 11).

Atomic oxygen degrades the epoxy binder in S-glass composite epoxy which constitute the structural material from which the solar array mast is made. The glass fibers matrix as a result may disintegrate (from fiber rupture) and consequently, this introduces degradation in mechanical and physical properties of the S-glass epoxy composite. The PAEP program will study and implement protection schemes for the solar array mast structural members against atomic oxygen attack.

Structure Protection

Unprotected graphite epoxy truss members degrade at the same rate as unprotected Kapton as demonstrated in the shuttle experiments. As previously mentioned, this degradation is due to the graphite fibers and epoxy binder reacting with atomic oxygen. Such degradation results in mass loss and deterioration in the mechanical properties of the graphite epoxy. Efforts are oriented toward protecting the truss tubes using protective layers of aluminum which can be applied using the coating technology or adhesive bonding technology. An important issue in manufacturing the protected tubes is the mismatch in the coefficient of thermal expansion (CTE). The objective is to minimize the mismatch in order to reduce microcracking at the aluminum/composite interface (ref. 12).

Johnson Space Center and Langley Research Center are actively involved in efforts to manufacture durable truss members that are stable in atomic oxygen and thermal cycling environment. Several programs existed and continue to exist to thermally cycle different protection schemes and monitor the mechanical properties change as a function of the number of cycles.

Lubricants Degradation and Protection

Lubricants are subject to chemical interaction with atomic oxygen and UV. Organic polymeric lubricants oxidize in the presence of atomic oxygen to produce volatile carbon oxides. Silicones on the other hand undergo a chemical surface reaction that alter the surface composition, i.e., develop layers of silicon oxide which may damage the lubricated surface. Molybdenum disulfide, which is considered as a potential space lubricant reacts with atomic oxygen to form brittle molybdenum oxide and volatile sulfur oxide (ref. 13). Lubricants that are exposed to atomic oxygen are subject to chemical reactions. However, enclosed lubricants are protected and thereby expected to experience minute degradation of performance.

Thermal Control Coatings Degradation

Organic and inorganic thermal control coatings are expected to react to the atomic oxygen and UV environment. As shown in figure 7, the thermal control organic film, most known in the spacecraft industries as silver Teflon, consist of a fluorinated ethylenepropylene (FEP) layer coated with silver on the unexposed surface and adhered to the substrate to be thermally controlled (ref. 14). The FEP layer is known to react and experience degradation in optical properties and mass due to the UV and atomic oxygen effects.

An inorganic coating is made of three main ingredients: pigment, binder, and water as a solvent. The most three known inorganic thermal control coatings are Z93, S13G/LO and zinc orthotitanate. The first (Z93), consisting of a zinc oxide pigment and a potassium silicate binder, showed small increase in the solar absorptivity, α_s, and no change in thermal emittance, ε_t, after extended UV exposure (5000 equivalent sun hours ESH). Degradation of solar absorptance and thermal emittance of the Z93 due to atomic oxygen is not expected to be significant because of the lack of atomic oxygen reactive materials in the coating structure. The second coating (S13G/LO), which is made of zinc oxide/potassium silicate pigment/binder and treated with silicone binder is expected to degrade in performance (increase in α_s and decrease in ε_t) because of the anticipated interaction of the silicone binder with AO and UV radiation (ref. 15). The zinc orthotitanate pigment, when treated with silicate binder and water solvent, results in zinc orthotitanate thermal control coating (ref. 16). Similar to Z93, this paint under UV exposure of 5000 ESH, exhibited little increase in the α_s (ref. 15). In addition, atomic oxygen effects are not anticipated to change the solar absorptance and thermal emittance (ref. 16).

It is worth noting that, although inorganic coatings are not greatly degraded by the environment, they have some drawbacks such as brittleness, poor adherence, and require special handling and processing procedures. Moreover, thermal cycling effects (which introduce cyclic thermal stresses on the coating and result in microcracking), and contamination effects (which induce deposits on the surface and result in changes in the thermo-optical properties) are two additional effects that can potentially couple with UV to follow in higher degradation.

Durable Thermal Control Coatings

Due to the various environmental factors that affect the thermal control coating performance, a new approach was initiated at JSC to develop a high emittance (no less than 0.75) and low solar absorptance (no higher than 0.2 over 10 years lifetime) thermal control coating over an aluminum substrate for the Space Station central radiators. The new approach which is based on matching the CTE's of the coating and substrate uses aluminum conversion coatings. Samples of anodized aluminum, silicones, and fluorocarbons emitting layers over aluminum substrate were fabricated and tested for limited number of thermal cycles. Future plans include testing and evaluation of sample performance in atomic oxygen, UV, extended thermal cycling, and contamination environments (ref. 17).

PHOTOVOLTAIC POWER MODULE ELECTRICAL INTERACTION WITH LEO ENVIRONMENT

Electrical interaction of the power systems with the environment are described by the plasma interaction phenomena such as parasitic current collection and arcing in equatorial orbital environment, and charging in polar orbital environment.

Electrically biased structures in plasma environment establish a potential distribution such that the total collected ion and electron currents balance. Since the thermal velocities of electrons is significantly higher than the ions, the area of positive potential relative to the plasma (where electrons are collected) will be smaller than the area of negative potential (where ions are collected) at equilibrium. The solar arrays similarly exhibit a potential distribution. Enhanced current collection (snap-over) is known to occur in the positive potential area whereas arcing is known to take place toward the negative potential end of the array (ref. 18).

Current Collection

Collected currents depend on the thermal ion and electron velocities and the plasma sheath width. The plasma sheath is defined as the space between the surface and ambient plasma where electric fields exist. since the array will establish a potential distribution, the plasma sheath thickness which is a function of potential will vary on the conductive surface of the array and so do the collected currents. In the present solar array design, only the copper pads and the cell edges are suspected to be collection sites. The impact of these current collection sites on the whole solar array performance is yet to be analytically and experimentally determined in the plasma interaction test which will be discussed later. Surfaces of high positive potential relative to the plasma, experience drastically increased electron collection currents because the normally insulating surfaces will transport charges like the conducting surfaces (ref. 19). The severity of this effect is to be experimentally assessed in the plasma interaction test as well.

Arcing

Arcing to plasma has been observed to take place at regions of negative potentials relative to the plasma ground. Arcing mechanism is postulated to be accompanied with electron emission and current surges into the plasma (ref. 20). Moreover, arcing is a function of the operating voltage of the array and the plasma condition. A true arcing voltage threshold (which is the voltage below which arcing never occurs) may exist for a specific plasma condition. Conditions for occurence of arcs have not yet been completely determined. However, existence of an area of negative potential relative to the plasma, and an insulator/metal geometry have associated to arcing to the plasma (ref. 19).

Excessive arcing damages the solar array materials and components such as the solar cells and the substrate. Plasma interaction ground testing results of an array of wrap-around solar cells negatively biased to -600 V and exposed to argon plasma of $10^{12}/m^3$ show that the array experienced 2.5 percent power degradation and collected approximately 10 μa over 50 hours (ref. 19). Material damage follows from the high current densities experienced during arcing and the high energy fluxes that could locally damage the chemical bonding and structure (ref. 21).

Charging

Surface charging follows from the collection of high energy electrons (between 1 and 10 KeV) which exist in the geosynchronous and polar orbits. Collection of highly energetic particles give rise to KeV surface potentials which enhance and cause arcing to plasma, surface contamination, and possible damage of the interconnects. The station polar platform solar arrays may experience such environment the effect of which is yet to be experimentally determined in the plasma interaction test (refs. 18 and 19).

The solar array plasma interaction test is planned at NASA Lewis to test and verify the operating voltage of the solar array. An active space station solar array panel capable of generating a nominal 80 V will be exposed to the simulated plasma environment. A power supply will be used to bias the panel with the appropriate potential to simulate the orbital nominal potential of 160 V (two panels in series). During testing, collected currents and arcing will be closely monitored. In the same test, energetic electron beams will be used to simulate the polar plasma charging effects and their impact on arcing rates and currents. The test is planned to be performed during the summer of 1988 at NASA Lewis plasma simulation facility.

PHOTOVOLTAIC POWER MODULE PHYSICAL INTERACTION WITH LEO ENVIRONMENT

As previously mentioned, physical interaction effects are manifested as atmospheric drag effects which are not discussed here and particulate impact on the photovoltaic power surfaces.

Modeling

Analytical studies of the meteoroid and debris impacts on an orbiting surface require a damage model and a flux model. The damage model calculates the size of particles that can partially or fully penetrate a surface of certain thickness, physical, and mechanical properties. The particle size that is calculated from the experimentally derived damage model can then be used in the flux equation to calculate the flux of particles of certain size or higher that could penetrate or damage the surface. Figure 8 shows the meteoroids and debris flux models used in the probability impact analysis.

Impact on Array Performance

Meteoroids and debris only degrade the performance of the PV module; their impact on the solar arrays and the radiator surfaces is not life threatening. Degradation of power output from the solar arrays can be related to texturing of the coverglass of the solar cells which promote light scattering losses. Penetration of meteoroids and debris through the substrate can open circuit the solar cell string, thereby reducing the power output. These potential losses can be accounted for by oversizing the solar array and increasing the redundancy. It is noteworthy that oversizing factors are based on the probability of impact, penetration, and breakage of the circuit which makes the analysis rather conservative.

Impact on Fluid Lines

The impact of a particle and its penetration in a fluid line can break the fluid loop in the thermal system. If the fluid loop is redundant, this leaves the thermal system with one operational fluid loop the failure of which result in the inability of the thermal control system to control the temperature of the batteries and the power management and distribution equipment. To account for such an effect, probability of impact and penetration, and fluid lines bumpering analyses are performed to optimize the bumper thickness and spacing as function of weight and reliability requirements.

Impact on Radiator Performance

In a heat pipe radiator, penetration of a particle through the heat pipe disables only the impacted panel and reduces the overall performance of the radiator. To take this effect into consideration, oversizing and increased redundancy based on the reliability requirements can be factored into sizing the heat pipe radiator (ref. 22).

CONCLUDING REMARKS

This paper presented an overview of the Photovoltaic power module of the space station and its interaction with the low earth orbital environment. The interactions that were described are of interest to the photovoltaic power module designers. Atomic oxygen for example represent a threat to the material of the solar arrays. Plasma interaction with the solar array may degrade its electrical performance. Meteoroids and debris impact degrade the solar cells and the substrate of the solar array. These threats and potential degradations, when considered in the design phase, result in an array that can survive these environmental threats.

In-house testing and analysis programs are directed toward supporting the formulation and development of solutions to the aforementioned threats or concerns. Other programs such as the PAEP are designed to implement potential solutions into the hardware manufacturing such as the solar array.

Natural LEO environment is not the only environmental concern to the designers of the PV module. Induced environment such as induced external contamination, vibration, electromagnetic interference, induced brightness and particulate, and others are of consideration to the designers and the user of the space station micogravity and observation capabilities. These induced environments are considered in the design in the form of requirements assembled by space station working groups and used by the designers of the space station systems. With these requirements and early design considerations, it is hoped to make the space station systems survive the environment and be used to their maximum capabilities at an optimum cost to NASA.

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TABLE 1. - REACTION EFFICIENCIES OF SELECTED MATERIALS WITH ATOMIC OXYGEN IN LOW EARTH ORBIT

Material	Reaction efficiency, cm^3/atom
Kapton	3×10^{-24}
Mylar	3.4
Tedlar	3.2
Polyethylene	3.7
Polysulfone	2.4
Graphite/epoxy	
1034C	2.1
5208/T300	2.6
Epoxy	1.7
Polystyrene	1.7
Polybenzimidazole	1.5
25% Polysiloxane/45% Polyimide	0.3
Polyester 7% Polysilane/93% Polyimide	0.6
Polyester	Heavily attacked
Polyester with Antioxidant	Heavily attacked
Silicones	
RTV-560	0.2*
DC6-1104	0.2*
T-650	0.2*
DC1-2577	0.2*
Black paint Z306	0.3 to 0.4*
White paint A276	0.3 to 0.4*
Black paint Z302	2.03*
Perfluorinated polymers	
Teflon, TFE	<0.05
Teflon, FEP	<0.05
Carbon (various forms)	0.9 to 1.7
Silver (various forms)	Heavily attacked
Osmium	0.026

*Units of mg/cm^2 for STS-8 mission. Loss is assumed to occur in early part of exposure; therefore, no assessment of efficiency can be made.

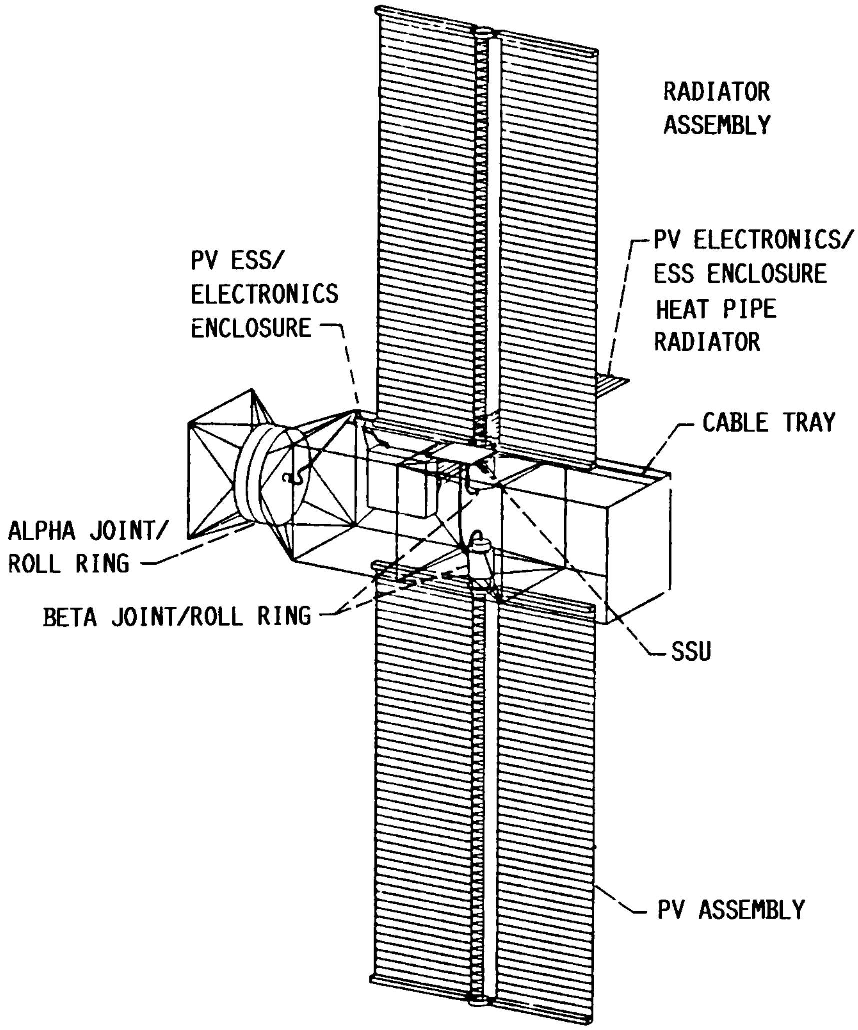


FIGURE 1. - CONFIGURATION OF THE PHOTOVOLTAIC POWER MODULE OF THE SPACE STATION.

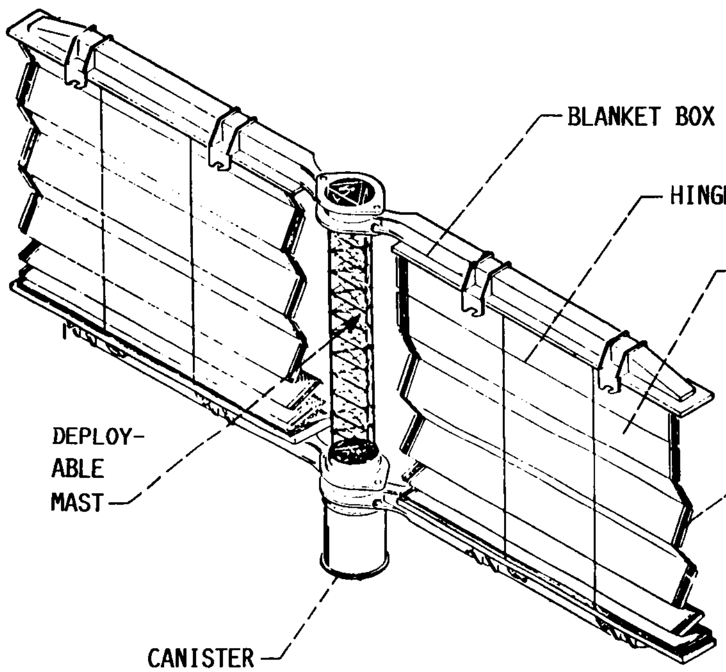


FIGURE 2. - DEPLOYABLE RETRACTABLE SOLAR ARRAY STRUCTURE FOR THE SPACE STATION PHOTOVOLTAIC POWER MODULE.

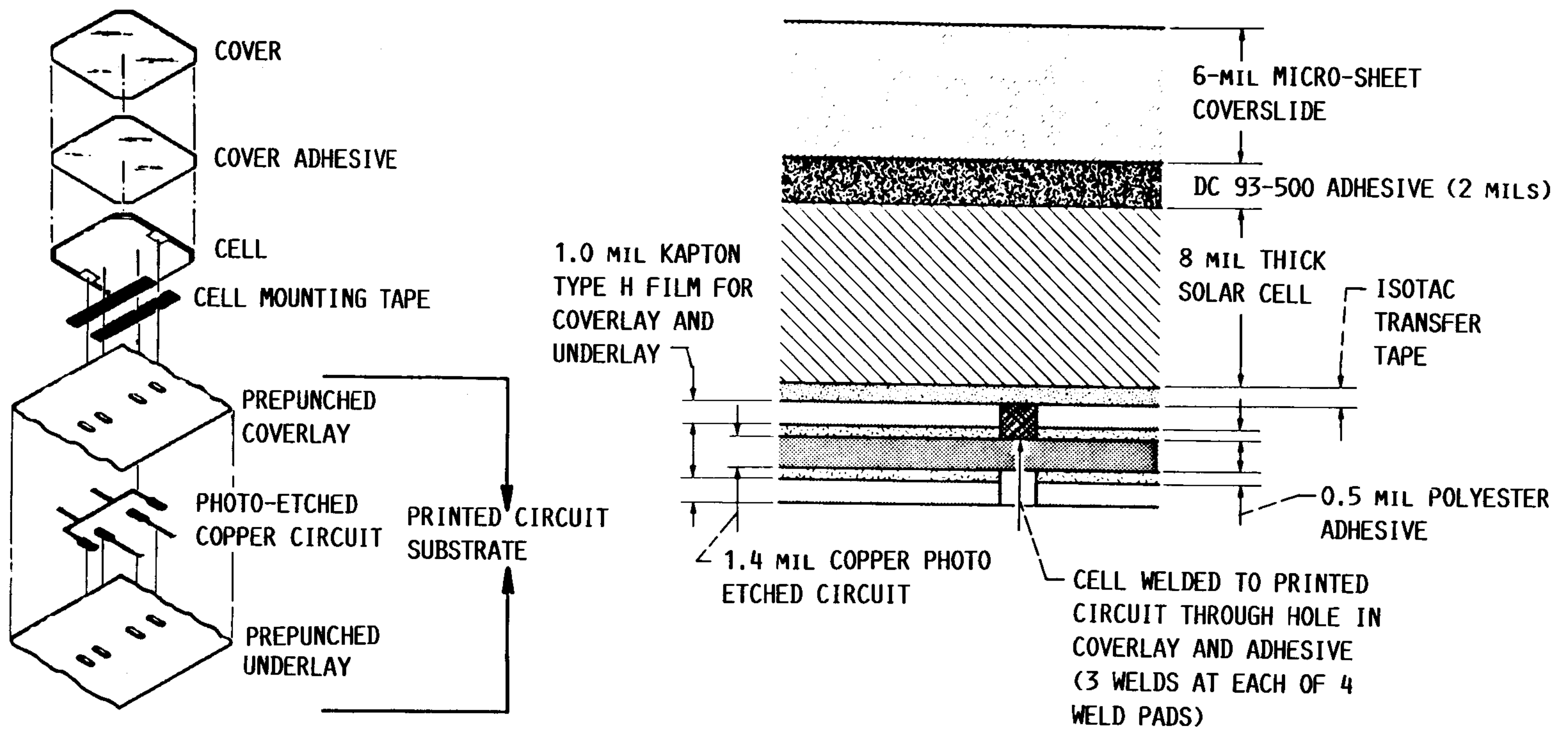


FIGURE 3. - SOLAR CELL - SUBSTRATE STRUCTURE FOR THE SPACE STATION SOLAR ARRAY.

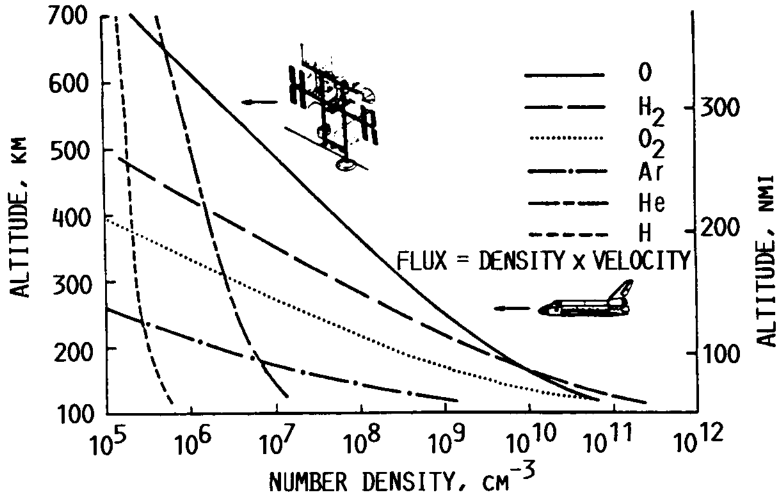


FIGURE 4. - LEO ENVIRONMENT NEUTRAL CONSTITUENTS AS FUNCTION OF ALTITUDE.

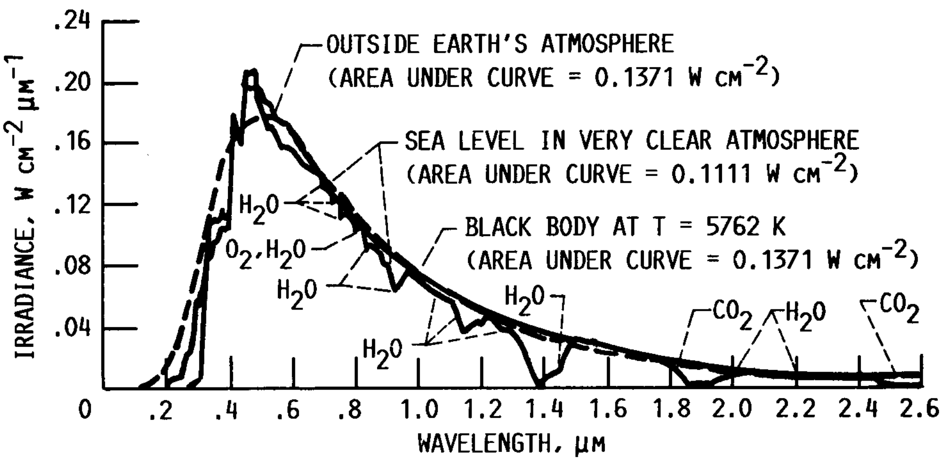


FIGURE 5. - NORMAL SPECTRAL IRRADIANCE AT SEA LEVEL, OUTSIDE EARTH ATMOSPHERE, AND OF A BLACK BODY RADIATING AT 5762 K.

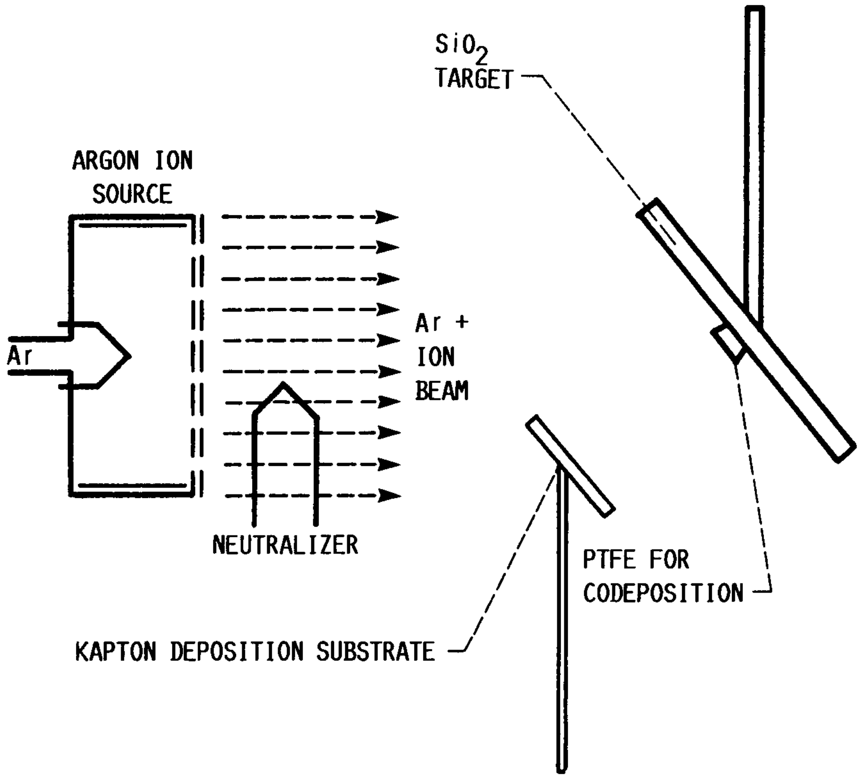


FIGURE 6. - ION BEAM SPUTTER DEPOSITION FACILITY.

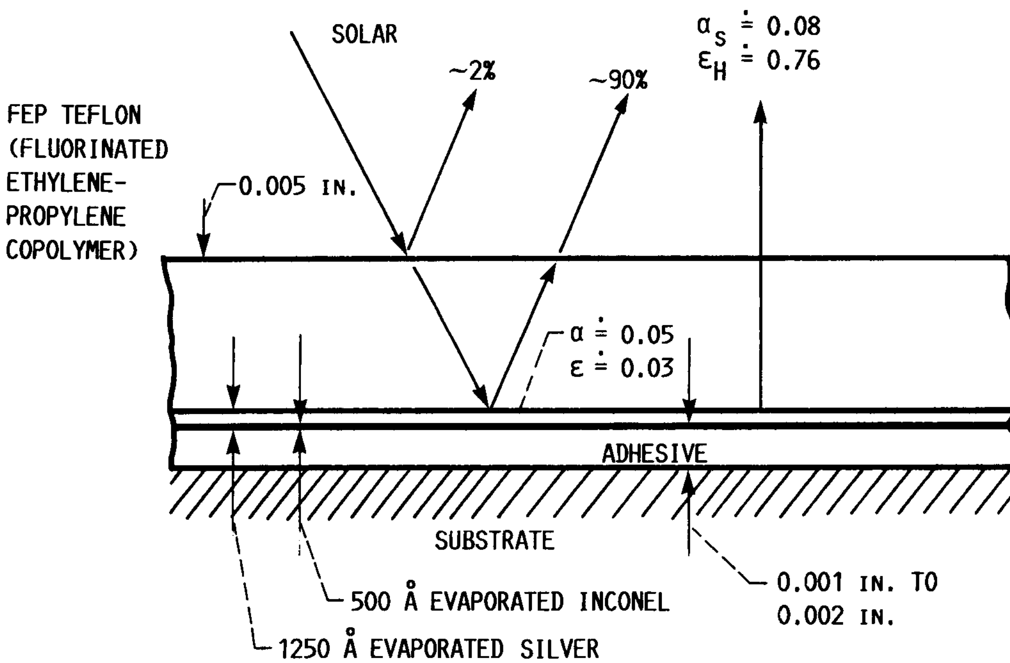
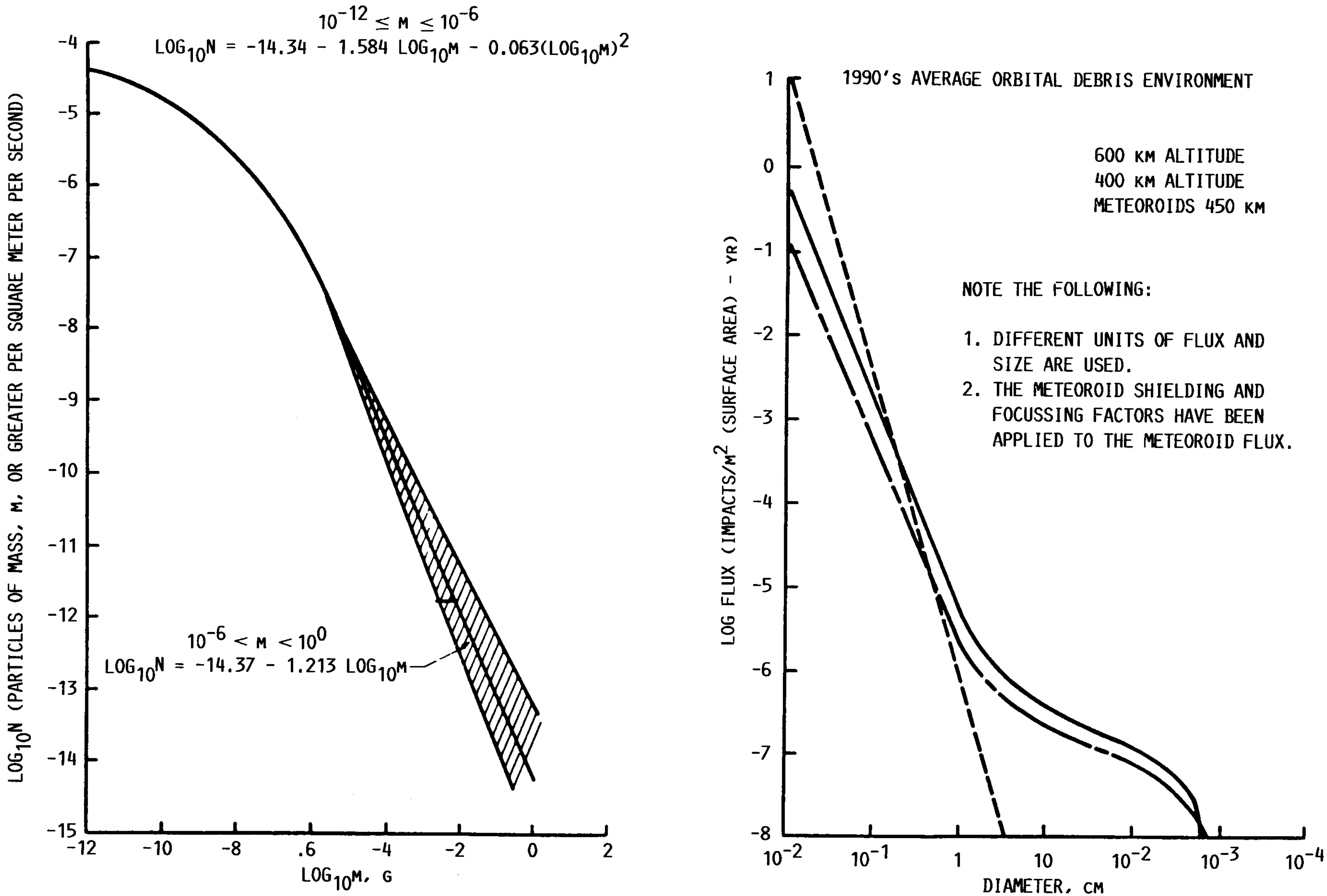


FIGURE 7. - STRUCTURE AND OPERATION OF THE SILVER TEFLON THERMAL COATING.



(A) TERRESTRIAL METEOROIDS MASS-FLUX DISTRIBUTION (REF. 3).

(B) METEOROIDS AND 1990 AVERAGE ORBITAL SPACE DEBRIS FLUX-SIZE DISTRIBUTION (REF. 3).

FIGURE 8.

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16. Abstract

A summary of the Low Earth Orbital Environment, its impact on the Photovoltaic Power systems of the Space Station and the solutions implemented to resolve the environmental concerns or issues are described in this paper. Low Earth Orbital Environment (LEO) presents several concerns to the Photovoltaic power systems of the Space Station. These concerns include atomic oxygen interaction with the polymeric substrate of the solar arrays, ionized environment effects on the array operating voltage, the effects of the meteoroids and debris impacts and penetration through the different layers of the solar cells and their circuits, and the high energy particle and radiation effects on the overall solar array performance. Potential solutions to some of the degrading environmental interactions that will provide the photovoltaic power systems of the Space Station with the desired life are also summarized in this paper.

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