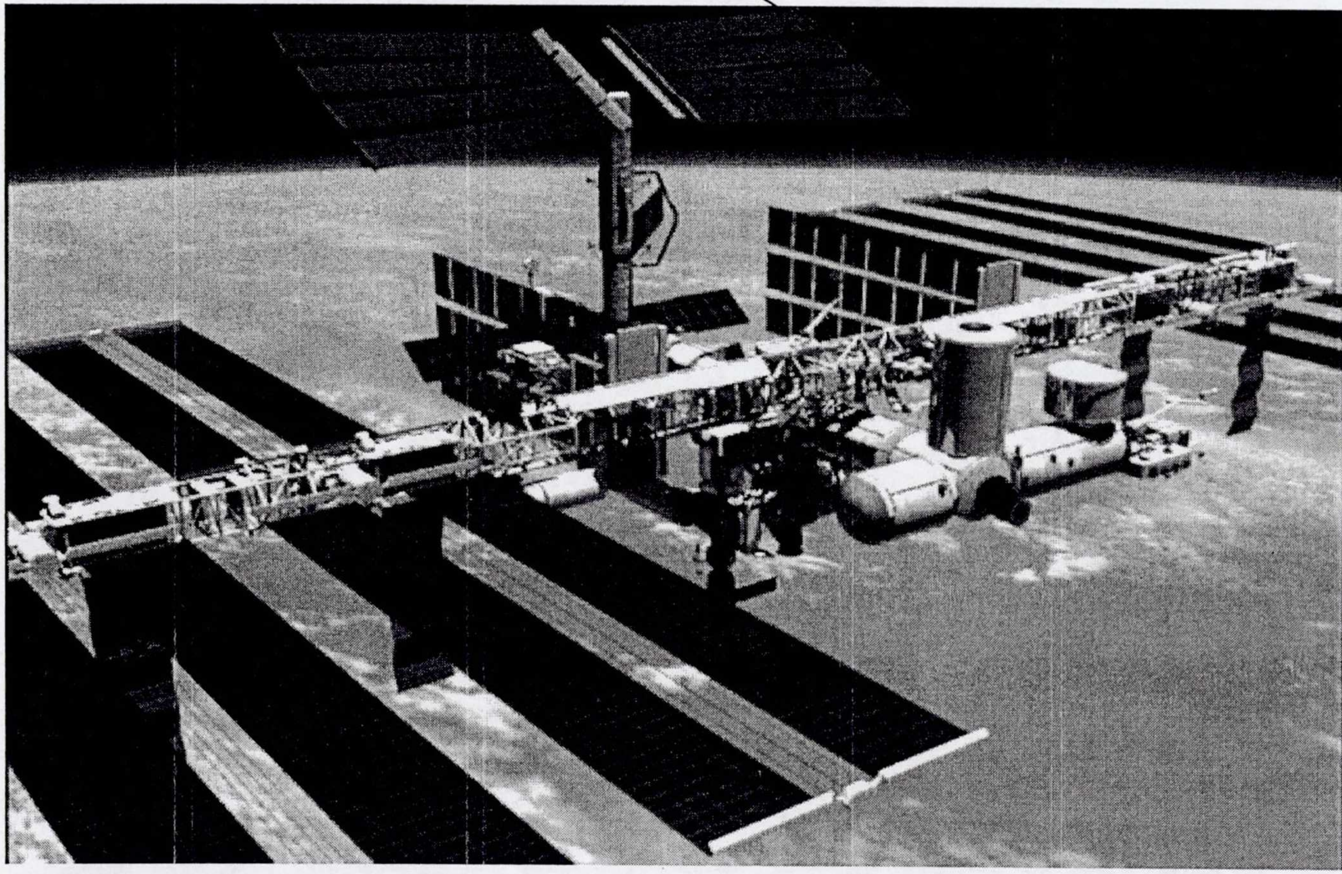
Source of Acquisition
NASA Johnson Space Center

International Space Station



Power Systems

Part I

THE BASICS OF POWER

What is POWER?

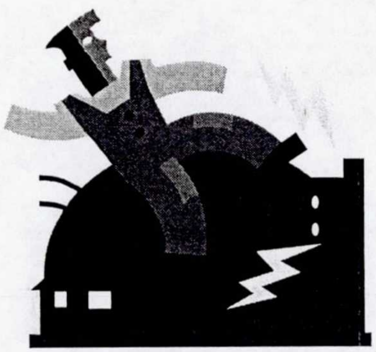
POWER is the product of

VOLTAGE

And

CURRENT

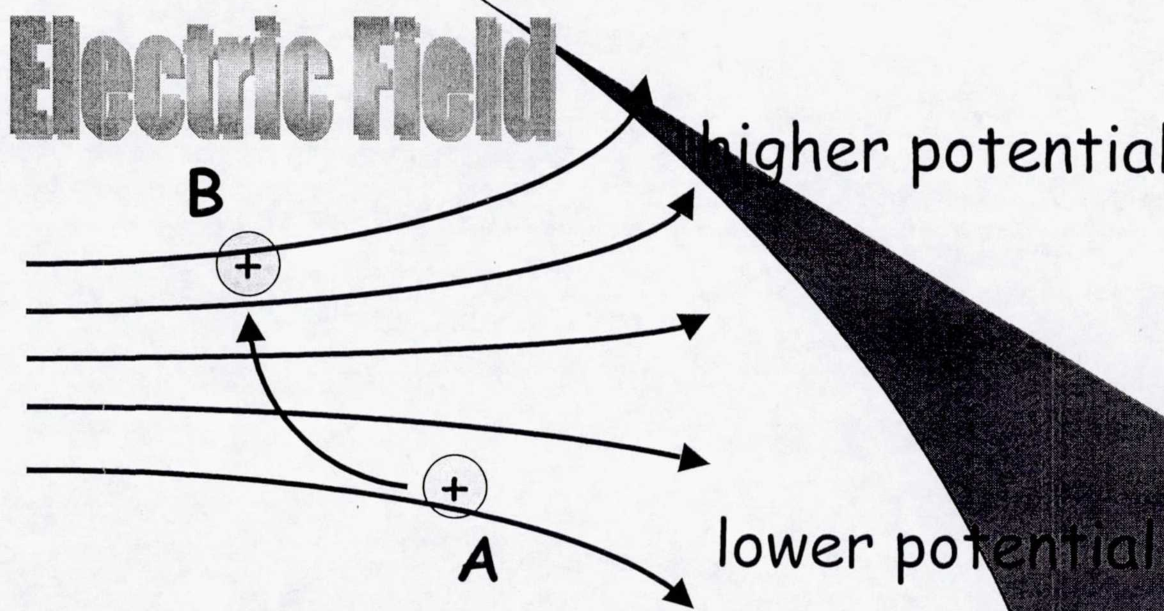
$$P = V * I$$



Units of Power = Watts
1000 Watts = 1 kiloWatt or 1 kW

What is VOLTAGE?

VOLTAGE = ELECTRIC POTENTIAL

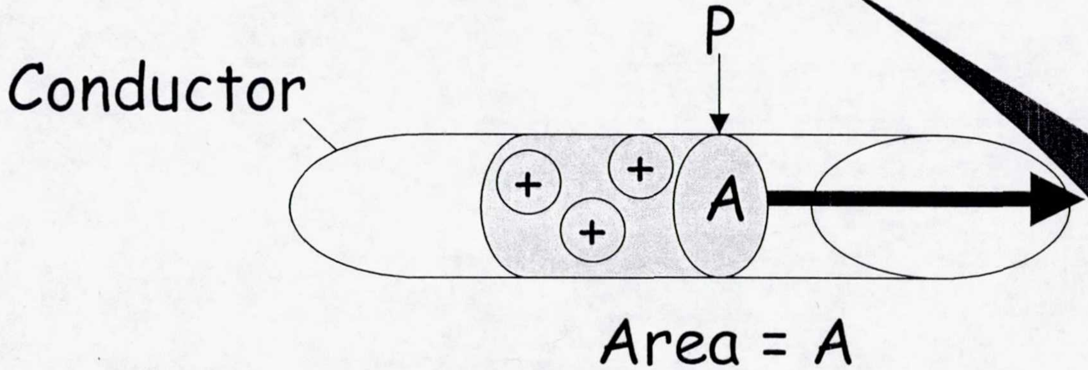


The Potential Difference $V_B - V_A$ is the WORK PER UNIT CHARGE necessary to move the charge from point A to point B

1 Volt = 1 Joule per Coulomb

What is CURRENT?

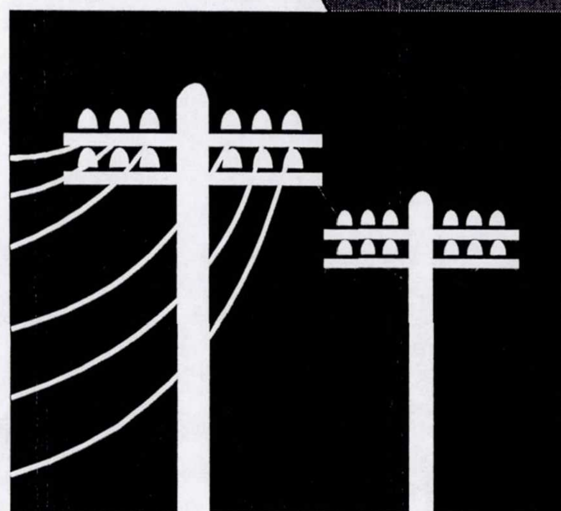
CURRENT = MOTION OF CHARGED PARTICLES



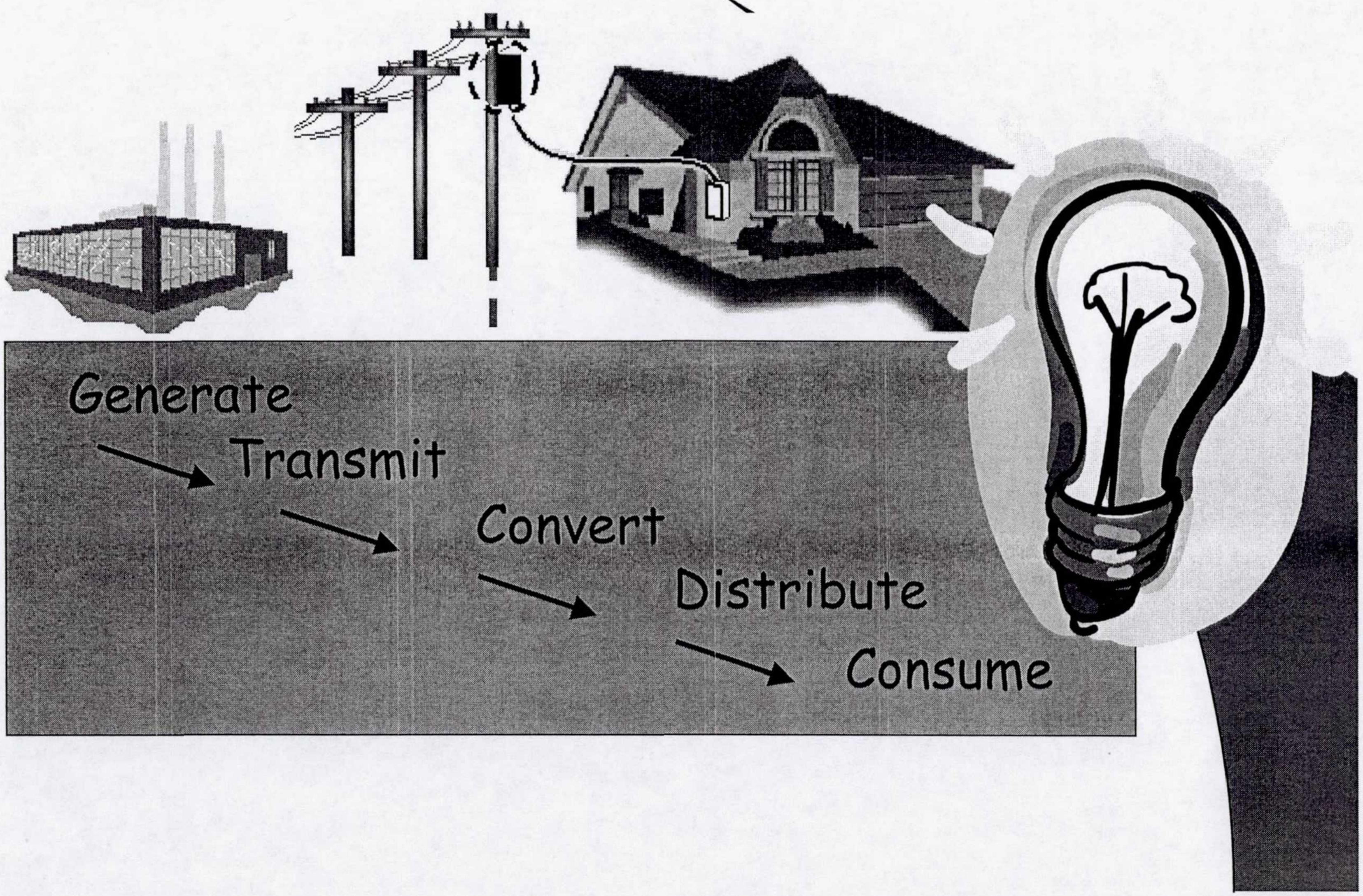
CURRENT is the AMOUNT OF CHARGE flowing through area A at point P PER UNIT TIME

or RATE OF FLOW OF CHARGE through that area

1 Ampere = 1 Coulomb per Second

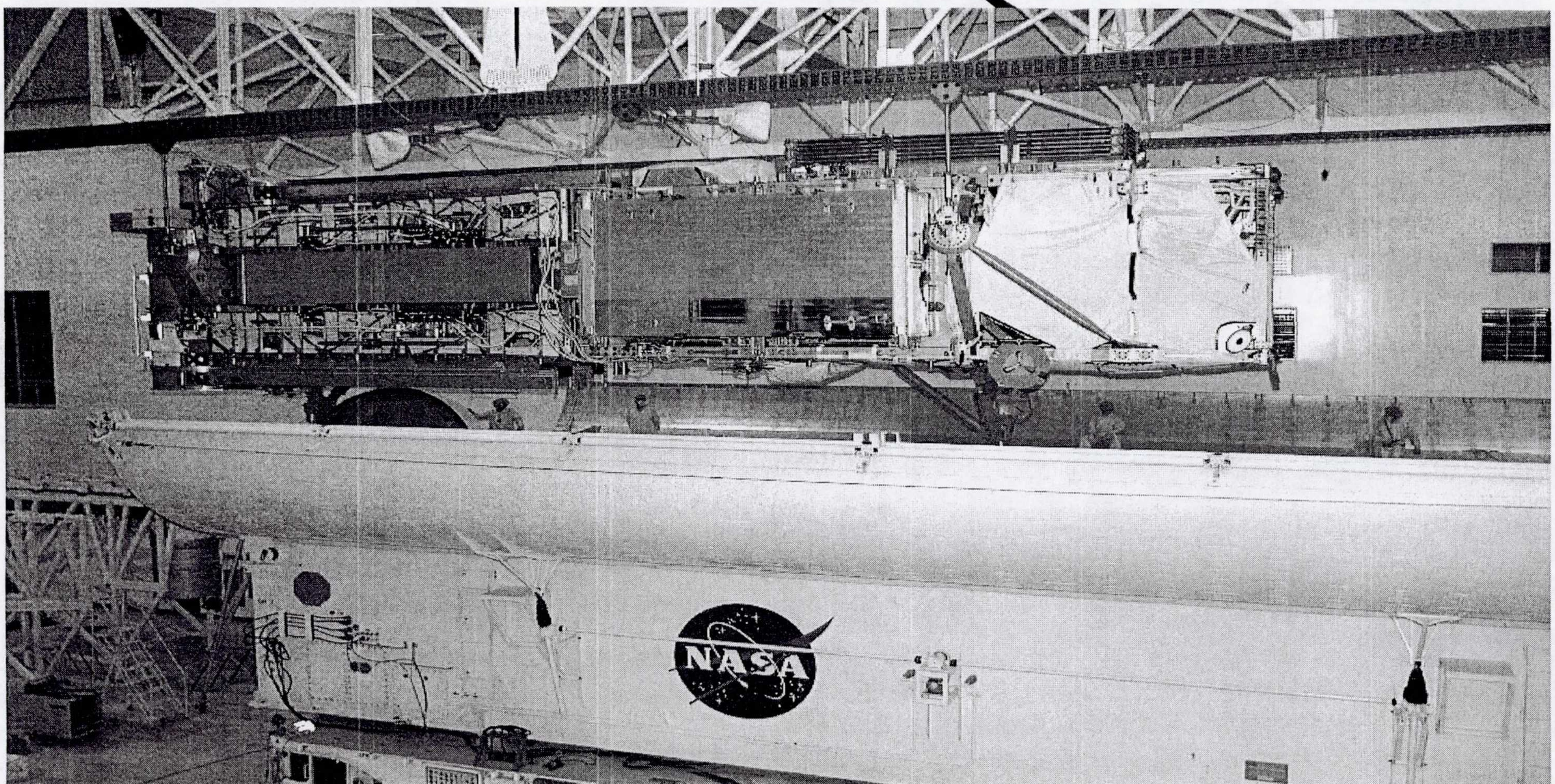


Distributed Power Systems on Earth



Part II

SPACE POWER SYSTEMS DESIGN CONSTRAINTS



Space Power Systems Design Constraints

The degree of design difficulty varies greatly with the mission's location and operating environment

In EARTH ORBIT, the primary challenge is ECLIPSE periods
ECLIPSE occurs when the Earth shadows the spacecraft from the Sun

In Low Earth Orbit (LEO), 1 orbit ~ 92 minutes

Eclipse periods can last up to 35 minutes in LEO

Eclipse periods are LONGER but LESS FREQUENT at higher altitudes

Power System must be designed to withstand hot & cold temperature extremes and be able to store Energy

Space Power Systems Design Constraints

Other Space Environments

LUNAR SURFACE: the primary challenges are

- 354 Hour Lunar Night
- Surface Dust
- High Daytime Temps (212+ deg F)

MARS: the primary challenges are

- Atmospheric Dust
- 12.5 Hour Night
- Cold Temperatures

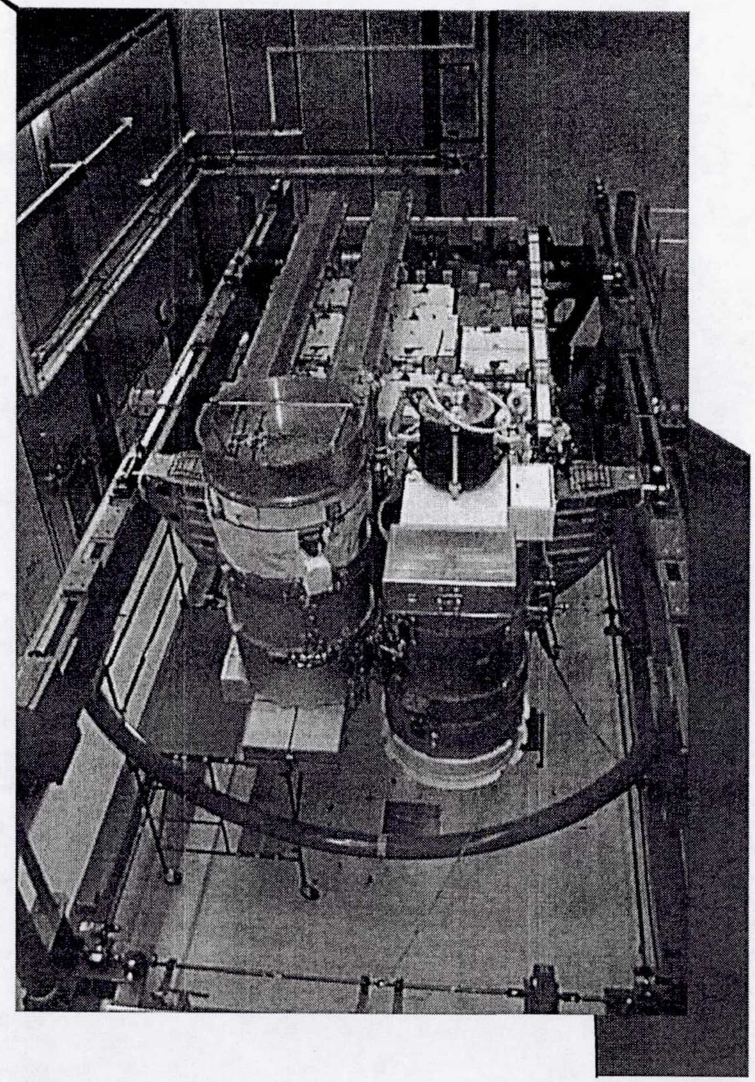
OUTER PLANETS: the primary challenges are

- Very Cold Temperatures
- Low Solar Power
- Radiation Belts

Space Power Systems Design Constraints

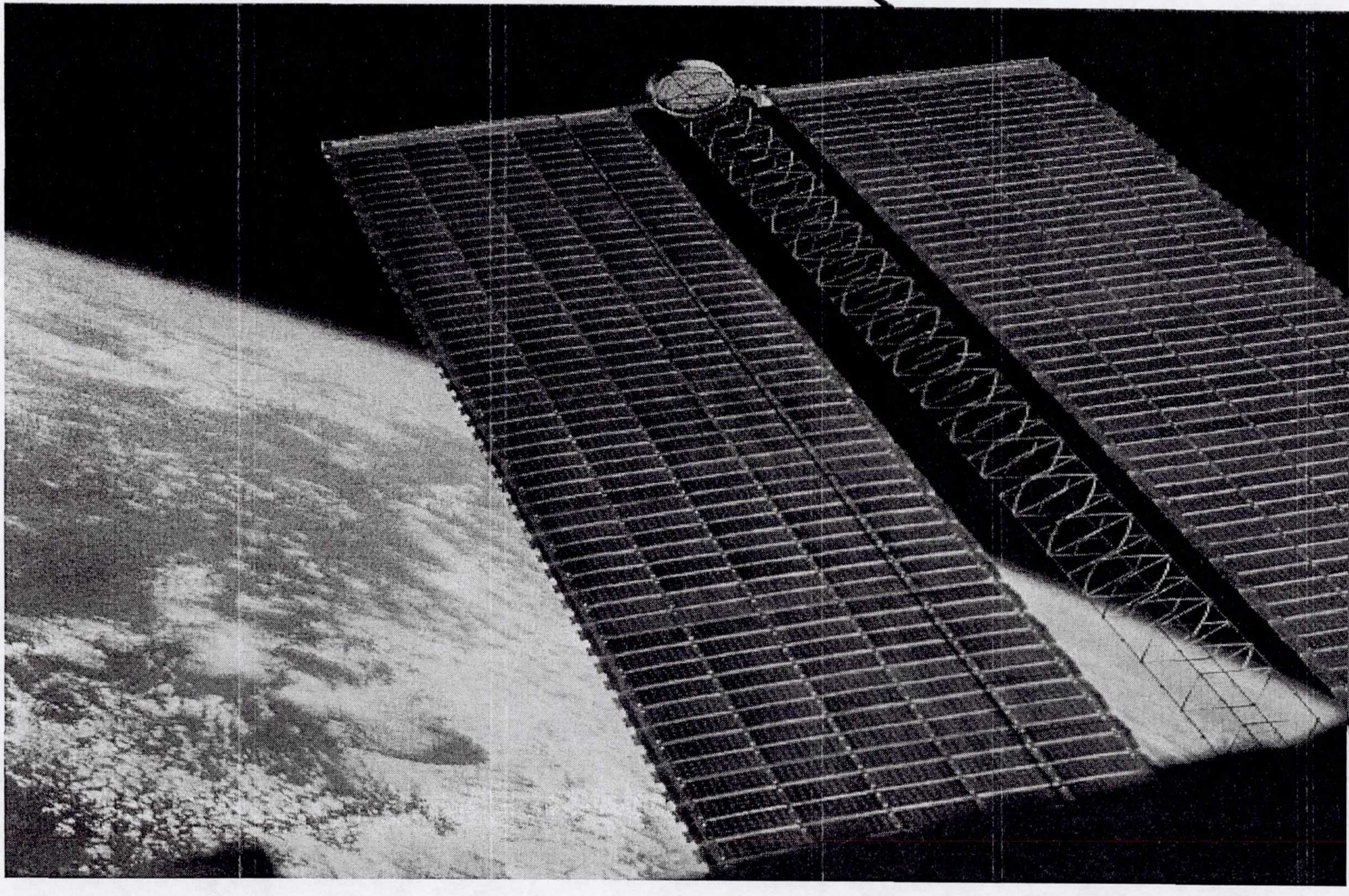
Other Design Factors to Consider

- Safety
- System Mass
- System Area
- System Volume
- Spacecraft Constraints & Interfaces
- Thermal Environment
- Maintenance Requirements
- Deployment Techniques
- Fault Analysis



Part III

SOLAR PHOTOVOLTAIC POWER SYSTEMS



Solar Photovoltaic Power Systems

A typical Photovoltaic (PV) Array consists of:

Solar Cells

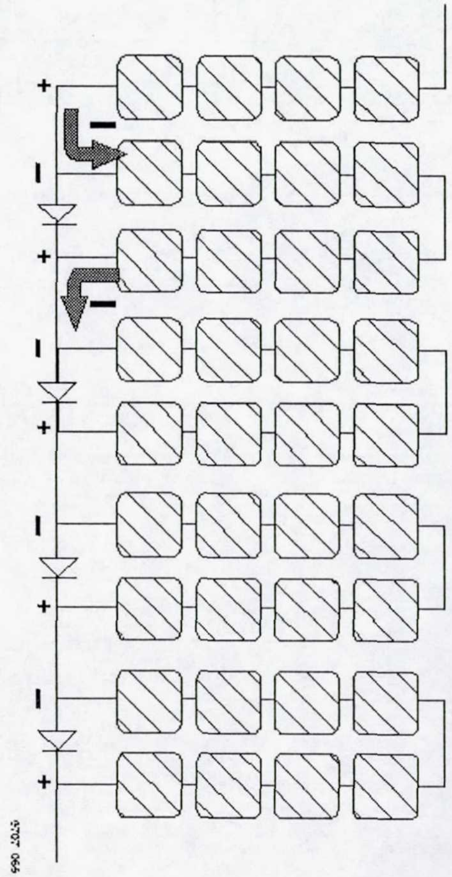
Electrical Connections Between Cells

Bypass Diodes

Substrates

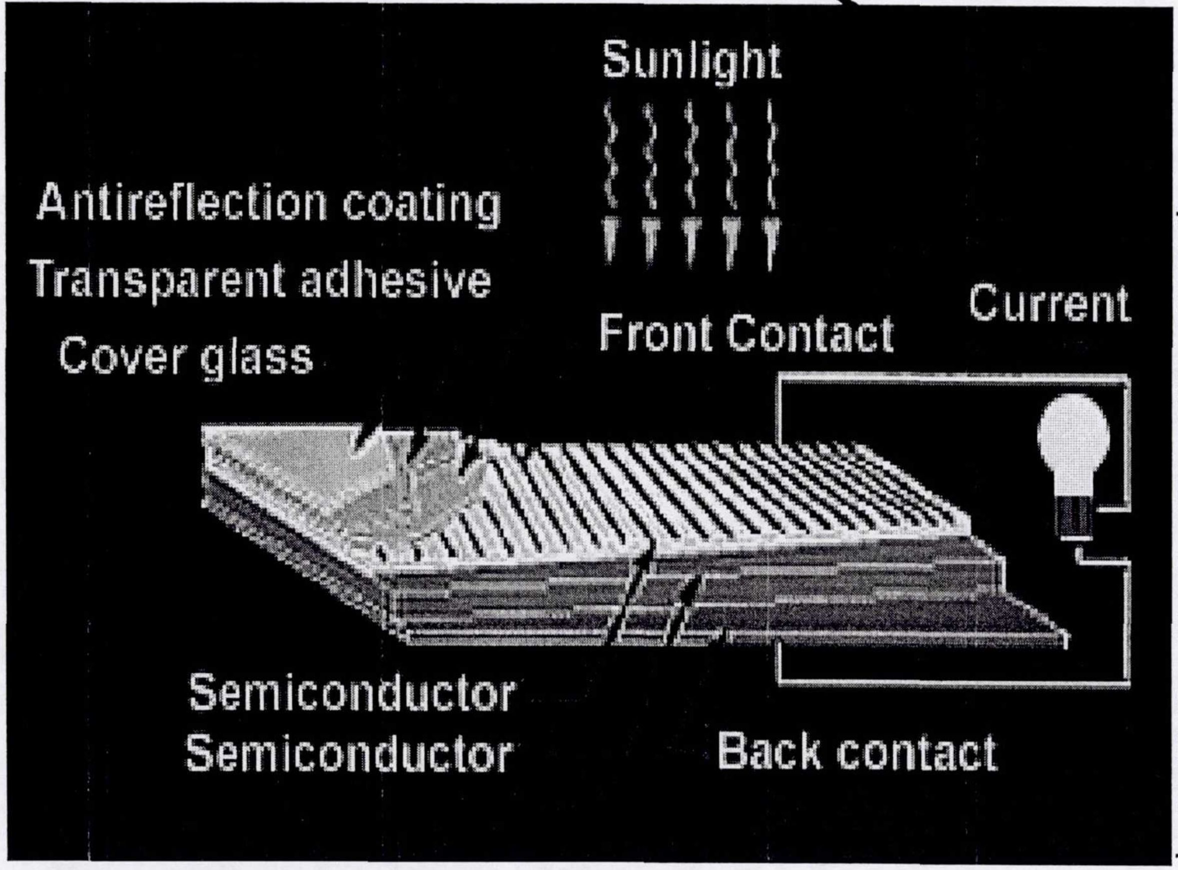
Boom and Deployment Mechanisms

Pointing Mechanisms



Solar Photovoltaic Power Systems

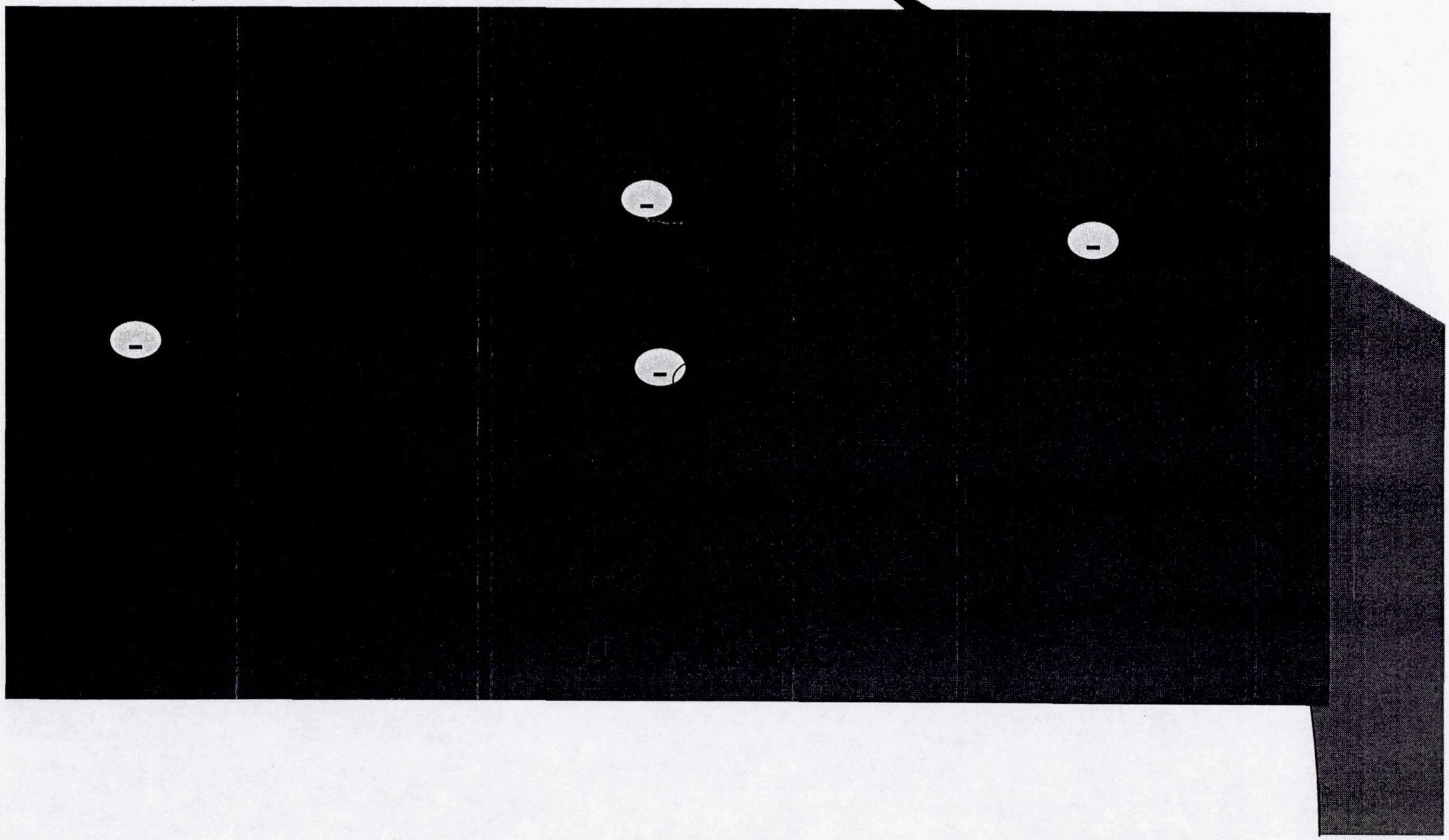
A Typical Solar Cell



(FROM U.S. DEPT. OF ENERGY)

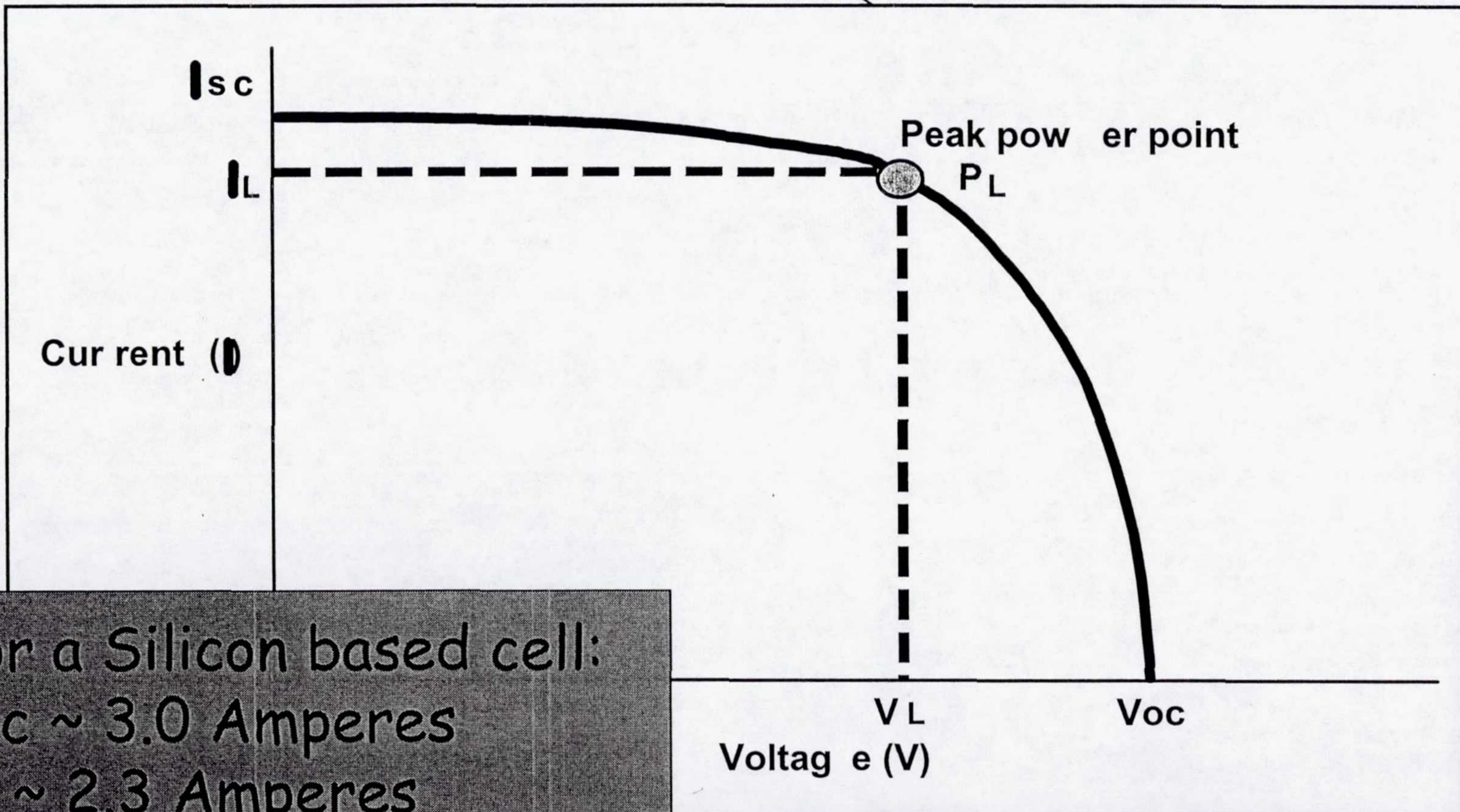
Solar Photovoltaic Power Systems

What Makes Charges Flow in Solar Cells?



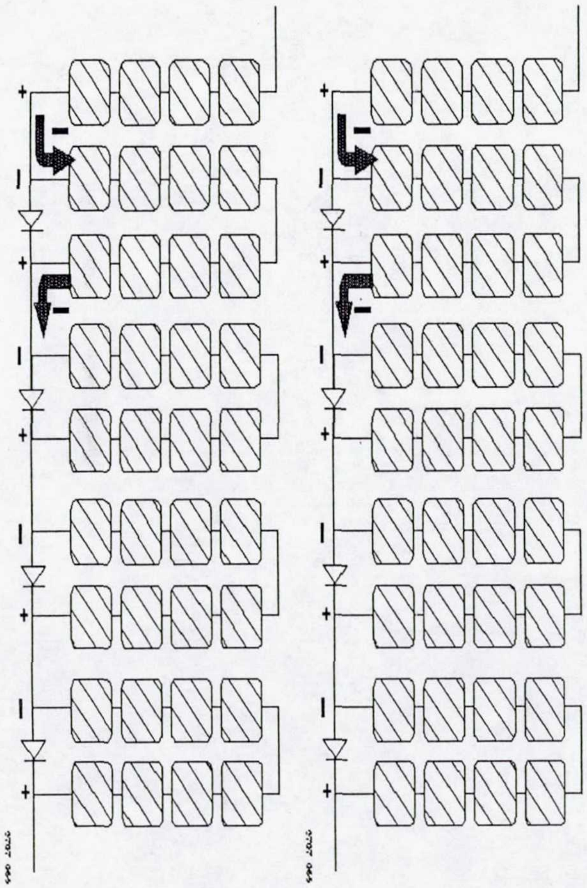
Solar Photovoltaic Power Systems

Typical Solar Cell Current-Voltage Characteristic



For a Silicon based cell:
- Isc ~ 3.0 Amperes
- I_L ~ 2.3 Amperes
- V_L ~ 0.5 Volts
- Voc ~ 0.6 Volts

Solar Photovoltaic Power Systems



How Do We Get The Desired Voltage?

We connect the solar cells in SERIES...

0.5 Volts + 0.5 Volts + 0.5 Volts +...

How Do We Get The Desired Current?

We connect strings of solar cells in PARALLEL...

2.3 Amperes + 2.3 Amperes + 2.3 Amp...

The current produced is influenced primarily by the AREA OF THE CELL And by the INTENSITY OF LIGHT incident on the cell

Solar Photovoltaic Power Systems

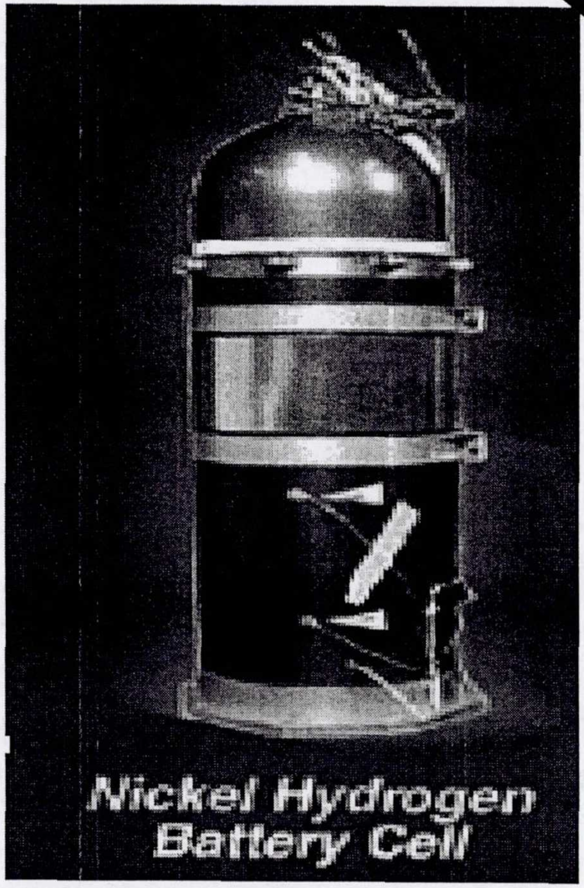
Types of Solar Cells

Solar Cell Type	Efficiency	Voltage @ Pmax
Silicon	15%	0.6
Gallium Arsenide	19%	0.9
Concentrator	21%	2.2
Triple Junction	30%	2.3

Four Junction cells are currently being developed and are expected to reach efficiencies of 40%

Part IV

Energy Storage For Space Power Systems

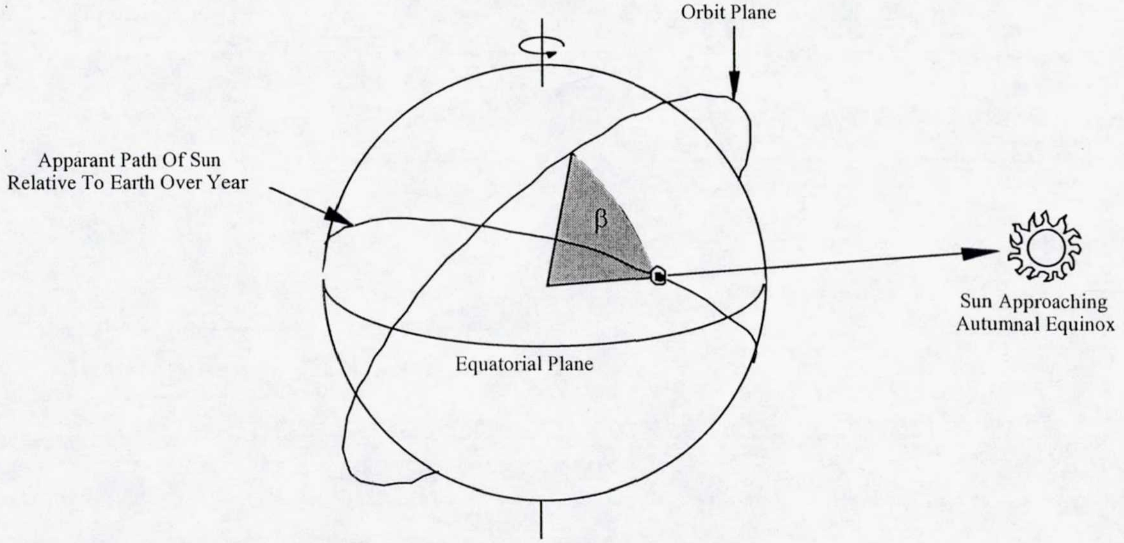


Energy Storage for Space Power Systems

Power systems in orbit need ENERGY STORAGE whenever the Earth or the Orbiting Structure **SHADOWS** the Spacecraft

Duration of ECLIPSE periods influenced by Solar Beta Angle

Solar Beta Angle Is The Angle Between The Orbit Plane And The Vector To The Sun



Solar Beta Angle Changes Throughout The Year Because Of Inertial Precession Of The Orbit Plane And The Earth's Orbit Around The Sun

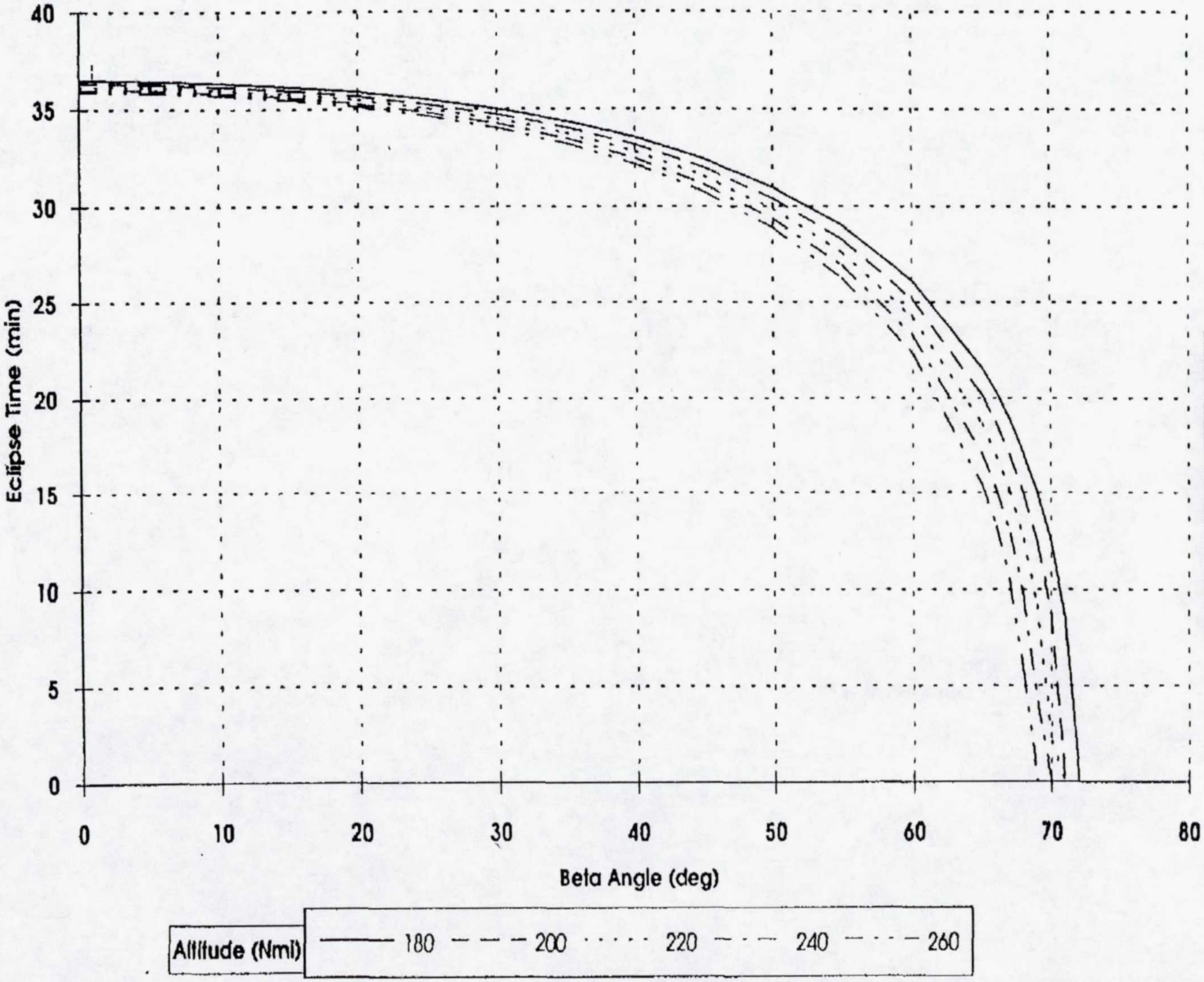
Energy Storage for Space Power Systems

Energy Storage Systems are replenished during sunlit periods of orbit (INSOLATION)

Energy Storage Systems are depleted during dark periods of orbit (ECLIPSE or SHADOW)

Energy Storage for Space Power Systems

Orbit Eclipse Time vs. Solar Beta Angle



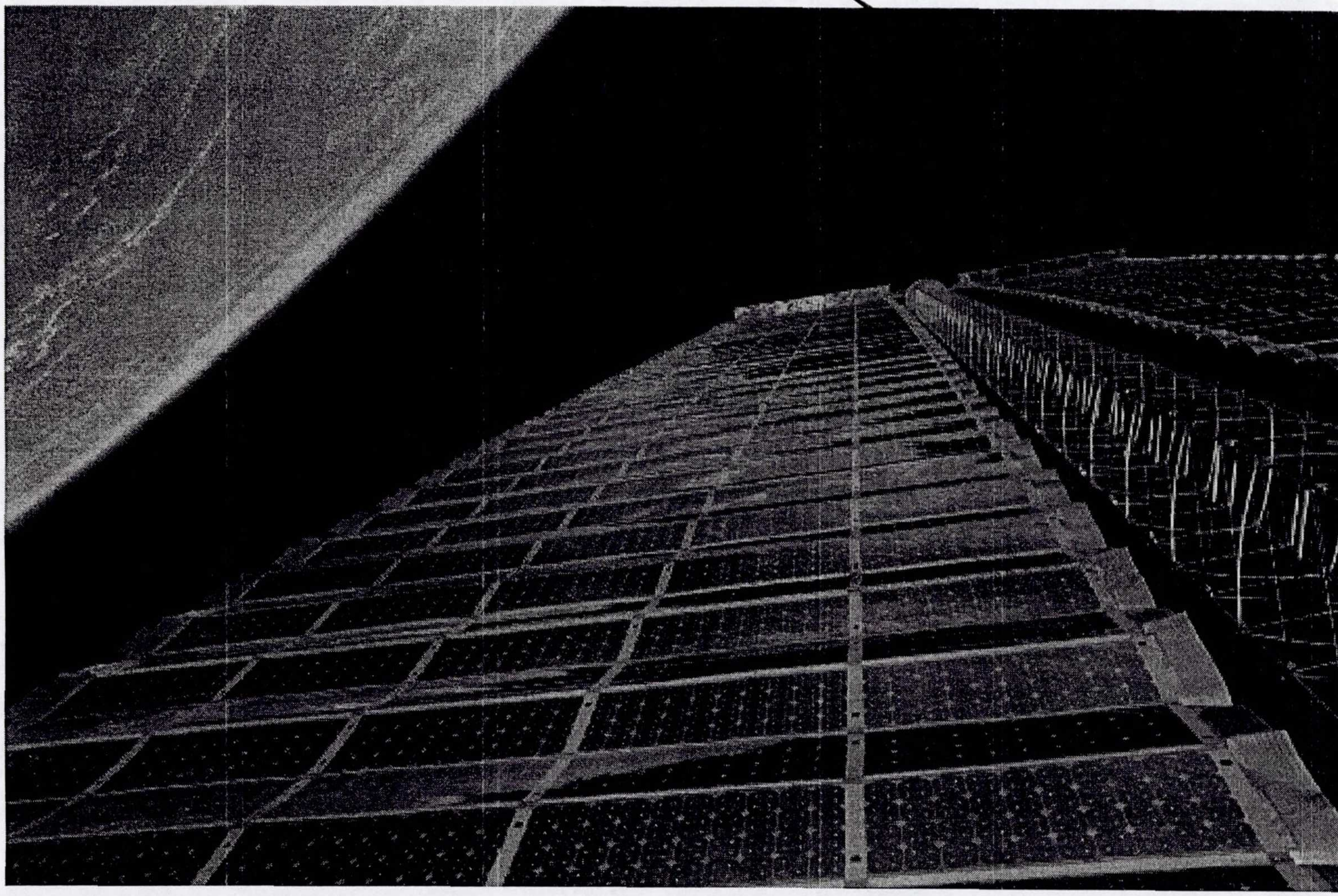
Energy Storage for Space Power Systems

For long missions such as a Space Station (15+ years), a RECHARGEABLE SYSTEM is preferred

RECHARGEABLE SYSTEM = BATTERIES

Battery Type	NiCd	NiH_2	NiMH	Li-ion	NaS
Specific Energy	39 W-hr/kg	70 W-hr/kg	--	150 W-hr/kg	110 W-hr/kg
Temp Limits	-40,+158 Deg F	+23,+68 Deg F	+23,+68 Deg F	-40,+158 Deg F	572 Deg F
Self Discharge	20% 1 month	60% 1 month	60% 1 month	0.2% 1 month	~0% 1 month
Charge Voltage	1.3 V	1.4 V	1.4 V	4.1 V	2.1 V
Discharge Voltage	1.2 V	1.3 V	1.3 V	3.7 V	1.8 V

Part V
Challenges of Operating Power Systems in Earth Orbit



Challenges of Operating Power Systems in Earth Orbit

Atomic Oxygen - prevalent [illegible] Low Earth Orbit
- ca[illegible]ses m[illegible]erials to erode

Radiation - m[illegible]re pr[illegible] t [illegible]her altitudes
- c[illegible] se [illegible]ilure of
[illegible]

Orbital Debr[illegible] [illegible]ginati[illegible]
[illegible]ft

Micrometeoroi[illegible] [illegible]riginating [illegible]
[illegible] asteroids or co[illegible]

Debris sizes range f[illegible] [illegible]limeters to 10's of centime[illegible]
to entire stages of l[illegible]nch vehicles ... BIG!

Debris impacts occur at 22,000 miler per hour!

Challenges of Operating Power Systems in Earth Orbit

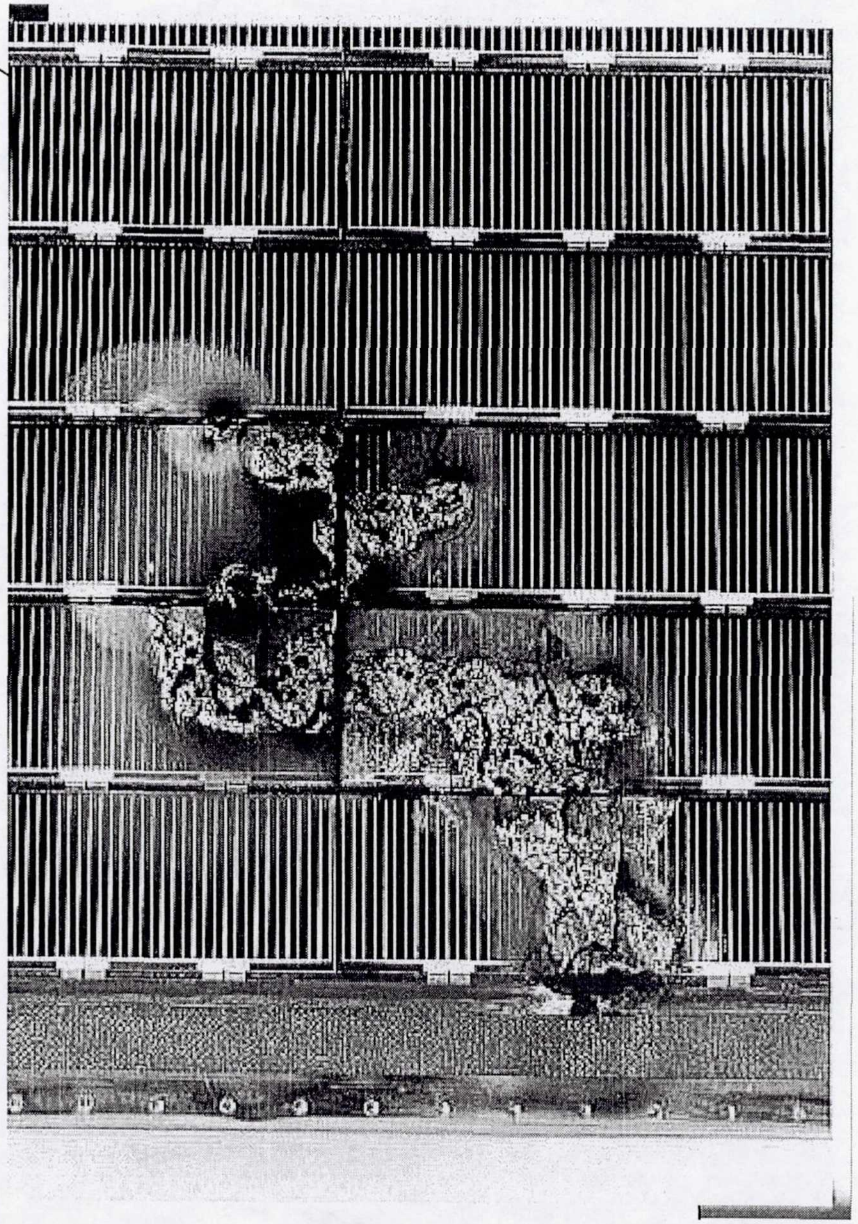
Plasma Environment – consists of electrons and positively ionized atoms or molecules

Positive surfaces on the Spacecraft, for example solar cells, collect the negatively charged electrons from the plasma

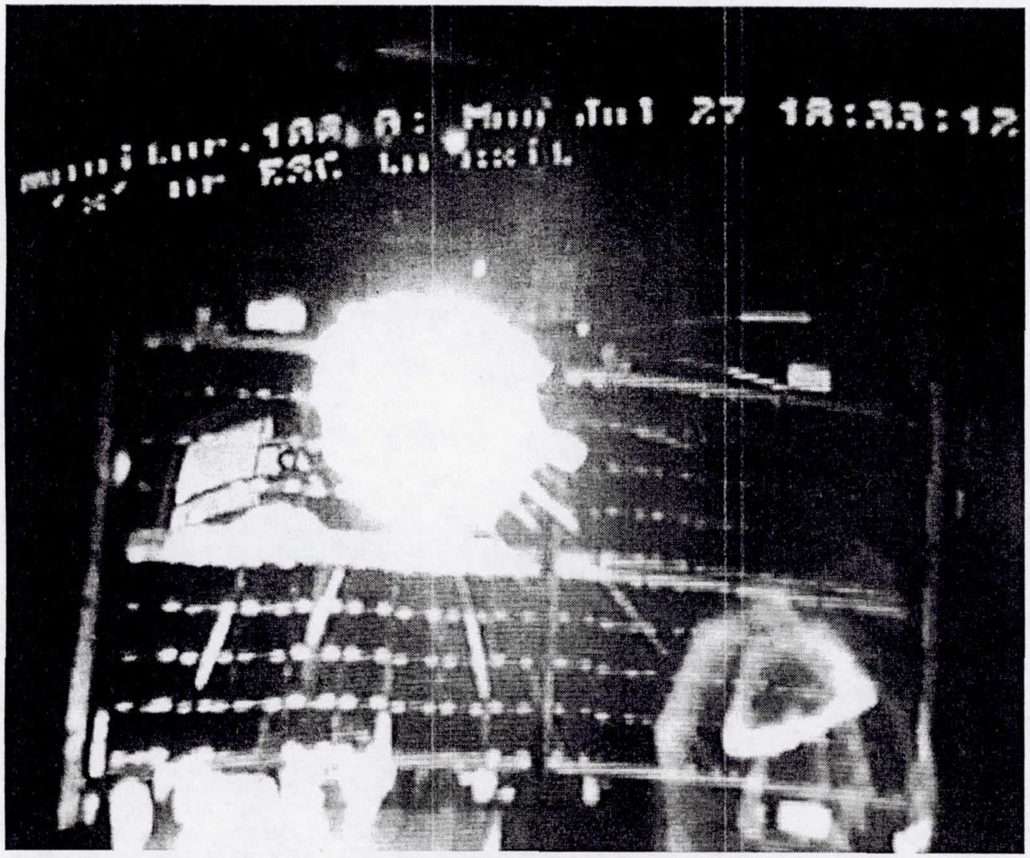
Negative surfaces on the Spacecraft can suffer from electrical arcing if the conditions are conducive

Challenges of Operating Power Systems in Earth Orbit

Flight Array from Eureca Mission

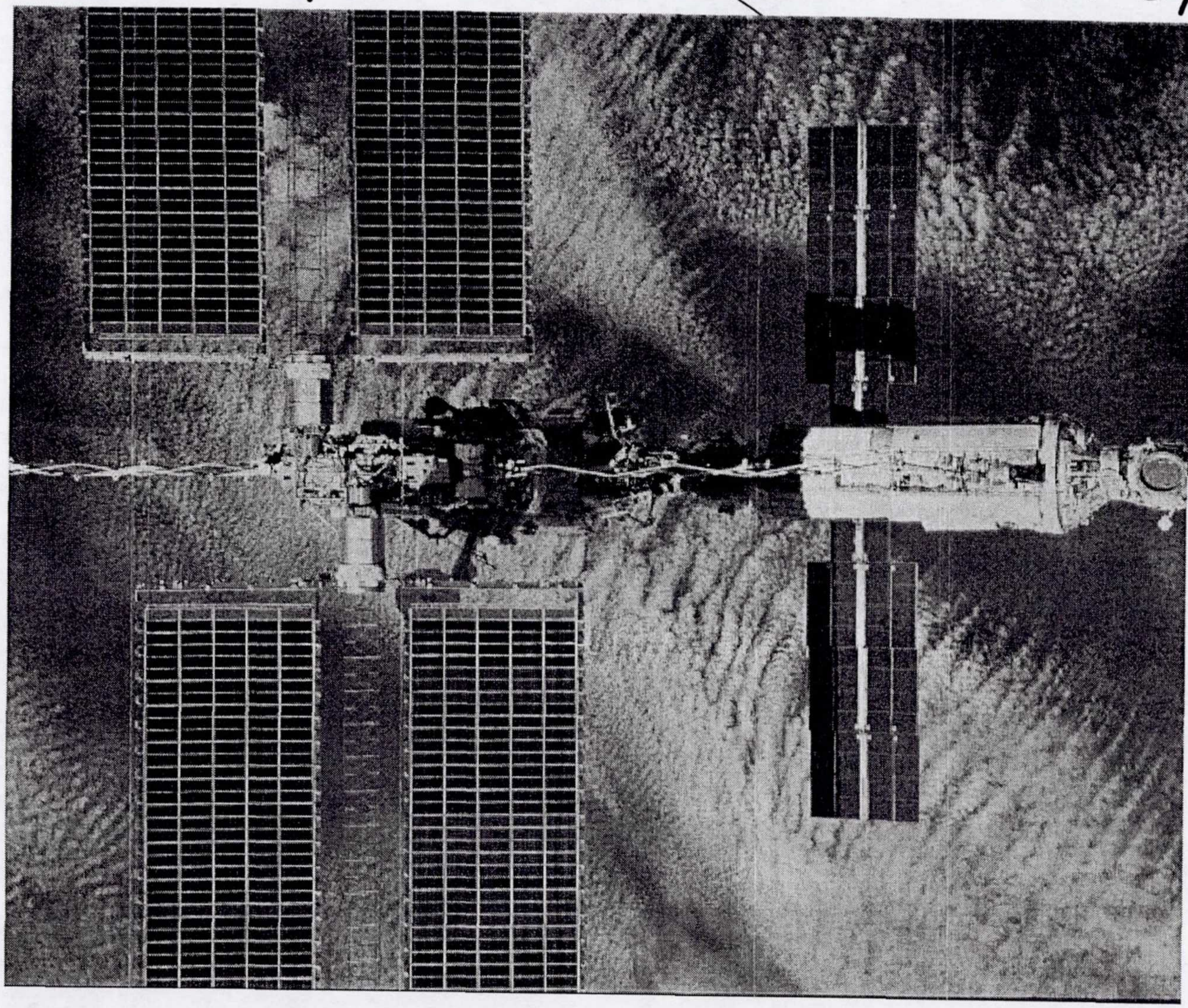


EOS Array during test



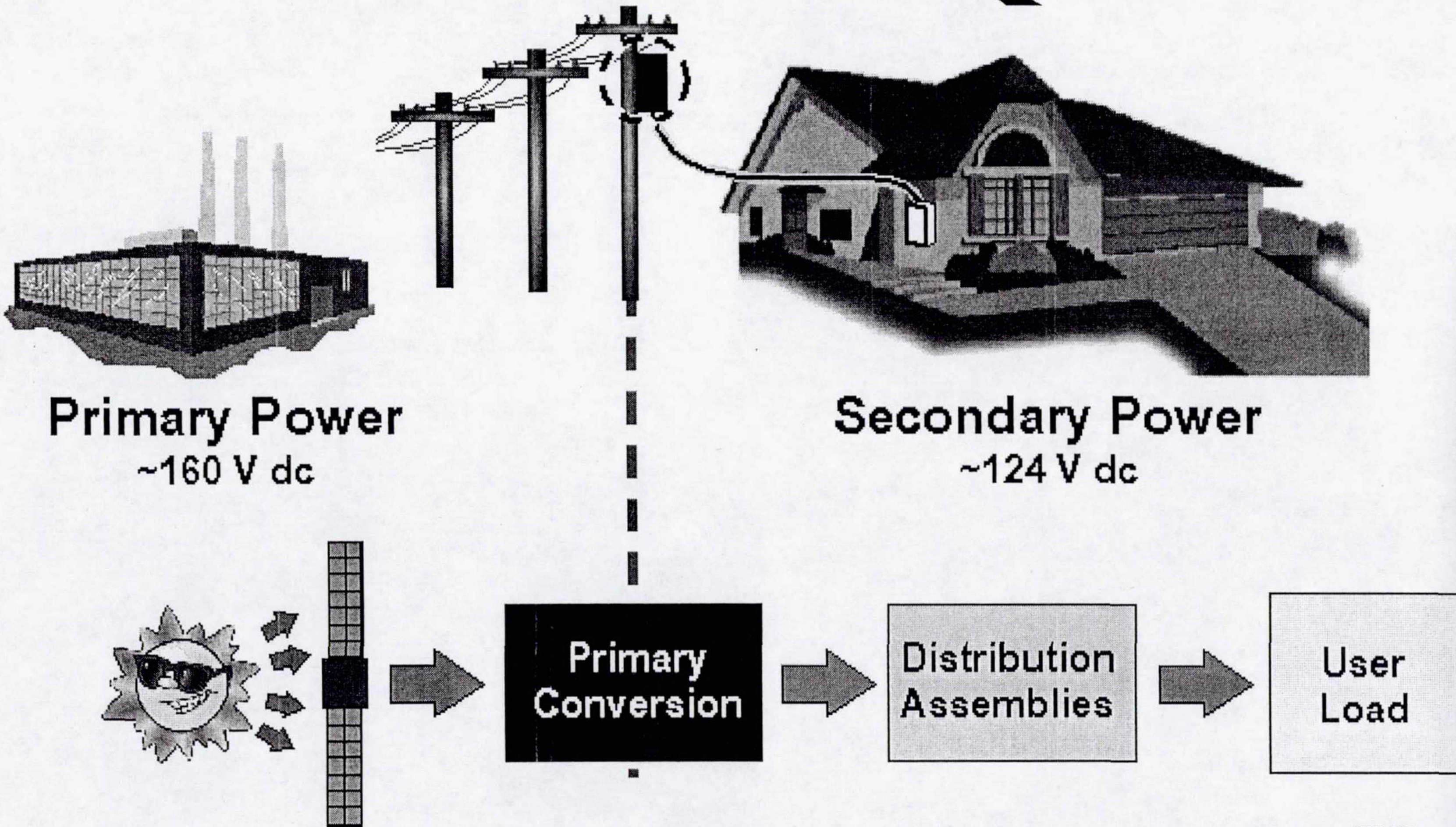
Part VI

International Space Station Electrical Power System



International Space Station Electrical Power System

Distributed Power Systems on The International Space Station

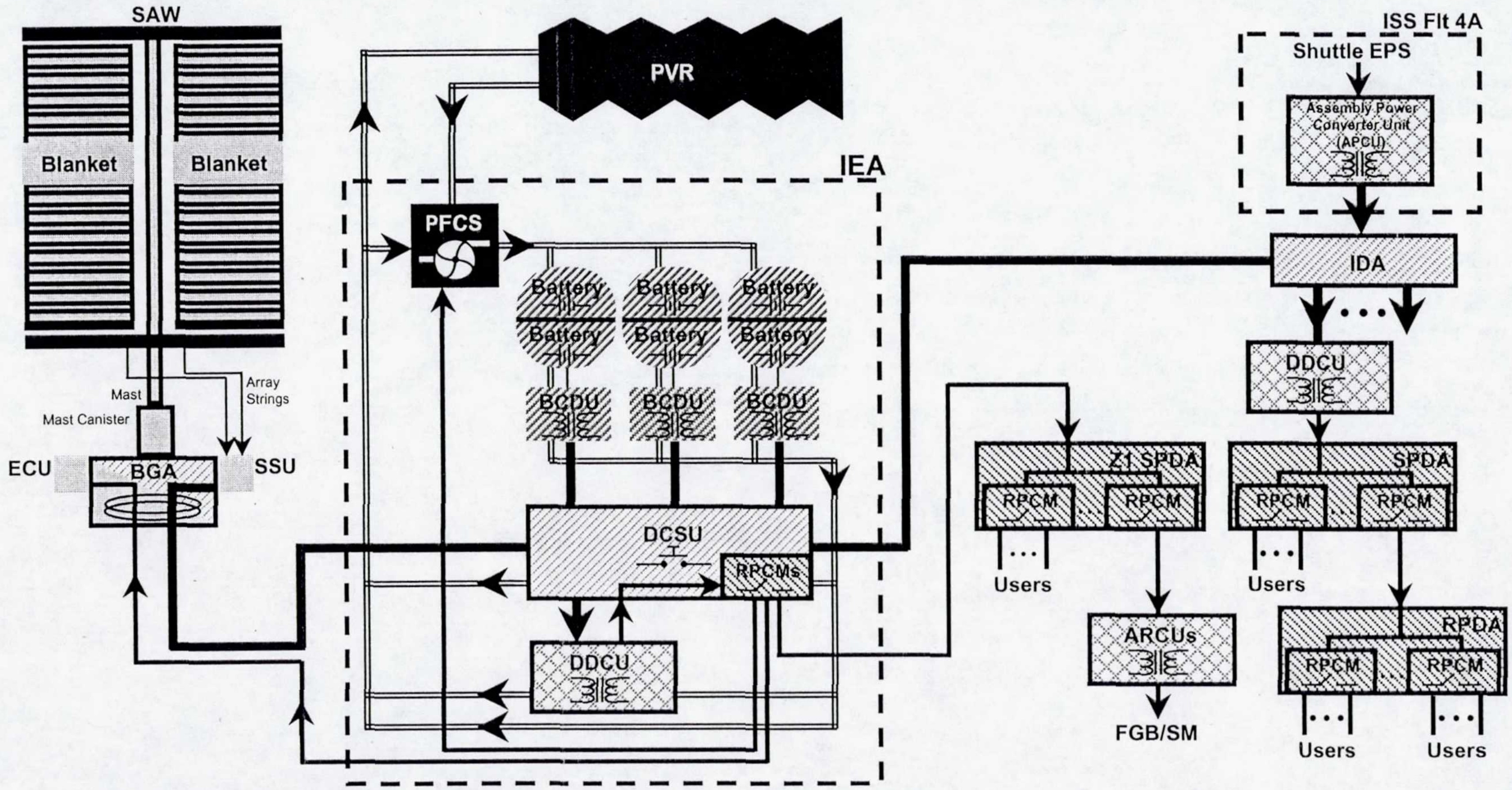


International Space Station Electrical Power System

REFER TO ISS 8A EPS CONFIGURATION

ISS 8A US Electrical Power System

Rev B - 1/29/98



Legend: Primary Power Flow — Secondary Power Flow — Thermal Cooling Flow

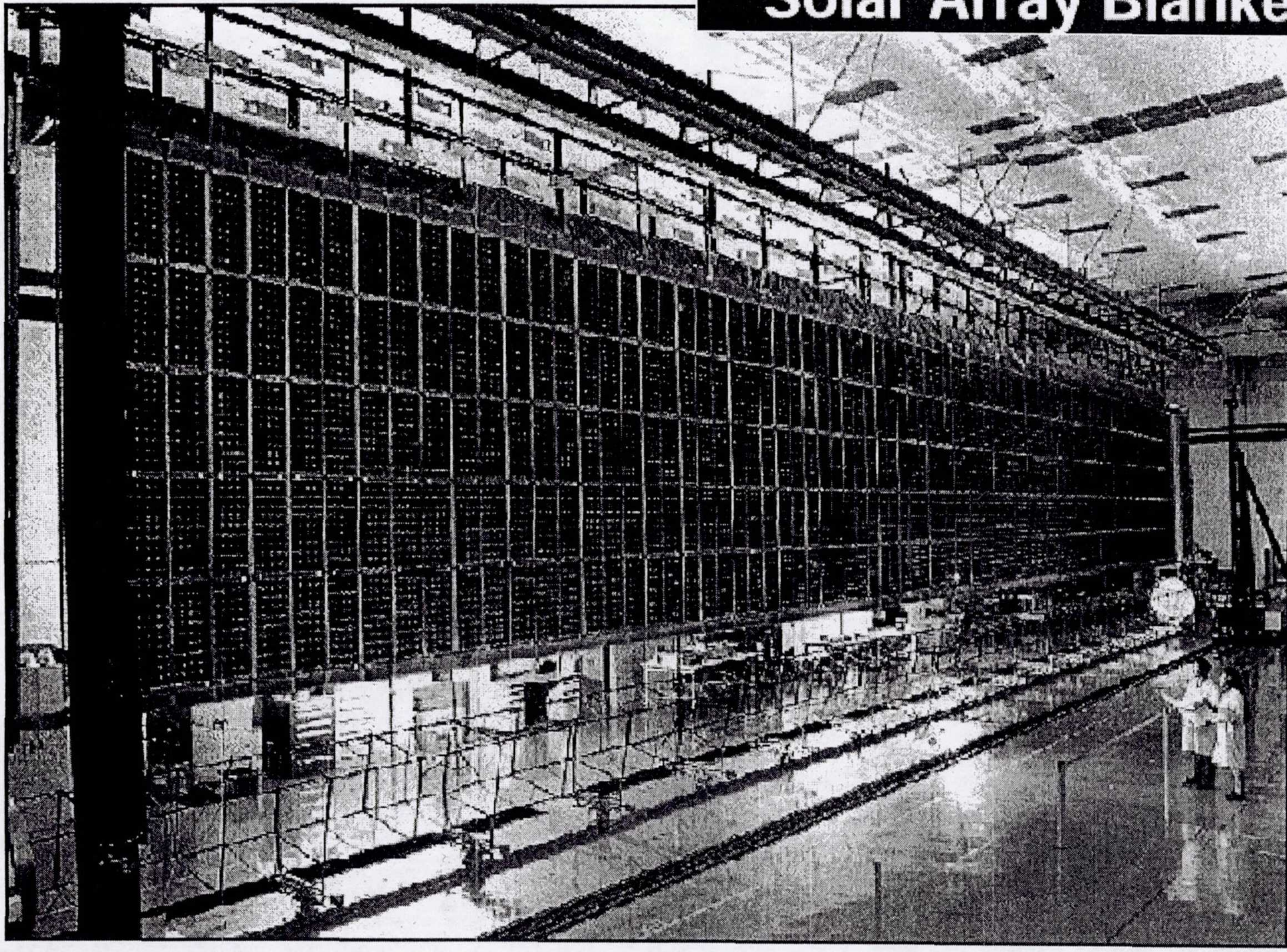
Power Generation — Power Storage — Primary Power Distribution — Power Conversion — Secondary Power Distribution — Photovoltaic Thermal Control System (PVTCS)

Acronyms:

- ARCU - American to Russian Converter Unit
- BCDU - Battery Charge/Discharge Unit
- BGA - Beta Gimbal Assembly
- DCSU - Direct Current Switching Unit
- DDCU - DC to DC Converter Unit
- ECU - Electronics Control Unit
- IDA - Integrated Diode Assembly
- IEA - Integrated Equipment Assembly
- PFCS - *Pump Flow Control Subassembly*
- PVR - PhotoVoltaic Radiator
- RPCM - Remote Power Controller Module
- RPDA - Remote Power Distribution Assembly
- SAW - Solar Array Wing (also called PVA - Photovoltaic Array)
- SPDA - Secondary Power Distribution Assembly
- SSU - Sequential Shunt Unit

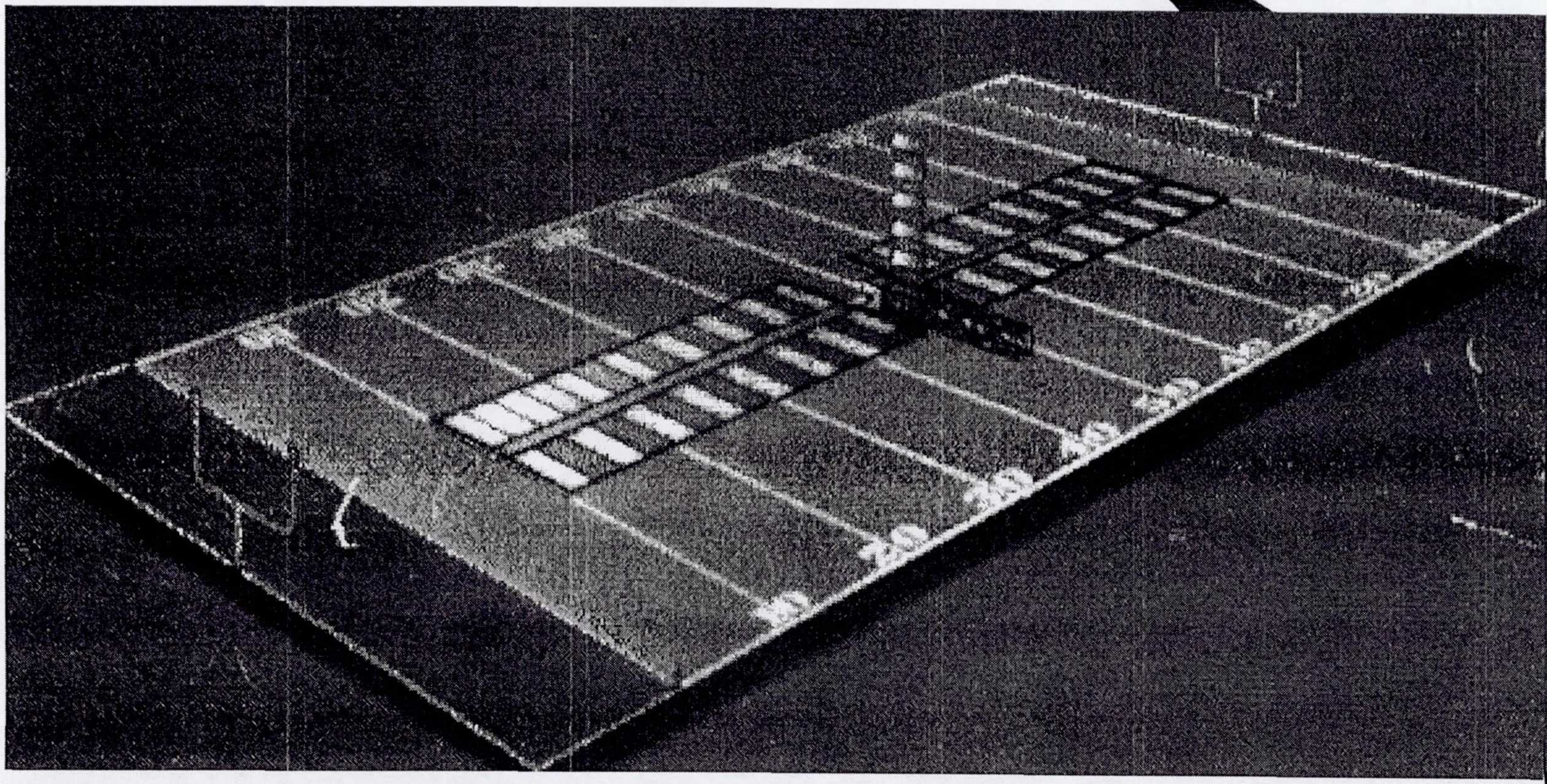
International Space Station Electrical Power System

Solar Array Blanket



International Space Station Electrical Power System

Each Solar Cell is 3.2x3.2 inches
Cells are grouped into 82 Strings each containing 400 cells
32,800 Solar Cells on each Solar Array Wing
Each Solar Array Wing is 104 feet long



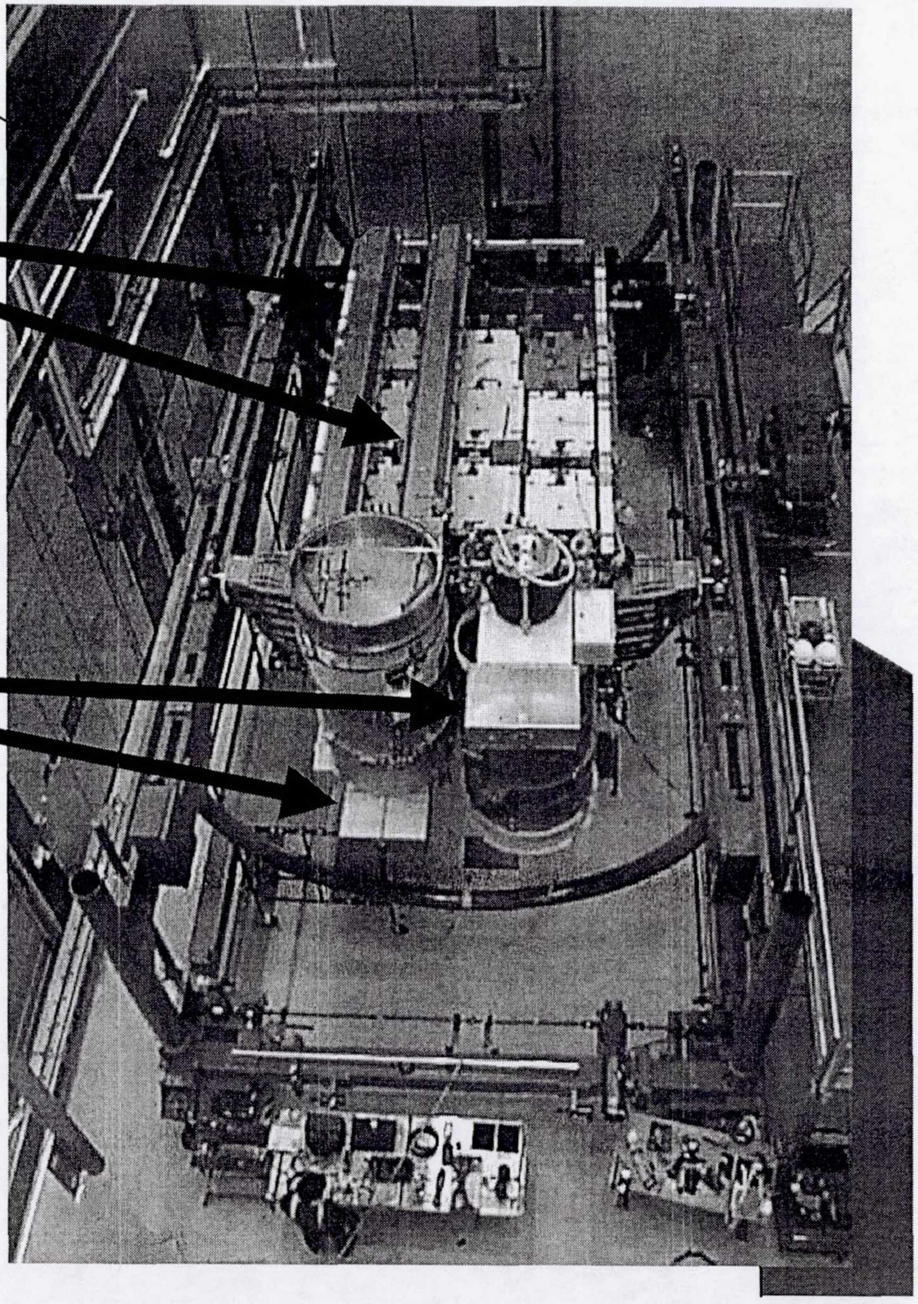
International Space Station Electrical Power System

Solar Array Blanket Boxes

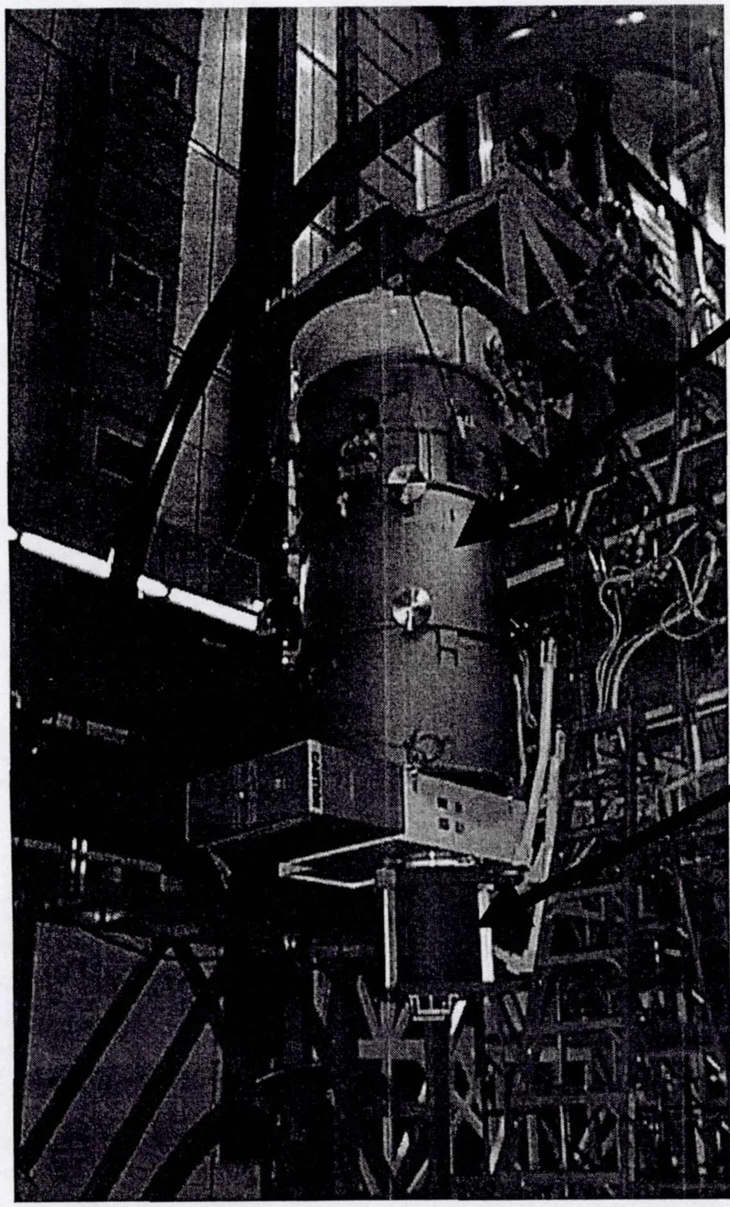
- Storage containers for Solar Array Blankets
- Deployment mechanisms

Sequential Shunt Units

- Regulates the Energy collected from the Solar Arrays to a preselected Voltage Setpoint
- Adjusts the Current to meet the demand of the loads



International Space Station Electrical Power System



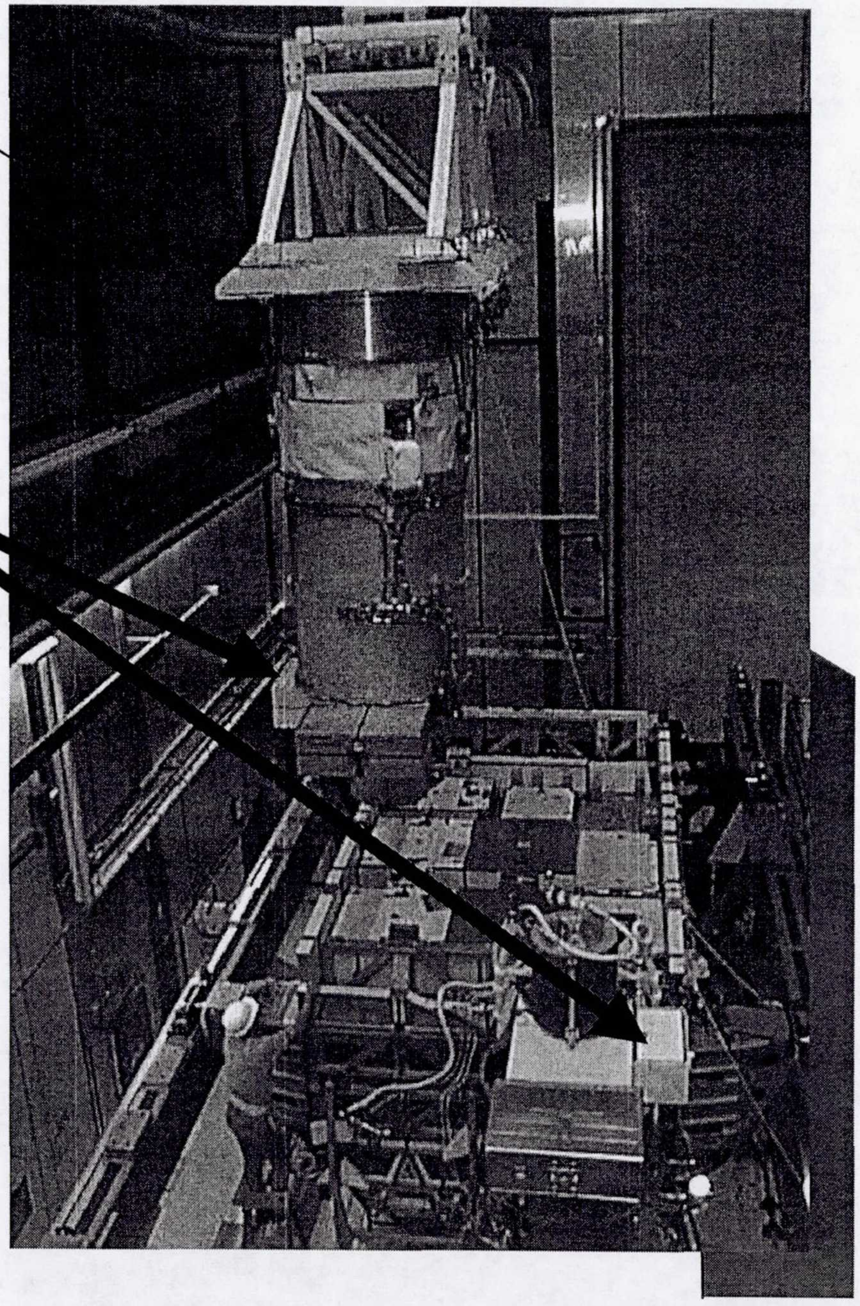
Solar Array Wing Mast Canister

- Storage container for SAW Mast
- SAW deployment mechanisms

BETA GIMBAL ASSEMBLY

- Gimbals the Solar Array Wing to a commanded position
- Provides 360 degree rotation

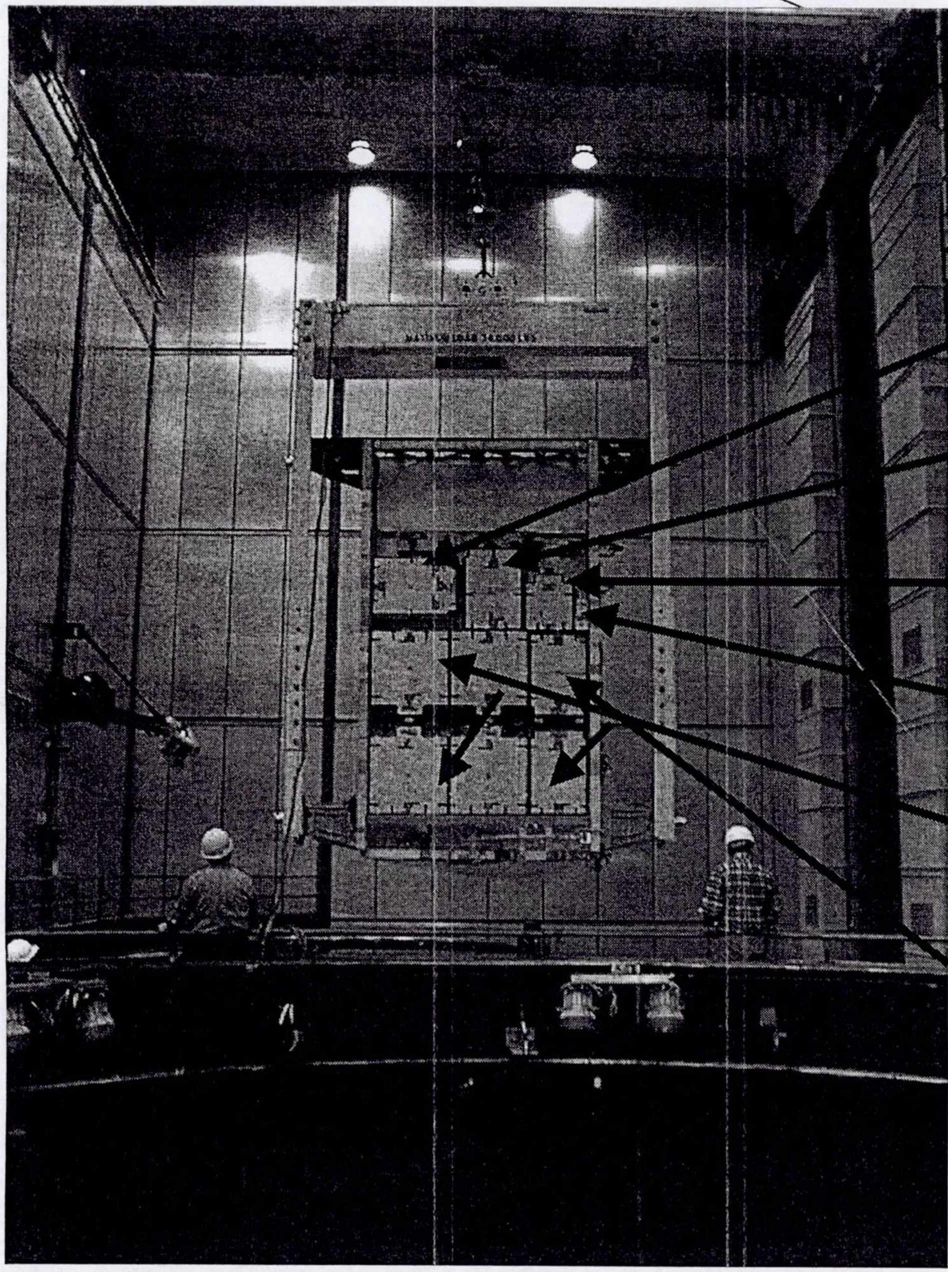
International Space Station Electrical Power System



Electronics Control Unit

- Computer controller for the Solar Array Blanket Box and Beta Gimbal Assembly mechanisms

International Space Station Electrical Power System



Integrated Equipment Assembly

Thermal System Pump (PFCS)

Primary Power Relay Unit (DCSU)

Power Converter Unit (DDCU)

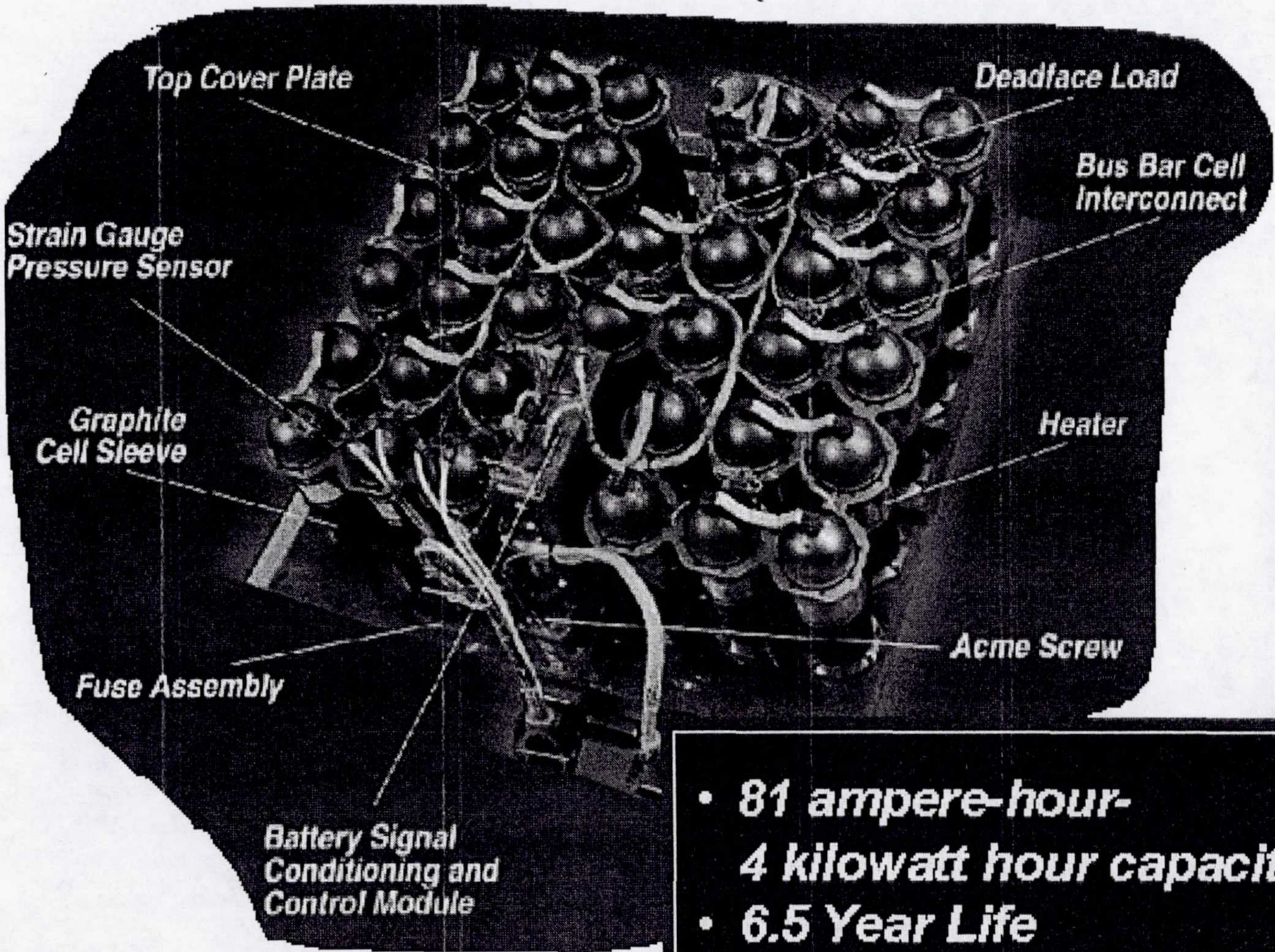
Power System Computer (PVCU MDM

Batteries

Battery Charge Controllers (BCDU)

International Space Station Electrical Power System

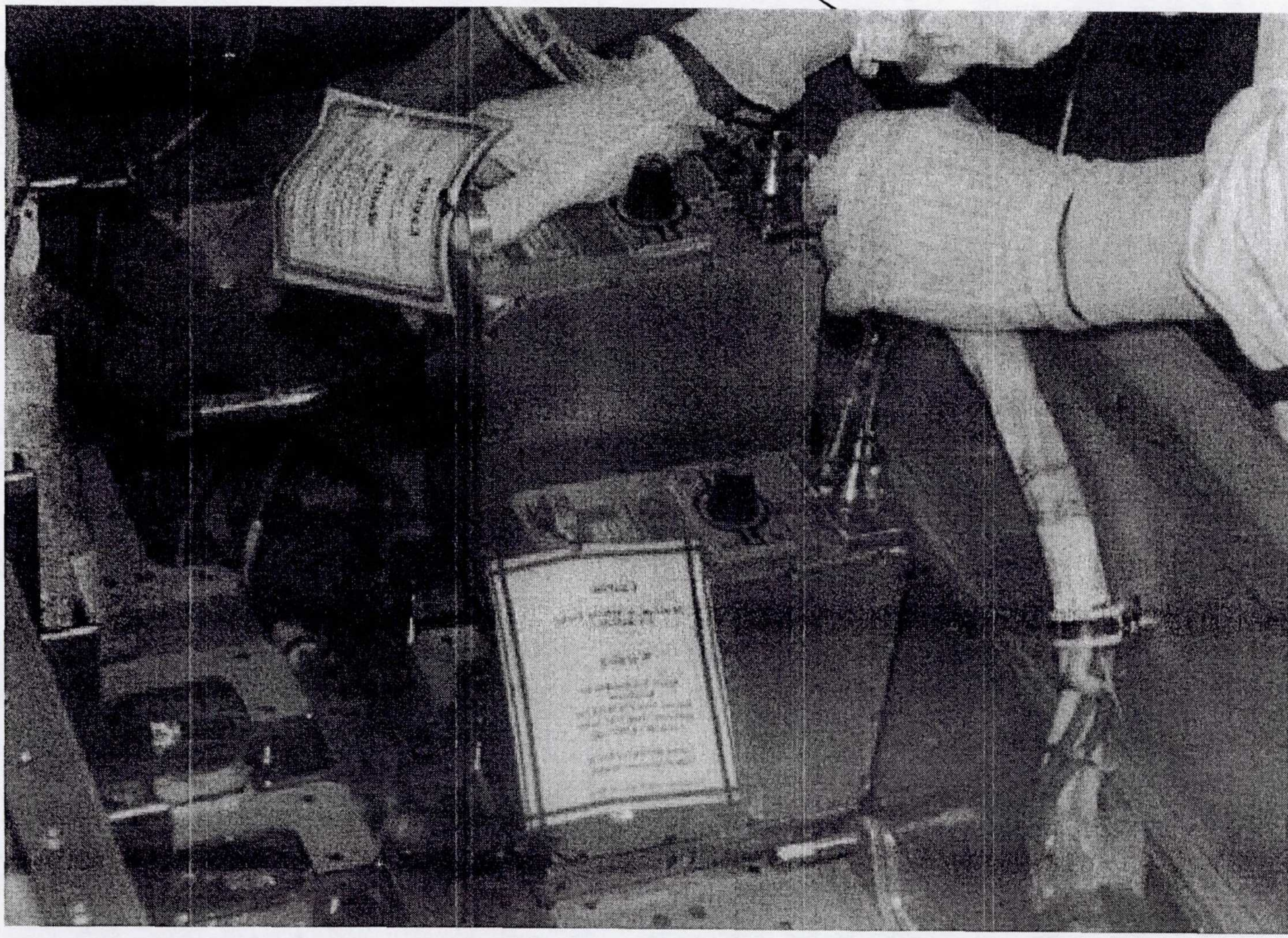
Batteries - 38 NiH_2 Battery Cells Wired in Series



- 81 ampere-hour-
  4 kilowatt hour capacity
- 6.5 Year Life
- 38,000 orbit cycles

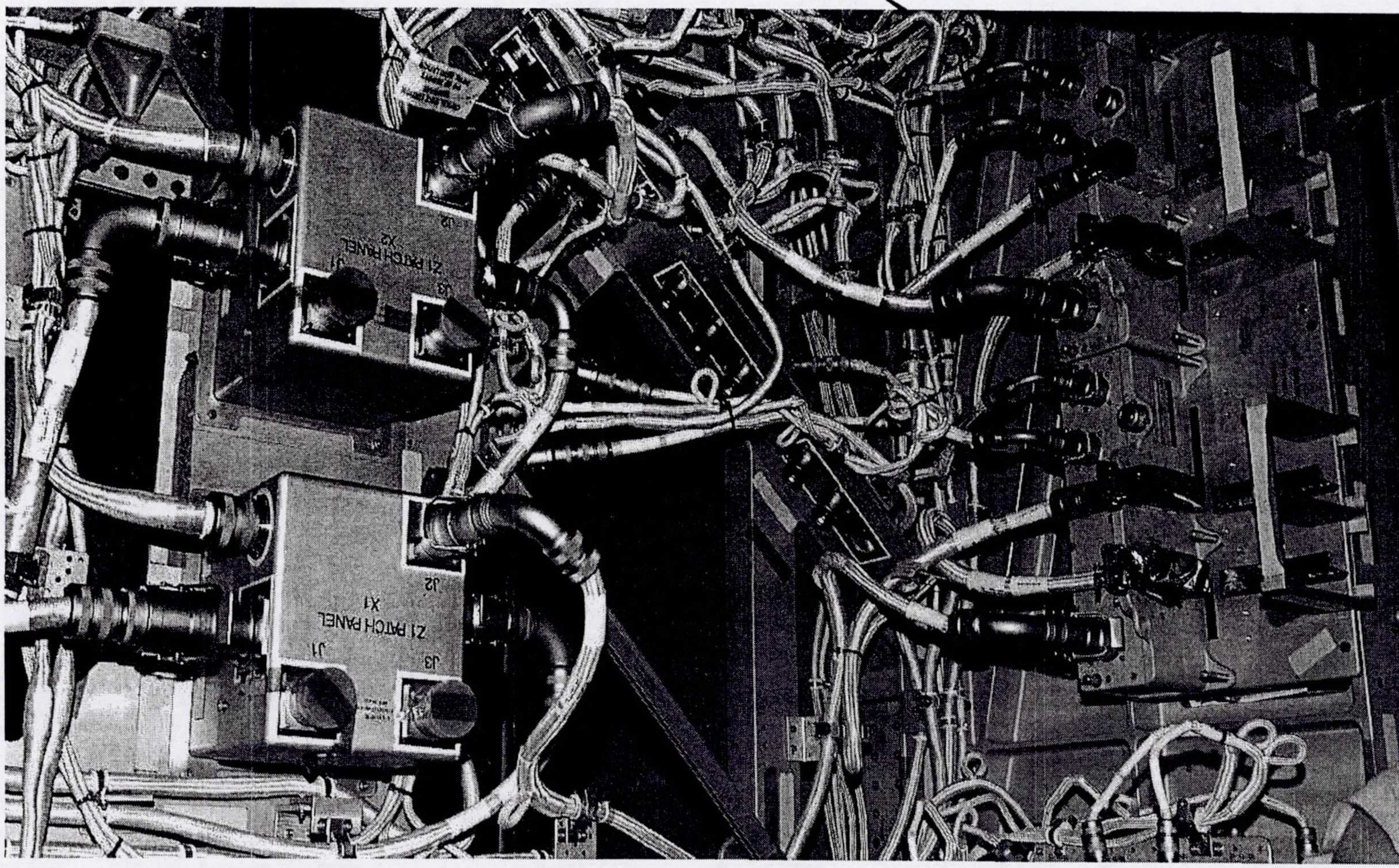
International Space Station Electrical Power System

Secondary Power Relay Unit (RPCM)

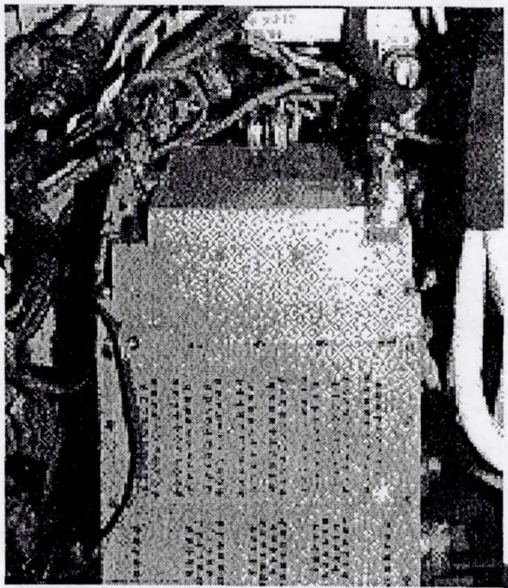


International Space Station Electrical Power System

Secondary Power Routing Junctions (Patch Panels)

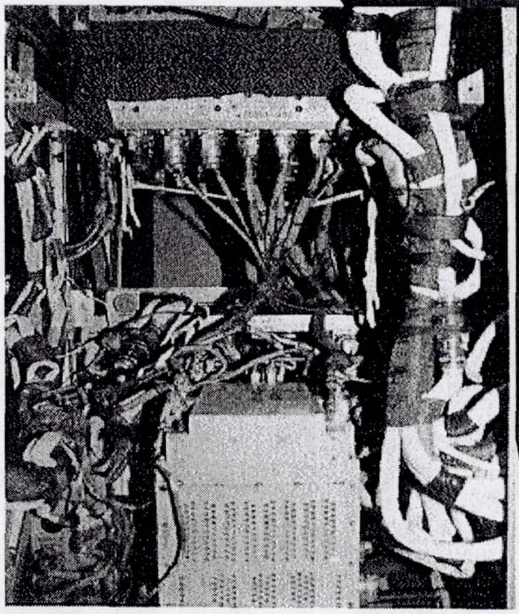


International Space Station Electrical Power System



Russian-to-American Converter Unit (RACU)

- Converts Russian power @ 28 Volts to US secondary power (124 Volts)



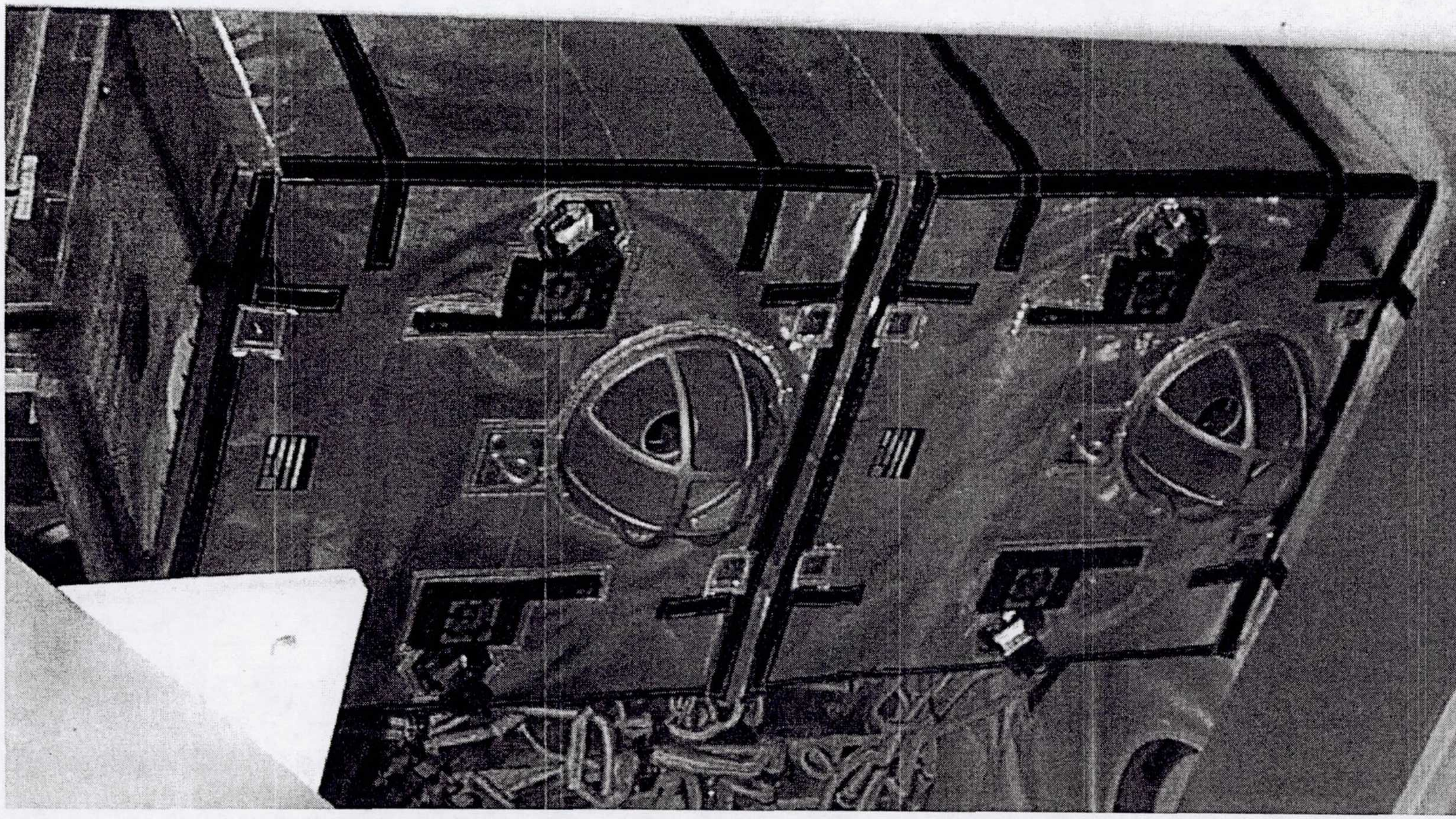
American-to-Russian Converter Unit (ARCU)

- Converts US secondary power (124 Volts) to Russian power @ 28 Volts

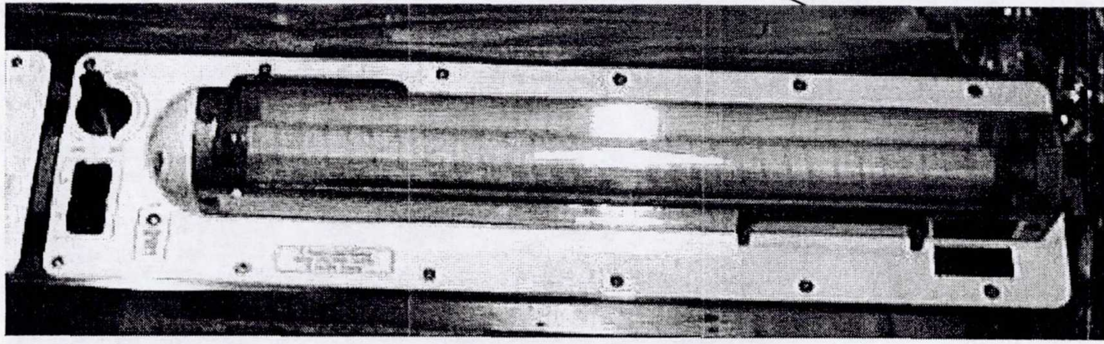
International Space Station Electrical Power System

Plasma Contactor Units

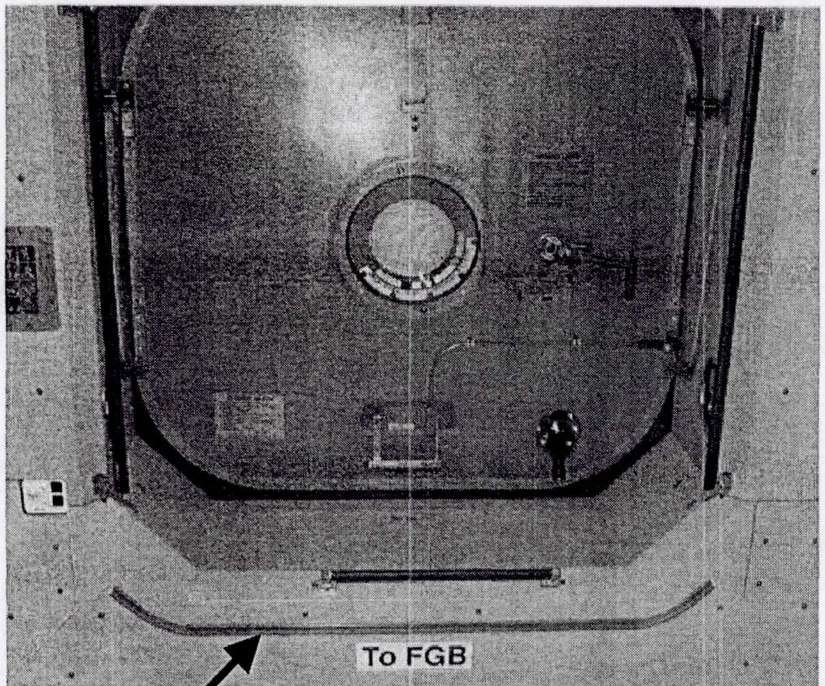
Provides a path for the electrons which collect on spacecraft surfaces to flow - NO ARCING!



International Space Station Electrical Power System

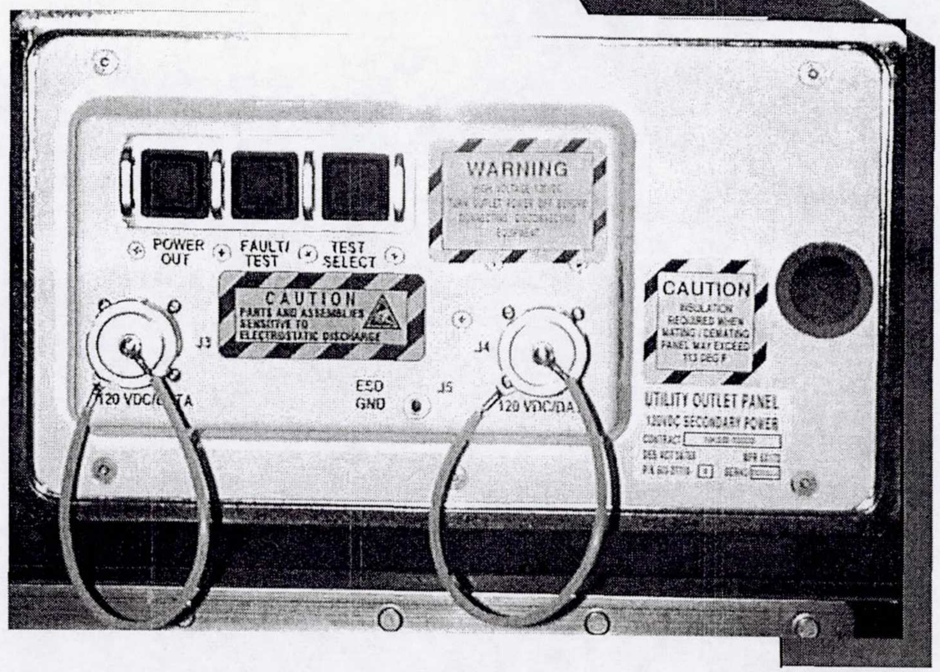


General Use Lights



Emergency Egress Lights

Utility Outlet Panels



International Space Station Electrical Power System