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SURFACE PHENOMENA IN PLASMA ENVIRONMENTS*

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PLASMA-SYSTEM INTERACTIONS PHENOMENA

From the viewpoint of plasma interactions, a space system may be regarded as a collection of conducting and insulating surfaces with active power generation and distribution systems in motion through the ionospheric or magnetospheric plasma and the Earth's magnetic field. The system comes into electrical equilibrium with the plasma by acquiring surface potentials such that the net current to the system as a whole, and to individual insulating surfaces is zero. This equilibration establishes the system and surface potentials relative to the plasma. It is a dynamic equilibrium, and the potentials will change whenever there is a change in the current densities to surfaces or the system. Higher energy environment components ($\geq$50 KeV) also cause charge deposition in insulators and radiation damage. These aspects are considered by others in this workshop and will not be discussed further here.

A SPACE SYSTEM IS A COLLECTION OF CONDUCTING AND INSULATING SURFACES WITH ACTIVE POWER GENERATION AND DISTRIBUTION COMPONENTS MOVING THROUGH AN ELECTRICALLY CHARGED "GAS" AND THE EARTH'S MAGNETIC FIELD.

o SYSTEM EQUILIBRATES ELECTRICALLY WITH PLASMA

  -- SUM OF CURRENTS = 0
  -- "GLOBAL" FOR CONDUCTORS (MUST INCLUDE INDUCED VXB.L POTENTIALS)
  -- POINT-BY-POINT FOR INSULATION

o ESTABLISHES SYSTEM AND SURFACE POTENTIALS RELATIVE TO PLASMA

o EQUILIBRIUM IS DYNAMIC: CHANGES WITH ANY CHANGE IN CURRENT DENSITIES

  -- NATURAL ENVIRONMENT
  -- ORBITAL POSITION/ORIENTATION
  -- EFFLUX
  -- "APPLIED" VOLTAGE VARIATIONS
  -- PARTICLE EMISSION BY VEHICLE
  -- ARCING, IONIZATION IN SHEATH
  -- ETC, ETC

HIGHER ENERGY ENVIRONMENT COMPONENTS ALSO CAUSE CHARGE DEPOSITION IN INSULATORS AND RADIATION DAMAGE

SYSTEM DRIVERS FOR PLASMA INTERACTIONS

The potentials and fields around orbital systems depend on the material properties which contribute to the currents which must be balanced (conductivities, secondary and photoelectron yields, dielectric properties, sputter yields, thickness of films, etc.), on local and overall geometry, and on electrical configuration, as well as on the plasma properties. Included in "local geometry" are the properties of adjacent materials, the presence of edges or holes in insulation, and local electric and magnetic fields produced by the system itself or by the equilibration process. Overall geometry includes the system and subsystem size and shape, and the orientation of surfaces to the system's orbital velocity vector, the Earth's magnetic field, and the Sun. Electrical configuration includes the system-produced voltage and current levels and frequencies, the insulation (or lack of same) of conductors from the plasma, and the electrical grounding scheme of the system. The importance of these various factors in determining the potential and field structures around the system will depend on the orbital altitude and inclination.

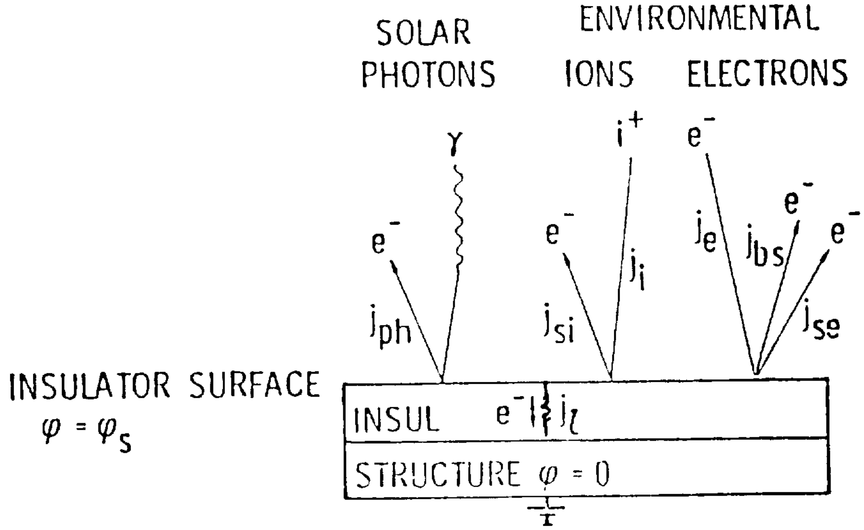
POTENTIALS AND FIELDS AROUND ORBITAL SYSTEMS DEPEND ON

- MATERIAL PROPERTIES OF STRUCTURE AND SURFACES
  - CONDUCTIVITIES/RESISTIVITIES
  - SECONDARY AND PHOTOYIELDS
  - DIELECTRIC CONSTANT AND STRENGTH
  - CHEMISTRY
  - THICKNESS
- GEOMETRY
  - LOCAL SURROUNDINGS
    - ADJACENT MATERIALS
    - EDGES, HOLES
    - LOCAL $\vec{E}$ AND $\vec{B}$ FIELDS
  - OVERALL
    - SYSTEM SUBSYSTEM SIZE
    - ORIENTATION TO $\vec{v}$
    - ORIENTATION TO $\vec{B}_E$
    - ORIENTATION TO SUN (GEO)
- ELECTRICAL CONFIGURATION
  - SYSTEM-PRODUCED VOLTAGE AND CURRENT LEVELS AND FREQUENCIES
    - EXPOSED AND INSULATED
  - GROUNDING SCHEME

CHARGING RESPONSE

The charging response of a surface in a plasma may be illustrated by considering the simple case of an insulating surface element, and the current densities which must be balanced to obtain net zero current, as is shown in the figure. The sources of current density to the surface element are environmental electrons and ions, secondary and backscattered electrons produced by these primaries, leakage current through the insulator, and, if sunlit, photoelectrons. For an isolated surface in a plasma, i.e., ignoring photoelectrons and leakage current, the rule of thumb is that the surface will charge negatively to a potential of the order of the electron temperature. The surface charges negatively because the electrons are much less massive than the ions, and consequently their flux is larger. This assumes that the electron and ion temperatures are approximately the same, which is true within a factor of about two for the orbital environments considered here.

SIMPLE CASE; CURRENT DENSITIES TO INSULATING SURFACE ELEMENT



SYMBOL	CURRENT DENSITY DUE TO
j_e	ENVIRONMENTAL ELECTRONS
j_i	ENVIRONMENTAL IONS
j_{ph}	PHOTO ELECTRONS
j_{se}	SECONDARY ELECTRONS DUE TO ELECTRON IMPACT
j_{bs}	BACKSCATTERED ELECTRONS
j_{si}	SECONDARY ELECTRONS DUE TO ION IMPACT
j_l	LEAKAGE THROUGH INSULATOR

EQUILIBRIUM CONDITION:

$$j_{net} = \sum_n j_n = 0$$

Thus, an isolated, shadowed body in a geosynchronous substorm environment, in which the electron temperatures are in the 10-15 KeV range, is expected to charge to kilovolts. This has been observed on the ATS-5, ATS-6 and Spacecraft Charging at High Altitudes (SCATHA) satellites in eclipse. Actually, these satellites charged to something less than the electron temperature because of secondary electron emission, but potentials of several kilovolts in eclipse were frequently observed; the record event charged ATS-6 to -19KV. In geosynchronous orbit, photoemission from sunlit surfaces is an important determinant of potentials because photoelectron current densities are of order $10^{-9}A/cm^3$, while environmental electron current densities are typically an order of magnitude less. Thus, in sunlight, the shadowed insulating surfaces of a spacecraft charge negatively while the sunlit surfaces stay near plasma potential until the negative potential on the shaded surfaces becomes large enough to form potential barriers on the sunlit side which suppress the emission of the low energy (T~2eV) photoelectrons, allowing the entire spacecraft to begin charging negatively. This process allows the development of kilovolt level differential potentials between various surfaces, with subsequent arc discharging and disruption of spacecraft systems as a consequence. In contrast to the geosynchronous case, the ionospheric plasma at low Earth orbit (LEO) has electron temperatures of order .1 eV, and electron current densities of order $10^{-5}A/cm^3$, so an isolated surface in this environment is expected to be within a volt of plasma potential, and photoemission does not play a large role. Another difference between the LEO and geosynchronous Earth orbit (GEO) cases is that the GEO plasma is so tenuous that potentials of a GEO system may be computed using Laplace's equation (i.e., ignoring space charge effects in the plasma) with appropriate boundary conditions on the surfaces and expressions for the current densities. However, in LEO, space charge plays an important role in sheath formation.

SHEATH RADIUS INCLUDING ELECTRON MOTION

A body immersed in a plasma will disturb the plasma in its vicinity. The region near the body in which the electric field is non-zero is the sheath. For a floating body, the scale size over which the plasma screens the charge on the body is the Debye length. For LEO plasmas the Debye length is on the order of cm. If a potential is applied to the body, the sheath dimension will be larger, and net current will be collected by the body. The figure illustrates a spherical space-charge limited sheath for the case of the applied **potential, ϕ much larger** than the electron and ion temperatures (θ_e and θ_i, respectively). This sphere is not in equilibrium with the plasma, but is collecting net electron current from it.

SPACE-CHARGE LIMITED SPHERICAL PROBE THEORY

sheath equations

$$\nabla^2 \phi = -\frac{\rho}{\varepsilon_0}$$

$$\rho = e\,(n_i - n_e)$$

$$n_i = n_0 \exp(-\phi / \theta_i) \cong 0$$

$$n_e = \frac{J_e}{e\,v_e}$$

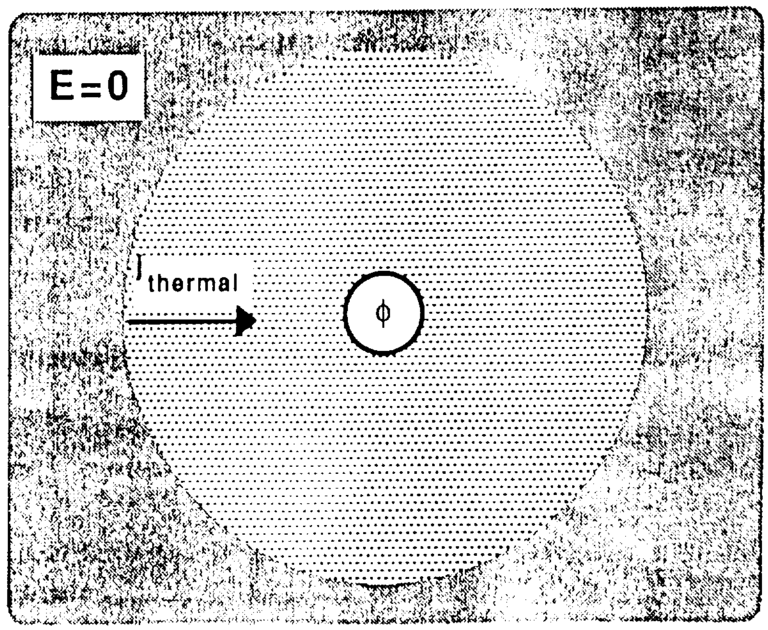
boundary conditions

$$\phi(r) = \phi_{sphere} \qquad \phi(R_{sheath}) \cong \theta_e$$

$$J_e(R_{sheath}) \cong J_{thermal}$$

result

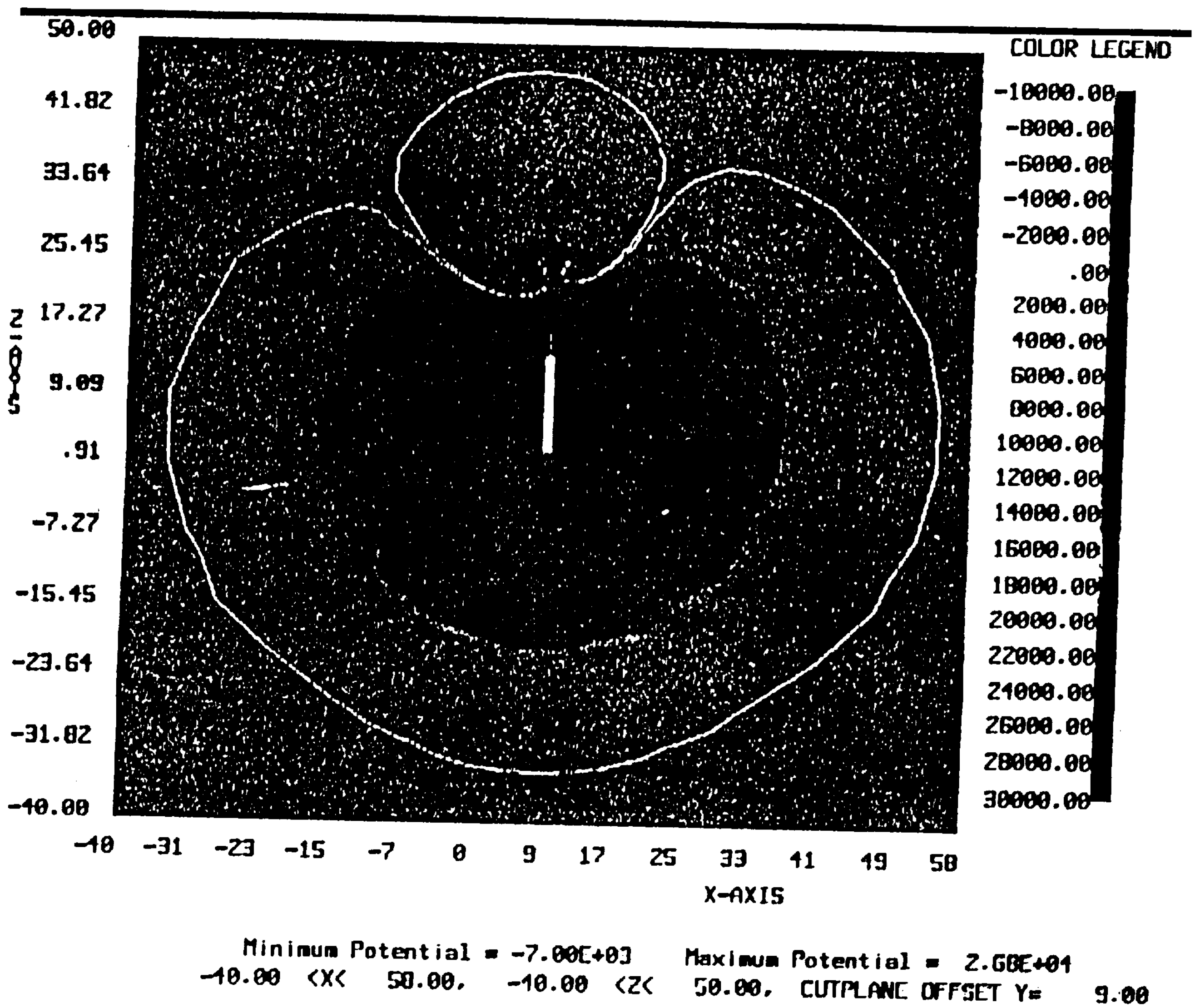
$$R_{sheath} = 9\ \mathrm{m}$$



S3-

SEPAR I
NASCAP*/LEO PLASMA SHEATH CALCULATION

A space system with a voltage applied between two parts will equilibrate by forming electron and ion sheaths such that (again!) the net current to the system is zero. The figure illustrates the electron and ion sheaths predicted around an object representing the SPEAR-I rocket experiment. The spheres on the top are biased positively with respect to the rocket body; the white lines show the sheath boundaries. Clearly, the sheath geometries are quite complex, even though the system geometry is relatively simple.



* NASA Charging Analyzer Program

NASCAP/LEO CALCULATION OF ELECTRON COLLECTION BY NON-SYMMETRICAL SHEATH

An additional complexity arises when the magnetic field is introduced. This figure illustrates the role of the magnetic field in altering electron current collection in the nonsymmetric sheath.

$n_e = n_i = 3 \times 10^{10}\ m^{-3}$

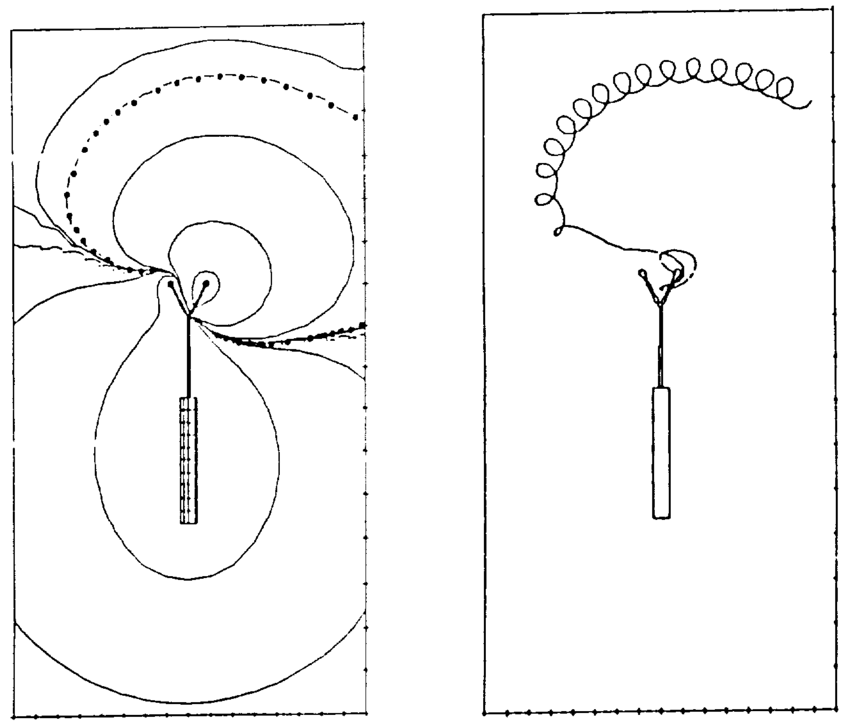
$\theta_e = \theta_i = 0.1\ eV$

$B = 0.4$ gauss

$\phi_{sphere\ 1} = 46\ kV$

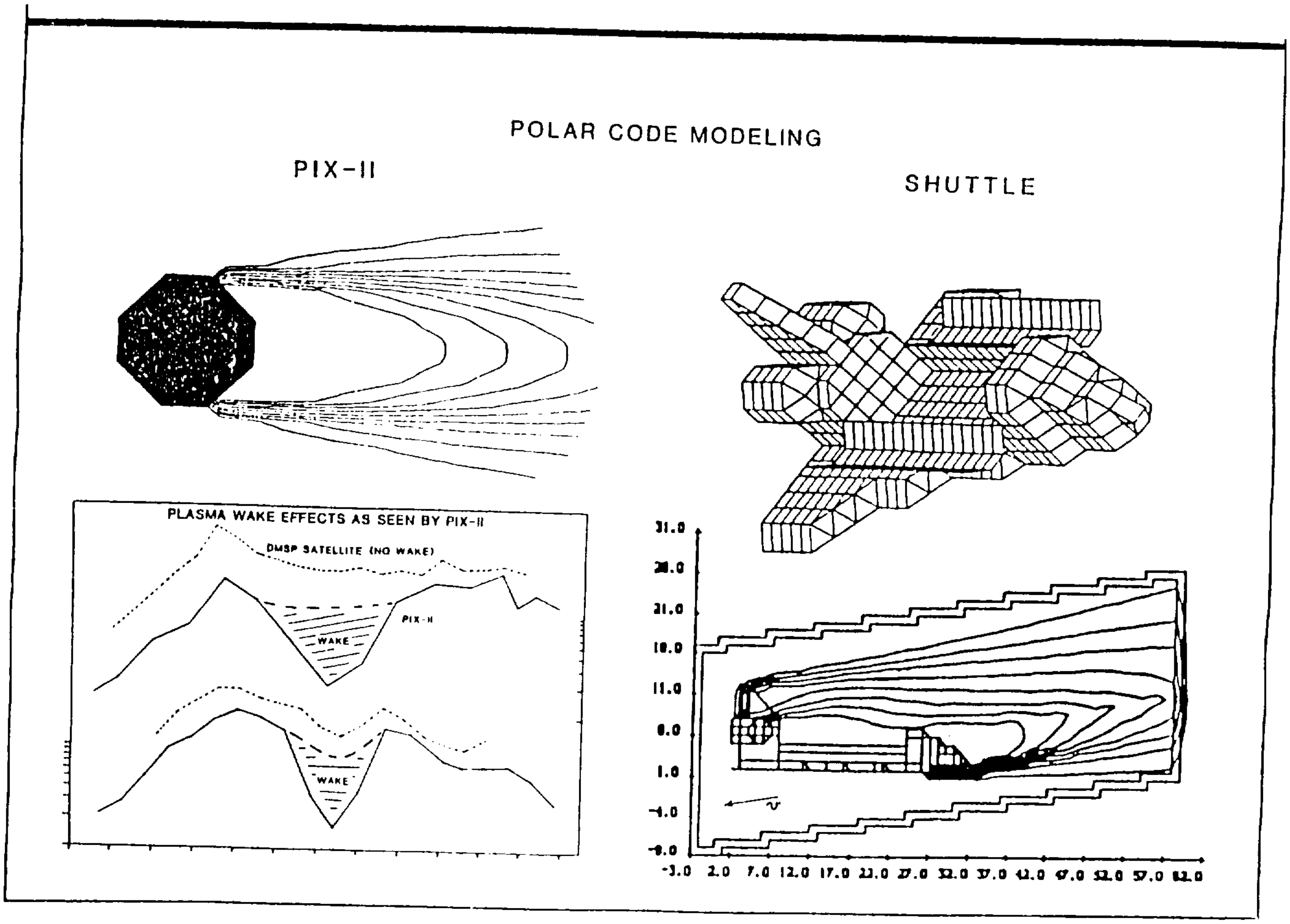
$\phi_{sphere\ 2} = 0\ kV$

$\phi_{ground} = -6\ kV$



RAM/WAKE EFFECTS

This chart illustrates the potential structures due to the motion of a simple (PIX-II) and a more complex (SHUTTLE) object through a plasma. Here, there are no applied biases nor any magnetic field. Evidently, the sheath structure around a "realistic" space system with applied biases (e.g., from the power system), in motion through the plasma and Earth's magnetic field is quite complex. Yet, a realistic assessment of plasma/charged particle interactions with surfaces demands an understanding of the local field structures.



CHARACTERISTIC MAGNITUDES

This chart indicates the characteristic length and potential scales for plasma phenomena in various Earth orbital regimes and indicates the factors which drive the determination of surface potentials and local fields.

In LEO, the characteristic plasma lengths are small, as are the naturally induced potentials which range from tenths of volts (the electron temperature), through tens of volts ($\vec{v} \times \vec{B}$ induced potentials for large systems). Wake potentials are also in this range. In this environment it is the system electrical and geometric configurations which dominate the interactions, with material properties a secondary consideration, except for the case of insulators near biased conductors. The naturally induced potentials are, however, large enough to create possible concern for thin films or coatings and for electrostatically enhanced contamination of sensitive surfaces (e.g., optics).

In GEO, the characteristic plasma lengths are hundreds of meters and the naturally induced potentials in the kilovolt range. Here, material properties and geometry (including shadowing) dominate the interactions, with system electrical configuration and a secondary consideration, except for very high voltage (>KV) systems.

Polar orbit represents a composite of the LEO and GEO cases and all factors must be considered.

LEO

o SYSTEM SIZE $>>$ DEBYE LENGTH (CM)
o SYSTEM VOLTAGES $>>$ NATURALLY INDUCED POTENTIALS (TENTHS TO TENS OF VOLTS)
 -- SYSTEM ELECTRICAL AND GEOMETRIC CONFIGURATIONS DOMINATE INTERACTIONS
  * IMPORTANCE OF MATERIAL PROPERTIES DEPENDS ON CONFIGURATIONS
  * SYNERGISTIC EFFECTS (METEOROID DAMAGE, CHANGES TO MATERIAL ELECTRICAL PROPERTIES, ETC.) IMPORTANT
 --NATURALLY INDUCED POTENTIALS OF CONCERN FOR
  * THIN FILMS OR COATINGS
  * ELECTROSTATICALLY ENHANCED CONTAMINATION
  * VERY LARGE SYSTEMS ($\gtrsim$50m)

GEO

o SYSTEM SIZE $<<$ DEBYE LENGTH (100's OF m)
o SYSTEM VOLTAGES $<$ NATURALLY INDUCED POTENTIALS (KV)
 -- SURFACE MATERIAL PROPERTIES AND GEOMETRIC CONFIGURATIONS DOMINATE INTERACTIONS
  * ELECTRICAL CONFIGURATION OF SECONDARY IMPORTANCE

PEO (polar Earth orbit)

o INTERMEDIATE CASE: CHARACTERISTIC LENGTHS AND POTENTIALS VARY WIDELY DEPENDING ON POSITION IN ORBIT AND AURORAL ACTIVITY
 -- BOTH "LEO" AND "GEO" CASES MUST BE CONSIDERED

COLLECTION OF CHARGED SPECIES TO SURFACES

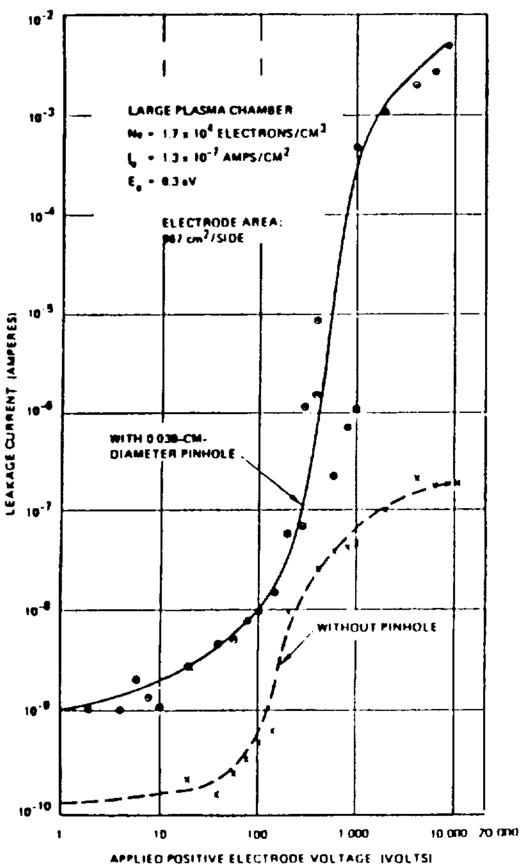
Let us leave the question of self-consistent determination of potentials relative to the plasma, and examine some of the phenomena associated with electron and ion collection, focusing on the role of materials and effects on them. This chart indicates phenomena associated with positive bias (electron collection). Note that in addition to phenomena associated with plasmas alone, the possibility of cascade ionization of neutral gases in the sheath must be considered.

ELECTRON COLLECTION:

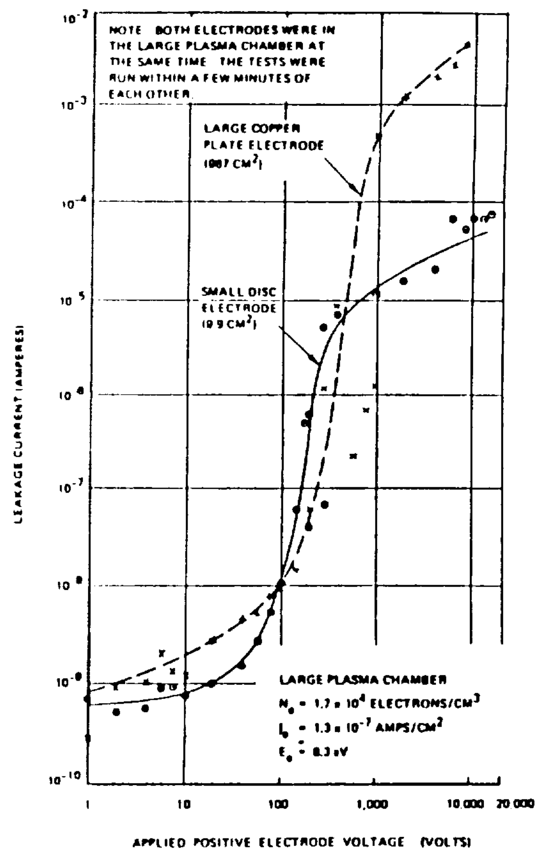
- O MAY HEAT SMALL AREAS
- O CURRENT DRAIN
- O MAY INFLUENCE SYSTEM FLOATING POTENTIAL DRASTICALLY BY SECONDARY ELECTRON EMISSION
  - Testing needed on secondary emission curves of many materials
- O WELL UNDERSTOOD TO BARE CONDUCTORS, SIMPLE GEOMETRIES
- O MAY BE INCREASED BY CASCADE IONIZATION OF SYSTEM GASEOUS EFFLUX
- O NOT KNOWN FOR ATOMIC OXYGEN (AO)-DEGRADED MATERIALS
  - Testing needed on degraded Kapton around pinholes, etc.

PINHOLE CURRENTS

This figure shows data (taken by K. Kennerud of Boeing) on electron currents collected by insulated electrodes with defects ("pinholes"). Note that the current rises sharply at applied voltages in the 100-1000 V range. The right-hand graph indicates that the level at which the current rise tapers off appears related to the size of the insulating surface area surrounding the pinhole. In the high-voltage regime, the current densities at the pinholes were large enough to cause severe degradation of the insulation near the holes.



LEAKAGE CURRENT COLLECTED BY A 10-INCH BY 15-INCH COPPER PLATE ENCAPSULATED IN 0.005-INCH THICK KAPTON – WITH AND WITHOUT A DEFECT



EFFECT OF ELECTRODE SIZE ON THE PLASMA LEAKAGE CURRENT COLLECTED BY A 0.015-INCH-DIAMETER PINHOLE IN 0.005-INCH-THICK KAPTON

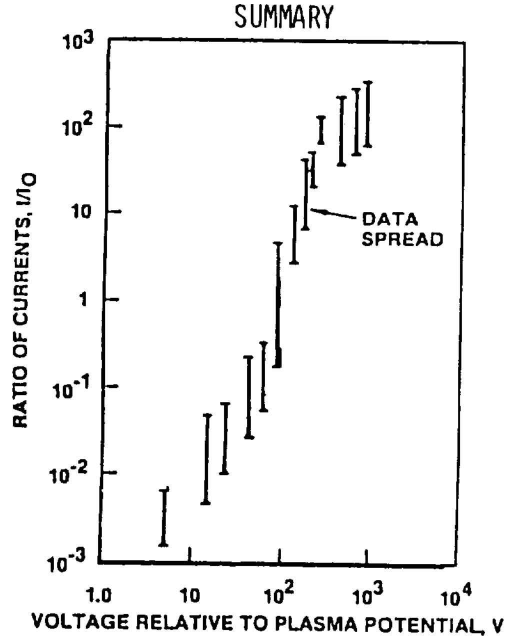
SOLAR ARRAY SURFACE VOLTAGE PROFILES AND COUPLING CURRENTS

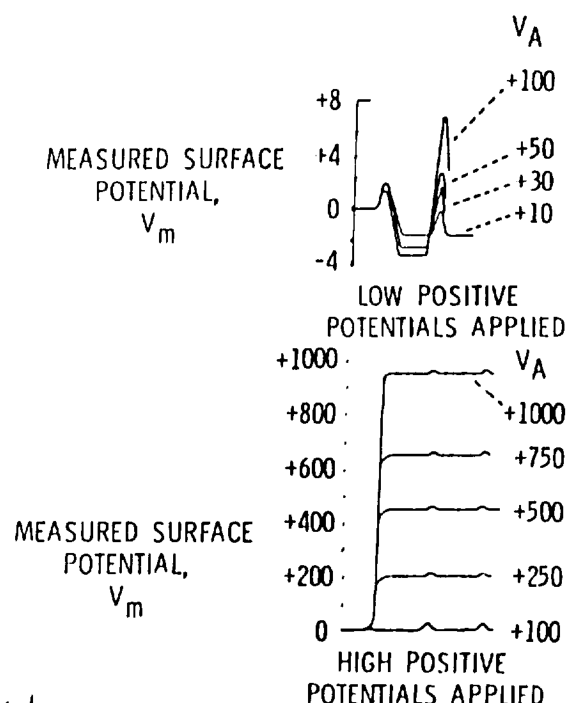
I-V curves similar to those for "pinholes" are observed when solar array segments are biased in plasmas. Surface potential traces (right) indicate that the low current/low voltage and high current/high voltage regimes are associated with very different potential profiles across the surface. For voltages $\lesssim$ 100 V (top), the profiles show the dielectric coverslide surfaces having slightly negative potentials, with the interconnects standing out in sharp relief. This is what one expects if the coverslides are behaving as "isolated" surfaces (electron temperatures in these tests are about 1 eV). When high voltages are applied to the interconnects (bottom), the surfaces of the coverslides are seen to attain positive potentials comparable to (but somewhat less than) the nearby interconnects. The latter condition is associated with the enhanced current region of the I-V curve. Two interrelated phenomena are believed to be occurring: expansion of the sheath due to the large potentials on the coverslides; and collection of secondary electrons generated on the coverslides. This condition is made possible by the secondary electron characteristics of the coverslide.

POSITIVE APPLIED POTENTIALS

2x2 CM CELLS

LERC GROUND TEST CURRENTS SUMMARY

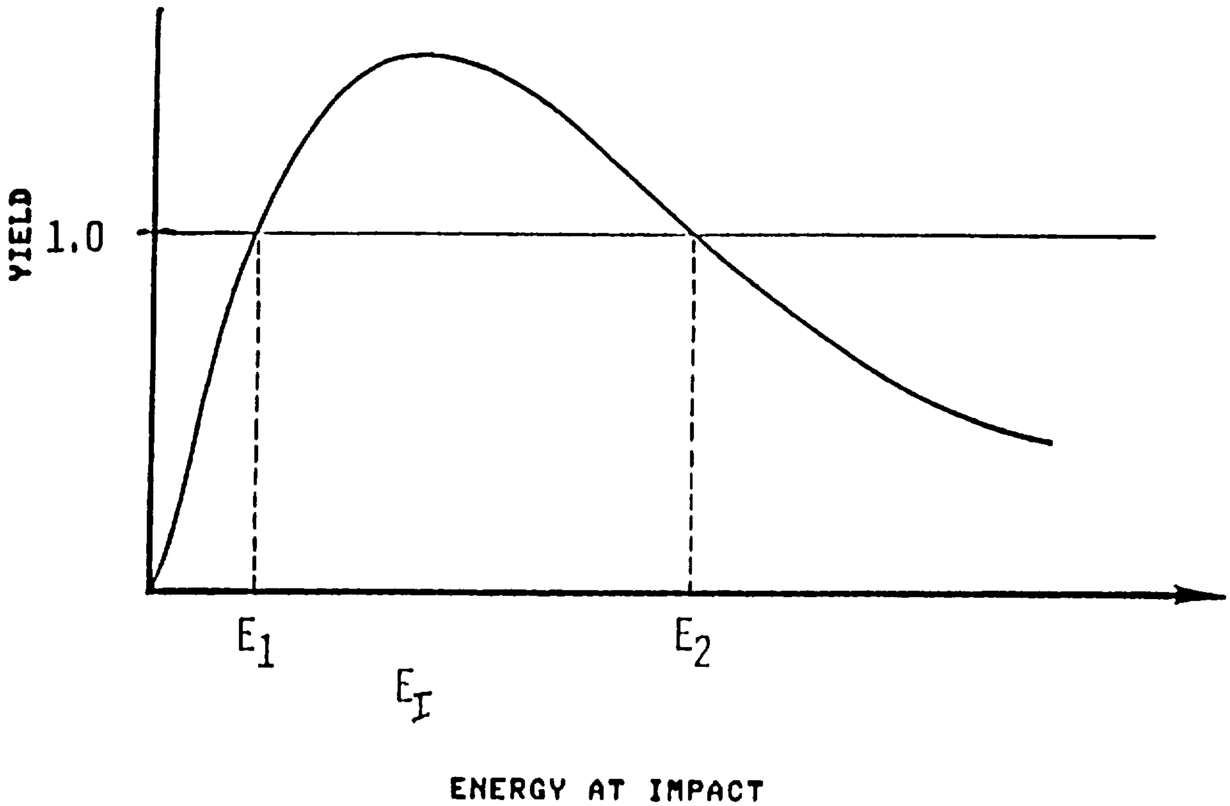




- O LOW VOLTAGE ENVELOPE: $I/I_0 \mathrel{\tilde{\propto}} V_I^{3/2}$
- O CONSISTENT WITH $I/I_0 \propto \Phi$, $\Phi = f_i \phi_i + f_c \phi_c$ with $-5V \lesssim \phi_c < 0$
- O HIGH VOLTAGE BEHAVIOR: $I/I_0 \propto V^x$, $x \lesssim 1$

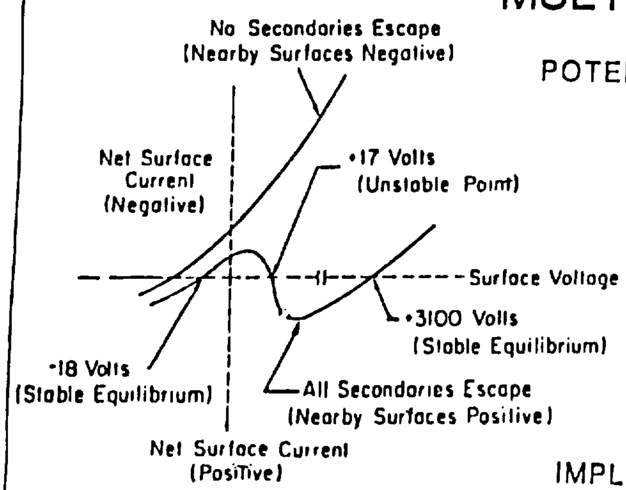
SECONDARY ELECTRON YIELD VERSUS ENERGY

This figure illustrates a typical secondary electron yield due to electron impact curve for an insulating surface. Shown is yield (secondary electrons out per primary electron in) as a function of primary electron energy at impact. Note that there is a range of primary electron energies for which the yield of secondary electrons is greater than 1.



The fact that typical insulators have secondary electron emission yields greater than one for a range of primary electron energies means that the I-V curve for such a surface in a plasma environment for conditions under which all secondary electrons escape is **multivalued**; i.e., there is no unique voltage for which the net current to the surface is zero. This in turn implies that the potential actually attained by an insulating surface in a plasma will depend not only on the emission characteristics of the insulator but also on the local electric fields which will determine what fraction of the secondary electrons escape, and on the initial conditions. Thus, hysteresis effects and rate of change effects are expected to be important in determining the final potential of an insulating surface.

HIGH SECONDARY YIELDS IMPLY



BOUNDING I-V CURVES FOR "SPACECRAFT" MATERIAL IN A 10-eV MAXWELLIAN PLASMA

MULTIPLE EQUILIBRIA POSSIBLE

POTENTIAL ON INSULATING SURFACE DEPENDS ON

- oSECONDARY YIELD
- oPLASMA PROPERTIES
- oPOTENTIALS OF NEARBY SURFACES
- o"INITIAL CONDITIONS"

IMPLIES POSSIBILITY OF

- oHYSTERESIS EFFECTS IN CURRENT AND VOLTAGE
- oRATE OF CHANGE EFFECTS

COLLECTION OF CHARGED SPECIES TO SURFACES

Turning now to negatively biased surfaces, we consider some of the effects of ion impact on surfaces. A brief discussion of arcing, which is observed on negatively biased systems in plasmas, will follow. Ions accelerated by local fields in the sheath will strike surfaces with an energy corresponding to the negative potential on them. Two consequences of ion impact which are important for surface materials are sputtering and chemical reactions enhanced by the energy of the accelerated ions. Oxygen erosion is generally attributed to atomic oxygen atoms because they are more numerous than are atomic oxygen ions. However, if the reaction rates increase strongly with impact energy, the ions may contribute significantly to the erosion process.

POSITIVE ION COLLECTION (IMPORTANT FOR INSULATORS UNDER AC BIAS, CONDUCTORS UNDER AC OR DC BIASES, INCLUDES COLLECTION AND IONIZATION OF GASEOUS EFFLUX):

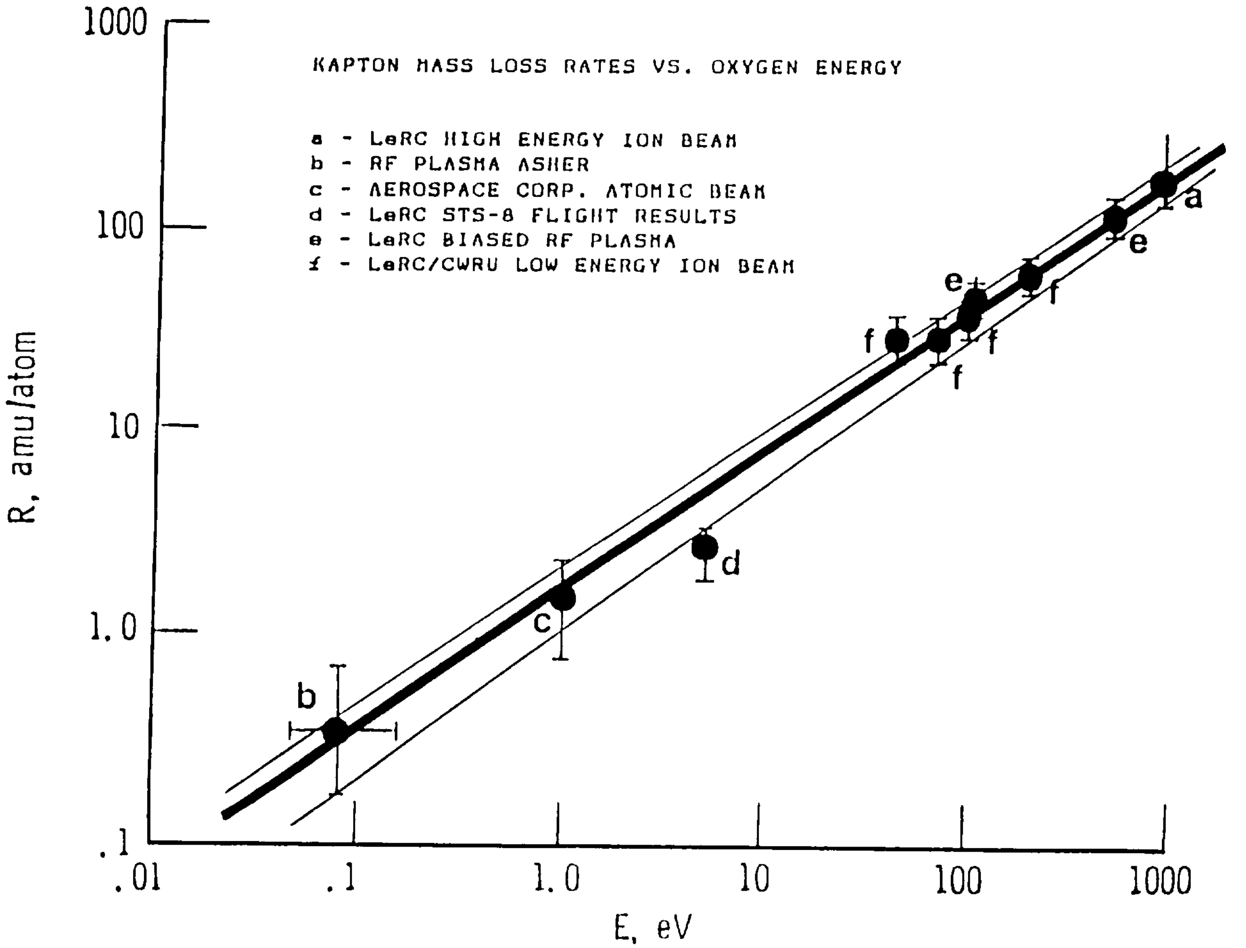
- O SPUTTERING
  - LOSS OF MATERIAL, CHANGE OF SURFACE PROPERTIES
  - RATES POORLY KNOWN FOR OXYGEN IONS
  - CHEMICALLY AIDED SPUTTERING?
  - HIGHLY MATERIALS-SENSITIVE

  Testing needed on materials in energetic oxygen ion beams

- O ENHANCED CHEMISTRY
  - LOSS OF MATERIAL, CHANGE OF SURFACE ELECTRICAL, MECHANICAL, OPTICAL, AND CHEMICAL PROPERTIES
  - OCCURS EVEN IN NON-RAM DIRECTIONS
  - ENHANCED AO REACTION RATES AT HIGH O ENERGIES MAY COMPENSATE FOR LOW ION DENSITY
    Materials-sensitive
    Tests needed on materials in energetic oxygen ion beams
  - NITRIDIZATION AND HYDRIDIZATION OF METALS
    Tests needed on metals in energetic nitrogen and hydrogen ion beams

KAPTON MASS LOSS RATES VERSUS OXYGEN ENERGY

This figure shows a plot of mass loss rates versus beam energy for kapton based on data from various sources, including ground tests with both ion and neutral oxygen sources and results from the STS-8 flight experiment. The plot indicates that the mass loss rates indeed increase with increasing impact energy for kapton, so that at high voltages, atomic oxygen ions may contribute significantly to erosion of this material. Similar curves for other materials are needed to allow assessment of the possibility for enhanced erosion.



ARCING TO OR THROUGH THE PLASMA

Arcing of negatively biased samples in plasma has been observed at potentials in the few-hundred volt range both on the ground and in space. Such arcing is a concern both for system performance (electromagnetic interference (EMI), upsets) and for long-term integrating of materials. Arcing of systems in plasmas is not yet well understood, but it is known to be sensitive to materials and geometry.

ARCING TO LEO PLASMA FROM NEGATIVELY BIASED CONDUCTOR/INSULATOR INTERFACES EXPOSED TO THE PLASMA:

- 0 MAY CAUSE ELECTRICAL DISTURBANCES, EMI, LOSS OF SURFACE MATERIAL, CONTAMINATION OF OTHER SURFACES
- 0 THRESHOLD $>$ 100 V, BUT MATERIALS-SENSITIVE
  - Copper threshold lower than for silver
  - More tests needed on other materials
  - May be sensitive to ion species (O^+, H^+ tests needed)
- 0 PINHOLES IN INSULATORS A CONCERN
  - Micrometeoroids and debris rates needed

ARCING THROUGH PLASMA BETWEEN EXPOSED CONDUCTORS AT DIFFERING POTENTIALS:

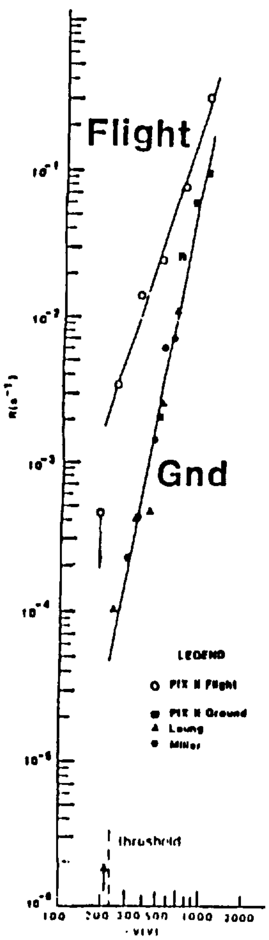
- 0 SIMILAR EFFECTS AS ARCING TO PLASMA
- 0 OCCURS, BUT NO INFORMATION ON THRESHOLDS, MATERIALS, OR ION SPECIES SENSITIVITIES
  - More testing needed

BREAKDOWN TO LEO PLASMA THROUGH THIN FILM DIELECTRICS

- 0 MAY DESTROY OR DAMAGE DIELECTRICS
- 0 DEPENDS ON DIELECTRIC STRENGTHS OF MATERIALS
- 0 PROBABLY DIFFERENT TO PLASMA THAN BETWEEN CAPACITOR PLATES
- 0 PROBABLY DIFFERENT TO AC VOLTAGES THAN DC, MAY DEPEND ON SIGN OF DC, AND ON ION SPECIES
  - Testing needed on representative materials in all relevant configurations and environments

ARC RATES ON SOLAR ARRAYS

This chart illustrates results of studies of arcing on solar cell arrays in ground chambers and in the PIX-II flight experiment. The data have been scaled according to the formula indicated. As can be seen, this scaling organizes the data from a number of ground experiments along a power law curve of arc rate versus negative voltage. The dependence of arc rate on voltage is different for the flight and ground test data--a result which is not presently understood. The "threshold" for arcing appears to be the same for the two data sets. The data available for newer technology solar cells (large area Si) suggest that the arc rates are also dependent on a power of the voltage. The exponent appears much larger when both sides of these samples, which featured **wraparound interconnects** and exposed copper on the back sides of the array segments, were exposed. This suggests that the rates (and perhaps the thresholds) for arcing are material dependent.



-GROUND VS. FLIGHT RESULTS-

0 SMALL AREA CELLS (2x2 AND 2X4 CM)

- THRESHOLD IN -200 TO -250 V RANGE
- ARC RATE $\propto n_i T_i^{0.5} M_i^{-0.5} V^a$ ABOVE THRESHOLD

  $a \simeq 3$ FOR FLIGHT DATA

  $a \simeq 5$ FOR GROUND DATA

- FLIGHT ARC RATE $>$ GROUND ARC RATE

0 LARGE AREA CELLS (5.9 x 5.9 CM, WRAP AROUND)

- GROUND TESTS ONLY
- INSUFFICIENT DATA TO DETERMINE IF THRESHOLD EXISTS
- RATE EXPONENTS:

  $a \simeq 5$ FRONT SIDE EXPOSED

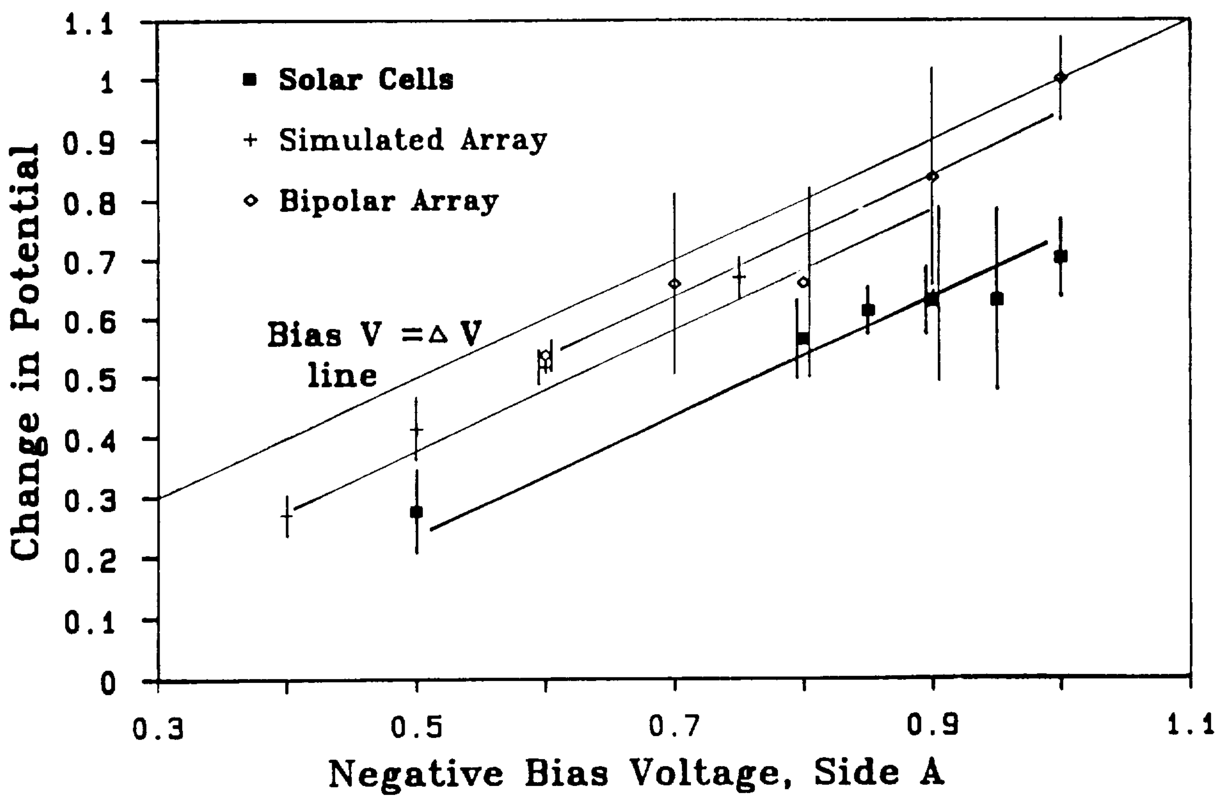
  $a \simeq 8$-10 BOTH SIDES EXPOSED

0 IMPLICATIONS

- ARC RATE SENSITIVE TO CELL TECHNOLOGY
- GROUND TO SPACE SCALING VERY RISKY WITHOUT FLIGHT TESTS

CHARGE LOSS

This chart gives further evidence of dependence of arc behavior on materials and geometry. Shown is charge loss, as reflected in change of potential during arcs on biased samples which are "decoupled" from the power supply during the arcs. The data indicate that a given sample tends to end an arc with a characteristic potential, suggesting the existence of a cutoff voltage, which may indicate a threshold for the arcs. The solar cell sample, which had 2 x 2 cm cells of the same design as the PIX-II cells, tended to cease arcing with about 200 volts remaining on the sample. This is consistent with the 200-volt threshold inferred for these cells from the previous figure. The simulated array had a pattern of Kapton and copper exposed and ceased arcing with less voltage on the sample (about 100 volts), suggesting a lower threshold. The bipolar sample was able to transfer charge from one side to the other and lost nearly all of its charge during arcs. This implies that local geometry is important in determining arc strength.



BREAKDOWN OF OPTICAL COATINGS AND OTHER THIN INSULATORS

Arcing is generally associated with application of voltages in the >100-volt range in LEO and with development of large differential potential due to fluxes of hot particles in GEO and PEO. However, very thin insulating films on large systems may be subject to breakdown due to the 10's of volts of potential which can be generated by $v \times B$ or wake effects on these systems. Breakdown strengths of such insulators may well be different when one "electrode" is a plasma than when placed between physical electrodes. In addition, breakdown strengths and resistivities are expected to be different for positive and negative bias applied when one "electrode" is a plasma.

O MAY HAPPEN AT EVEN LOW POTENTIALS BECAUSE OF HIGH FIELDS ACROSS VERY THIN FILMS

O CHANGES IN SURFACE OPTICAL, ELECTRICAL, CHEMICAL PROPERTIES
  - MAY LOSE RESISTANCE TO AO DEGRADATION
  - MAY CHANGE REFLECTIVITY, ABSORPTANCE, RESISTIVITY

O MEASUREMENTS NEEDED OF DIELECTRIC STRENGTH OF OPTICAL COATINGS, ETC. INTO PLASMA

ENHANCED COLLECTION OF DUST AND OTHER CONTAMINANTS

The local electric fields and surface charges developed in the sheath around a system can result in enhanced contamination of surfaces both by molecular and particulate contaminant sources. These processes are not well understood but may be significant, particularly for sensitive surfaces with long lifetime requirements.

- POSSIBLE SOURCES INCLUDE MICROMETEOROIDS, DEBRIS, SYSTEM EFFLUX, SPUTTERED AND VOLATILE CHEMICALLY-PRODUCED PRODUCTS
- MAY CAUSE ABRASION, OPTICAL CONTAMINATION, POINTS OF HIGH ELECTRIC FIELD FOR THIN FILM BREAKDOWNS
- DUST AND CONTAMINANTS MAY BE COLLECTED ELECTROSTATICALLY IF CHARGED BY PHOTOELECTRIC EFFECT OR CHARGE EXCHANGE PROCESSES, OR EVEN UNCHARGED BY POLARIZATION OF CHARGE ON PARTICLE SURFACE
- PHOTOELECTRON-YIELDS MEASUREMENTS NEEDED FOR POSSIBLE CONTAMINANTS, MICROMETEOROIDS AND DEBRIS

MATERIALS RESEARCH NEEDED TO TREAT PLASMA EFFECTS

This chart presents a summary of materials studies needed to assess the effects of plasma interactions on surfaces in space. Ground-based studies can provide much needed information, but cannot stand alone. "Space truth" will be needed both to "calibrate" the ground experiments, which can never perfectly simulate orbital conditions, and to validate models.

- O ARCING THRESHOLDS INTO AND THROUGH PLASMA
  - ALL MATERIALS EXPOSED AT HIGH POTENTIALS
  - OXYGEN AND HYDROGEN PLASMAS
- O DIELECTRIC STRENGTHS IN A PLASMA
  - THIN FILM DIELECTRICS
  - OPTICAL COATINGS
  - AC AND DC POTENTIALS
  - OXYGEN AND HYDROGEN PLASMAS
- O PHOTOYIELDS AND SECONDARY ELECTRON YIELDS
  - ALL SURFACE MATERIALS AND COATINGS AND THEIR OXIDES
  - DEBRIS AND MICROMETEOROID MATERIALS
  - AS FUNCTION OF INCOMING ENERGY AND ANGLE
- O BULK CHANGES IN ELECTRICAL PROPERTIES THROUGH CHARGE DEPOSITION
  - ALL ELECTRICALLY IMPORTANT SURFACE MATERIALS
  - AS FUNCTION OF INCOMING ELECTRON ENERGY
- O SPUTTERING RATES IN OXYGEN ION BEAMS
  - ALL MATERIALS LIKELY TO BE AT HIGH POTENTIALS
  - AS FUNCTION OF ENERGY AND ANGLE
  - CHEMICALLY AIDED SPUTTERING?
- O ENERGY DEPENDENCE OF ATOMIC OXYGEN ION REACTIONS
  - METALS AND INSULATORS, ALL EXPOSED MATERIALS
- O RATES OF OTHER HIGH ENERGY ION CHEMICAL REACTIONS

CHARGED PARTICLE INTERACTIONS WITH SPACE MATERIALS SUMMARY

To summarize, plasma interactions and their effects on materials depend on a number of factors, including the pre-existing environment, the properties of surface materials and the characteristics of the system. An additional dimension is the question of mission: some payloads may be much more sensitive to plasma interactions than others. As an example, a payload whose objective is to measure the ambient environment will be more sensitive to any effects than will a power system. Material-specific effects include charging and its associated effects, which can result in short- and long-term damage. Selection of materials for a particular application requires consideration of all factors and assessment of effects due to all causes. Proper selection and suitability determination requires analysis to identify the actual environment combined with testing under exposure to single and combined environment factors.

INTERACTIONS AND IMPACTS DEPEND ON

- o ORBIT (NATURAL ENVIRONMENT)
- o MATERIAL PROPERTIES
- o SYSTEM
  - -- OPERATIONS (EFFLUX, CONTAMINANTS)
  - -- LOCAL AND OVERALL GEOMETRY
  - -- ELECTRICAL CONFIGURATION
- o MISSION

INTERACTIONS WITH MATERIALS INVOLVE

- o SURFACE AND BULK CHARGING
  - -- LOCAL FIELDS AND CURRENTS
  - -- ARCING, SPUTTERING
- o IRRADIATION

EFFECTS ON MATERIALS INCLUDE

- o SURFACE CONTAMINATION AND DAMAGE
- o BULK DEGRADATION

MATERIALS SELECTION/SUITABILITY DETERMINATION REQUIRES

- o CONSIDERATION OF ALL INTERACTION FACTORS
- o ASSESSMENT OF AGING EFFECTS DUE TO ALL CAUSES
- o ANALYSIS COMBINED WITH TESTING UNDER EXPOSURE TO SINGLE AND COMBINED ENVIRONMENT FACTORS