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Abstract: Due to its high inclination orbit, International Space Station Alpha (ISSA) will occasionally experience surface charging by the high energy electrons of the auroral environment. This study looks at the frequency of these occurrences and recapitulates a charging model. ISSA should expect about 80 auroral encounters annually. If the plasma contactor is not run continuously, the vehicle may charge several hundred volts. Charge storage on standard space station coatings should not be a problem, but care must be taken that materials are not introduced inadvertently that cannot bleed off accumulated charge in a reasonable time. A conductivity requirement may be used to ensure surface materials do not charge to high voltages, or store charge for long periods of time.

Introduction

Charging of ISSA in the auroral zones must be considered because of the 51.6° inclination orbit. The auroral zones are populated by fluxes of precipitating electrons with energies in the $\geq$10's of KeV range which can act to charge spacecraft. The objective of this effort was to assess adequacy of the present ISSA design for this environment and to identify any additional requirements needed.

This study is broken into two major parts. First, the frequency of auroral occurrences is estimated. Then, the effects of charging are discussed.

Aurora Frequency

The frequency with which ISSA will encounter auroral conditions is addressed by evaluating the probability of an auroral encounter for a particular level of activity, and weighting the result by the probability of occurrence of the particular level of activity. Let $p(k_p,t,\phi)$ be the probability that an orbit of inclination, ϕ, passes through an auroral zone of activity, k_p, at a particular time of day, t. The average probability that the orbit passes through the auroral zone, $p'(\phi)$, is given by,

$$p'(\phi) = \int_0^9 \int_{0\text{hr}}^{24\text{hr}} f(k_p)\, p(k_p,t,\phi)\, dt\, dk_p$$

or,

$$p'(\phi) = \int_0^9 f(k_p) \int_{0\text{hr}}^{24\text{hr}} p(k_p,t,\phi)\, dt\, dk_p$$

$f(k_p)$ can be estimated from historical data, and $<p(k_p,t,\phi)>$ will be estimated from the size of the auroral oval.

In order to estimate the frequency of various levels of auroral activity, $f(k_p)$, historical values of the Kp and Ap Indices were tabulated. One of the indices used to describe the activity of the earth's magnetosphere is the Kp index (ref 1, p. 4-28). This index is a measure of the maximum range of deviations from the regular daily variation of the magnetic field over a three hour period. It is scaled by station location so that all stations give about the same reading for a given level of activity. The Kp index is based on K indices from 12 stations with geomagnetic latitudes between 48° and 63°. Since the K indices are logarithmic, they are converted to an A index (Table 1) for purposes of averaging over time.

Table 1. Relationship Between K and A Indices.

K	0	1	2	3	4	5	6	7	8	9
A	0	3	7	15	27	48	80	140	240	400

Some comments on the notation may be helpful. A lower case 'a' is normally used to indicate a three-hour value. An upper case 'A' is normally used to indicate a daily average. In addition a subscript is usually attached to indicate the station where the measurement was obtained, or a 'p' is used to indicate a planetary average. In this study, the planetary averages are used exclusively because we are interested in planetary effects. Several averages are used rather than only the daily average. In this study only the upper case labels are used to improve readability. The 3 hour values are indicated by, Ap_3, running averages are indicated with a subscript indicating the number of hours, Ap_9, or Ap_{24}, and the daily averages are indicated by, Ap_D.

Historical values of the Kp and Ap indices are available from the National Geophysical Data Center (ref 2), from 1932 through 1986. For this study dates from about the beginning of solar cycle 17 (Oct 21,1933) to about the end of cycle 21 (Oct 20, 1986) were used. This approach averages levels throughout a solar cycle. The 154864 values of the 3 hour Kp_3 and Ap_3 values were binned between the indicated value of Kp or Ap, and the next higher value, as were the Daily Ap_D Average. In addition, 9 hour and 24 hour running averages of the 3 hour values were maintained and tabulated. The percentage of the total in each bin is indicated in table 2.

Table 2. % Time Kp and the Respective Ap Values in Each Kp Interval

		Percentage of time at Ap level			
Kp	Ap	Ap_3	Ap_9	Ap_{24}	Ap_D
0	0	8.82	8.03	5.56	3.57
1	3	24.61	30.96	28.52	28.14
2	7	25.28	30.08	34.27	35.70
3	15	20.88	17.71	18.99	19.40
4	27	12.14	8.93	9.02	9.32
5	48	5.35	2.86	2.57	2.63
6	80	1.90	1.04	0.83	0.93
7	140	0.68	0.33	0.22	0.21
8	240	0.28	0.07	0.02	0.01
9	400	0.06	0.00	0.00	0.00

For purposes of predicting positions of the auroral oval, the Solar Terrestrial Dispatch (STD) (ref. 3) recommends using a combination of the 9 hour and 24 hour running averages but the procedure is weighted toward the 9 hour averages. The software used in this study, described later, uses an A index to estimate the auroral extent. For estimating the frequency of these occurrences, the frequencies appropriate for Ap_9 have been used.

Auroral Extent

The probability that an orbit passes through the aurora, $p(k_p,t,\phi)$, will be approximated by the fraction of the latitude circle corresponding to the inclination of the orbit contained within the auroral oval. This assumes that the probability of an orbit passing through its maximum latitude at a particular local time is equally probable for all local times. This approach should be satisfactory for mission durations whose orbits precess around the earth either an integral number of times, or a large number of times. Assuming no precession, this would occur over a year. For ISSA orbits, which take about a month to precess around the Earth, application of annual statistics is reasonable.

A model developed by STD, Professional Dynamic Auroral Oval Simulator, version 2.00c, was used to estimate the extent of the aurora for particular activity levels. Fig. 1 shows an example of a display from this model.

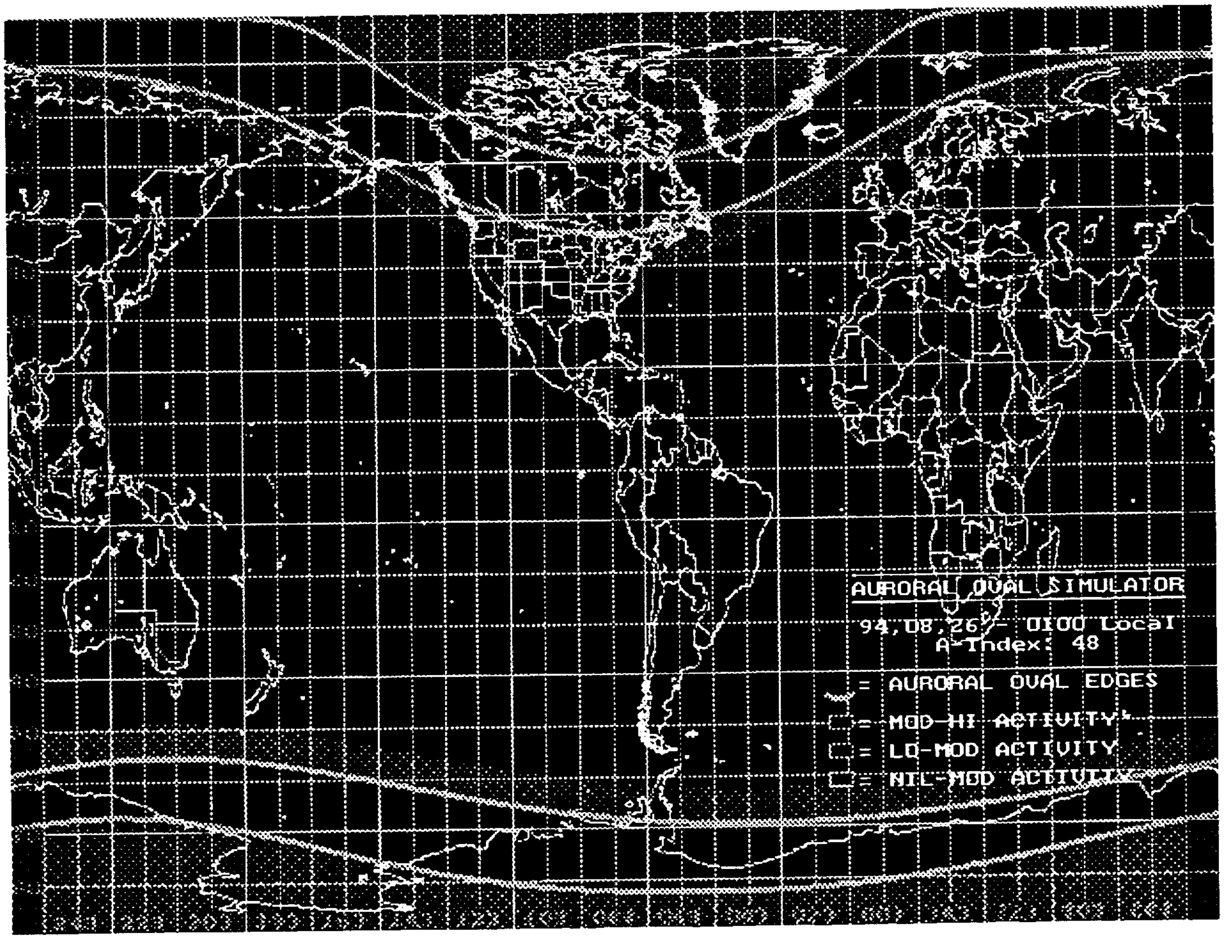

Figure 1. Aurora extent for an Ap_9 Index of 48 (Kp=5) at 1:00 AM EDT.

Hardy et al. [ref. 4] used Defense Meteorological Satellite Program, DMSP, observations and measurements to document the spatial extent and energy distribution of precipitating electrons. It is these electrons that give rise to the auroral displays, and the high energy content that gives rise to surface charging on polar orbiting spacecraft. They tabulated data according to Kp, magnetic latitude, and magnetic local time (MLT), i.e. position relative to the magnetic pole and the sun, for a 15 month interval. For each zone, the number flux for each of the electron energy detector channels was averaged to produce averaged spectra for each zone. From these spectra various integrated quantities can be calculated. Number flux, energy flux, and average energy were calculated for each zone.

STD has produced a similar model [ref 3]. Unfortunately, the procedure used to develop this model has not been published, or included in the users manual. However, according to Cary Oler of STD [ref. 5], the model is based on the work of Hardy et al., but a decade worth of DMSP data was surveyed instead of only a 15 month dataset. This extends the range of auroral activity covered by the model. The following is speculation on the STD model based on the results it produces. Presumably the model contains tables and interpolation methods for auroral activity. These are converted to geodetic coordinates based on day and time. Because the purpose of the STD model is to predict the location of optical aurora and shortwave radio effects, the data criteria may be different from those used by Hardy et al. The data may have been binned in zones based on Ap averages rather than Kp indices. The regions of particular activity levels probably represent average levels of activity. Particularly at lower activity level, or near the edge of the predicted auroral oval, there may be significant variations in the actual activity from the average activity levels.

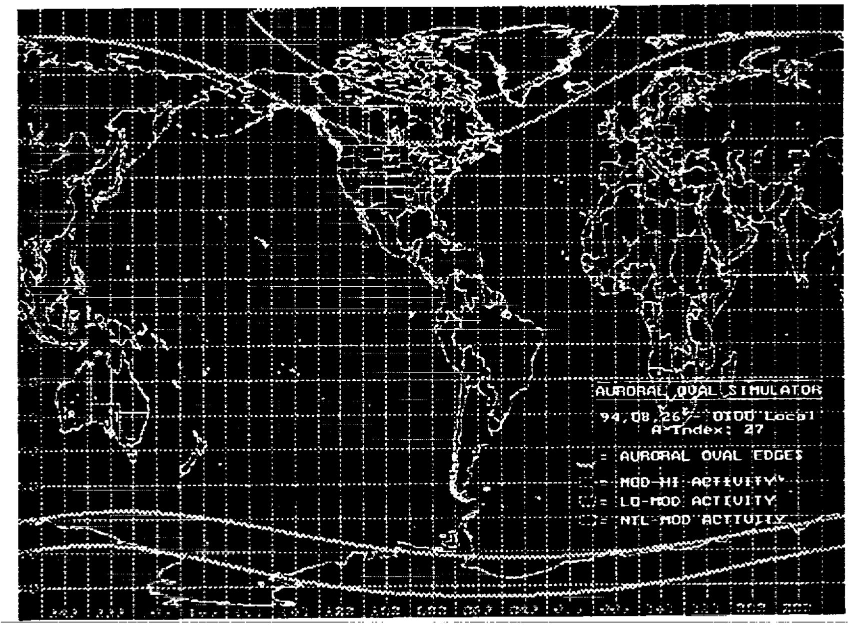

Figure 2. Auroral Extent near local midnight of the north magnetic pole for Apg = 27 (Kp = 4).

In applying the STD model, the optical option was used rather than the radio option. The radio option shows auroral ovals extending more equatorward than the optical option. According to the manual this is due to lower energy (30 eV) electrons which are not of concern for spacecraft charging. However, since the 400 km altitude of ISSA is much higher than the 100 km altitude of the optical aurora, the high energy electron precipitation at ISSA altitudes may occur about half a degree more equatorward than indicated by the model due to the shape of the Earth's magnetic field.

Figures 2 and 3 indicate the extent of the auroral oval near local midnight at each of the magnetic poles. An Ap_9 index of 27 (Kp = 4) is sufficient to bring the auroral oval to a geodetic latitude of 50^o where ISSA may be effected. Note that the equatorward extent, and the width of the oval crossing the 50th parallel, are slightly greater for the southern hemisphere (fig 3) than for the northern hemisphere (fig 2). Since the South Magnetic Pole is closer to the equator than the North Magnetic Pole, ISSA auroral interactions will be slightly more common in the southern hemisphere than in the northern hemisphere.

The extent of the auroral oval must be quantified in a way that can be related to the probability that ISSA will encounter it. The width of the oval at 50^o characterizes the fraction of the latitude circle that the aurora covers. This is approximately the probability that ISSA will encounter aurora for a particular level of activity and time of day.

In addition, the oval moves throughout the day. To account for this the width of the oval at 50^o is taken for six times throughout the UT day; 0000, 0400, 0800, 1200, 1600, and 2000. The six widths are averaged to get a time average of the probability of encountering aurora for a particular level of activity, $<p(k_p, t, \phi = 50^o)>$. Note that this procedure assumes that the auroral oval position does not depend on the time of year.

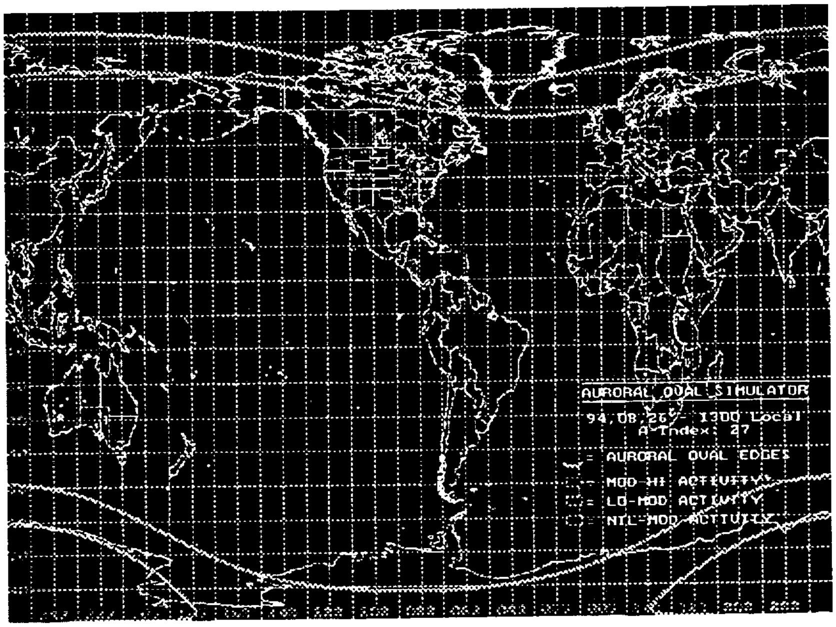

Figure 3. Auroral Extent near local midnight of the south magnetic pole for $Ap_9 = 27$ (Kp = 4).

Table 3 shows average widths as fractions of a circle for the auroral ovals at particular levels of auroral activity. The activity probability is from Table 2.

The product of these two quantities gives a probability that ISSA will encounter auroral activity during a particular high latitude pass at a particular activity level. The sum gives a total probability of encountering aurora for a particular north or south crossing.

Table 3. Probability of Aurora at 50° Latitude during Orbit

Ap_9	Activity Probability	North Width	Product	South Width	Product
15	0.1771	0.000	0.00%	0.000	0.00%
27	0.0893	0.028	0.25%	0.035	0.31%
48	0.0286	0.083	0.24%	0.090	0.26%
80	0.0104	0.141	0.15%	0.141	0.15%
140	0.0033	0.190	0.06%	0.199	0.07%
240	0.0007	0.273	0.02%	0.266	0.02%
Sum			0.72%		0.80%

Note that over a year ISSA should expect to encounter auroral conditions 80 to 90 times. However, these will probably not be distributed evenly throughout the year. Since this treatment does not look at different parts of the solar cycle; rise, maximum, fall, and minimum, the annual numbers will also vary. Since auroral activity lasts a few days, and tracks opposite from the sun's position, when an aurora occurs that intercepts the ISSA orbit auroral conditions may be encountered during many of the orbits over a few days, shifting from north to south pole as the earth rotates under the ISSA orbit.

The width of the auroral zone, *w*, at 50° latitude also gives an estimate of the duration of an auroral encounter. Since these widths are near the maximum latitude of the orbit, the widths used are about the same as the fraction of an orbit covered by the encounter. The duration will be approximately $w/360^\circ \times \cos\phi \times \tau$, were τ is the period of the orbit. So for a 90 min orbit during an $Ap_9=48$, the average width is nearly 30°, and the encounter may last about 4.8 min. The maximum auroral widths are about twice the average width for the lower levels of activity ($Ap_9=27,48$), but only about half again the average width for the higher levels of activity ($Ap_9=140,240$). In practice, ISSA will only rarely pass through the whole zone. It will more likely pass through about half the zone. However, since ISSA is essentially traveling along the edge of the auroral oval in these cases, encounters of much less than half the zone are not very likely.

Note that these durations are much longer than the 60s assumed in earlier work. These short durations were based on DMSP orbits which travel through the ovals rather than along them tangentially. Unless local short lived conditions are the dominant mechanism that give rise to charging situations ISSA should plan on charging encounters of several minutes, rather than one minute.

Uncertainties in Auroral Estimates

There is an uncertainty in the exact location of the auroral oval, which will serve to reduce the auroral encounters from the estimate calculated in this analysis. However, several assumptions are included in the technique which reduce the estimate and may compensate for this uncertainty.

The STD model displays a region where the aurora may be observed, rather than the exact location of a particular auroral arc. This is particularly obvious at low activity where even though the individual arcs are narrow (ref 6), the model gives a band a few degrees wide. Meng et al. (ref 6) comment that at low levels of activity the centers of the auroral oval are concentrated in a region with a radius of 3^o, and that the radius of the oval is $19^o \pm 5^o$. The STD model shows a width of the auroral zone at $Ap_9 = 0$ of about 8^o (i.e. $\pm 4^o$). Just because the orbit enters the auroral region indicated by the model does not mean it will experience auroral conditions. The data used in this analysis only indicate the bounds. However, this is probably more significant for low levels of activity than for higher levels.

The STD model includes a qualitative indication of confidence. At $Ap_9 = 27$ the activity at the edge of the oval is given as NIL-MOD, while at $Ap_9 = 48$ the activity is LO-MOD. The contribution to the ISSA encounters from $Ap_9 = 27$ may thus be a significant overestimate, but the higher levels should be reasonable.

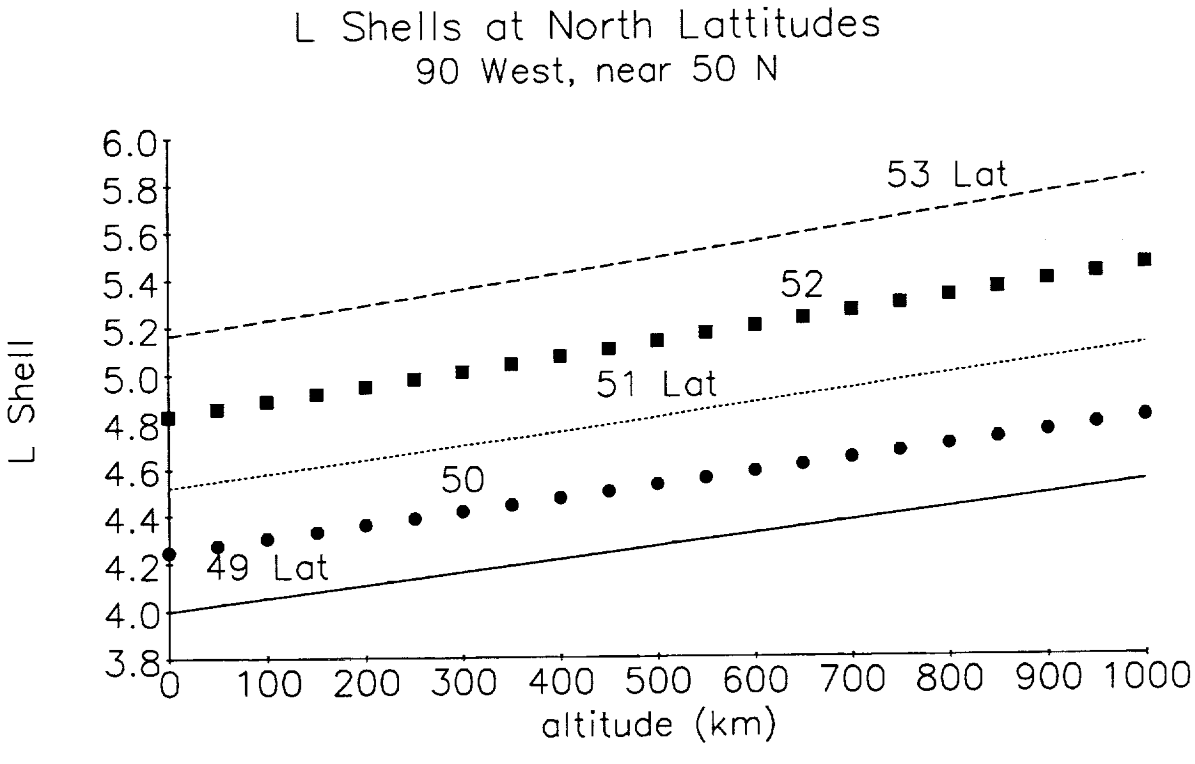

Figure 4. Relationship of L shell with altitude for several Latitudes at 90^oW longitude, from IGRF91.

There are several characteristics of the procedure used that will contribute to an underestimate of the activity. (1) The widths of the auroral zone were taken at 50^o rather than 51.6^o latitude. (2) The orbiting altitude of ISSA is higher than the visible aurora, 400 km rather than 100 km. (3) The effect of levels of activity are rounded down, i.e. activity in the range $27 \leq Ap_9 < 48$ is assumed to effect the region defined from $Ap_9 = 27$.

Because the auroral zones were measured about 1.6^o more toward the equator than the orbit inclination, encounters at $Ap_9 = 15$ are not considered, and the measured circle fractions of the auroral regions are smaller than they should be. The reason oval widths were measured at 50^o rather than 51.6^o is that the software maps included a reference latitude at 50^o. This made it easier to make consistent measurements of the aurora width.

Because of the 400 km altitude of ISSA, it will experience the electron precipitation that causes optical aurora slightly poleward of the ISSA orbit. The L shell coordinates indicate the magnetic field confined trajectories of charged particles in the magnetosphere. Figure 4 shows, for example, that at 90^oW, 51^oN and an altitude of 400 km the L shell value is 4.76, which at an altitude of 100 km corresponds to a latitude of 51.6^oN, about 0.6^o north of the high altitude position. The net result of this and taking measurements 1.6^o equatorward of the actual orbit, is that the measurements are applicable about 2.2^o too far equatorward. The uncertainty in activity location will be compensated for, to some extent, by contributions from activity from lower indices.

Spatial Energy Distribution

The foregoing has not addressed the energy distribution of an aurora. Hardy et al. (ref 4) studied the spatial distribution of the electron energy spectra, with the results indicated in figure 5. Of most interest to spacecraft charging is the location of the high energy electrons. One noticeable feature of the distributions is that the higher energy electrons are generally associated with the lower magnetic latitudes. This suggests that the above procedure of looking at the low latitude boundary of the auroral zone is reasonable for the auroral charging problem.

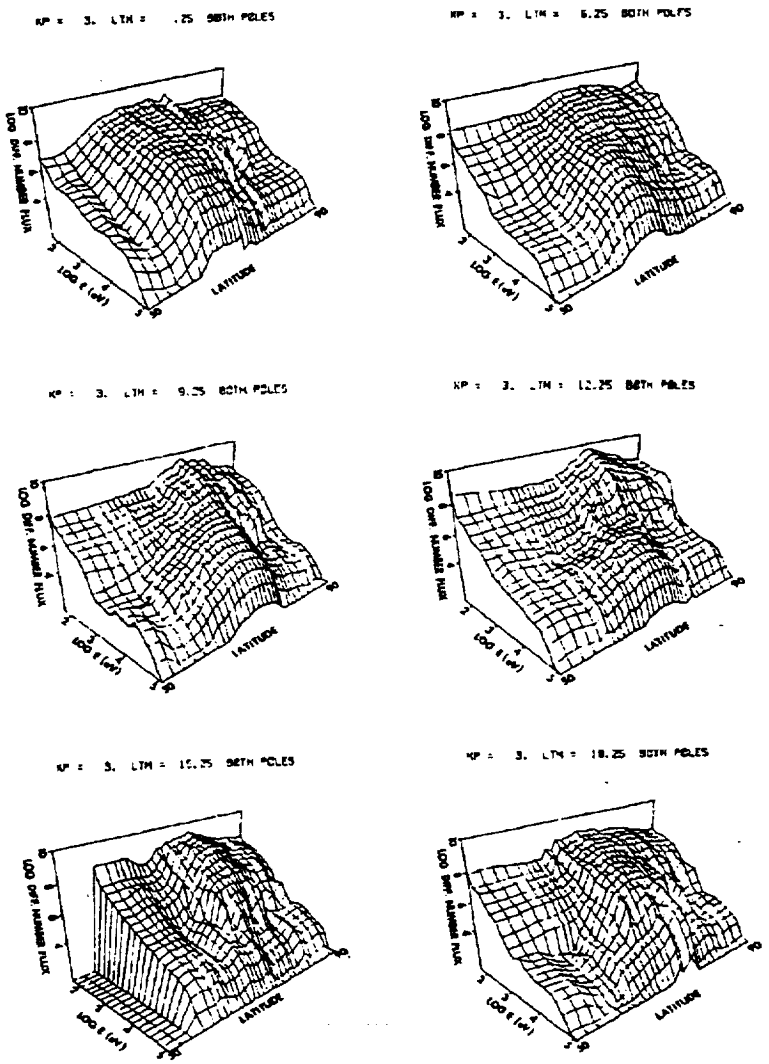

Figure 5. Three-dimensional plots of the average differential number flux spectra as a function of corrected geomagnetic latitude for six magnetic local times about the oval for Kp=3. (from ref 4)

Spacecraft Charging Due to Aurora

There are two general auroral charging cases to consider, with and without the plasma contactor (PC) operating. Operation of the PC will control the ISSA structure potentials to within ±40 volts of plasma potential in the auroral zones as well as in the ionosphere, because the current densities of auroral electrons are low enough that the PC electron emission current capability will easily compensate them. Even a 3 A PC should accommodate auroral currents to $3\text{x}10^5$ m^2. In the PC operational case, then, differential charging of dielectric surfaces is of interest. Without the PC operating, both charging of the vehicle as a whole and differential charging of surface dielectrics are possible. It is assumed that the PC will be operating when the US arrays are activated, because previous analyses have indicated that large negative structure potentials will result from operation of these arrays. It is also assumed that the Russian arrays are all floating. Pre-PC charging by auroral fluxes, if found to be a concern, may present a reason for PC activation before the US arrays are activated. This would affect operation plans more than design because at the time of this writing, the PC is planned for segment S0 or Z1 and will thus probably be available for early activation. The impacts of operating without a PC will also apply to operation if a design is implemented which turns the PC on and off as needed.

Analysis Considerations

The present analysis focuses on the PC operational case. Continual operation of the PC is the baseline mode for full-up system operation and therefore the determining factor for design adequacy. To estimate the charging rates and levels for surface dielectrics, and the rates of charge removal/relaxation (decharging), one needs to consider the environmental current sources, levels and durations of exposure and various properties of the dielectric materials. Environmental current sources include the precipitating auroral electrons, the background ionospheric plasma, and photoelectrons emitted from sunlit surfaces. Auroral electrons are a source of negative charge which can accumulate on surfaces or, for the higher energies, internal to dielectrics. The background ionosphere provides a source of positive charge (ions) to surfaces; surfaces facing into the velocity vector (ram surfaces) have ready access to these ram ions, while surfaces facing into the wake do not. Material properties important for charging response include dielectric constant, resistivity, thickness and secondary yield properties.

Environmental Current Densities

Environmental current densities for this analysis are based on estimates of typical values as follows. Typical values of photoelectron emission currents from surfaces subject to one sun illumination typically range from $2\text{x}10^{-5}$ to $8\text{x}10^{-5}$ A/m^2 or 2 - 8 nA/cm^2 (ref 7.). A value of $5\text{x}10^{-5}$ is used for the analysis. Ion ram current densities are found from

$$j_{ir} = n_i q \, v_r \qquad [1]$$

where n_i is cold (ionospheric) ion density in $\#/\text{m}^2$, q is the electronic charge in coulombs, and v_r is ram ion velocity, taken to be equal to vehicle orbital velocity of 7.7 km/sec. Several values of ion density are considered in the analysis, because this density varies diurnally and with solar activity, and has been observed to "drop out" during some times of high auroral activity by DMSP. Precipitating auroral electron fluxes are estimated based on spectra measured by DMSP. While DMSP is in a higher orbit than ISSA, these precipitating electrons are expected to travel down magnetic field lines with essentially unchanged spectra and are therefore believed appropriate for use in ISSA analyses. Two spectra were chosen for this analysis. One is a Fontheim distribution (sum of a hot maxwellian, a power law spectrum and a Gaussian distribution, see fig. 6) identified in the Spacecraft Surface Charging Handbook (ref. 8); the other is a hot maxwellian spectrum fit to an observed DMSP F7 charging environment. In computing current densities due to these hot electron environments it is necessary to account for secondary and backscattered electrons emitted by surface materials. For this analysis, secondary yield properties for SiO_2 were used on the assumption that these are reasonably typical for ISSA surface dielectrics. Table 4 summarizes the environmental current densities.

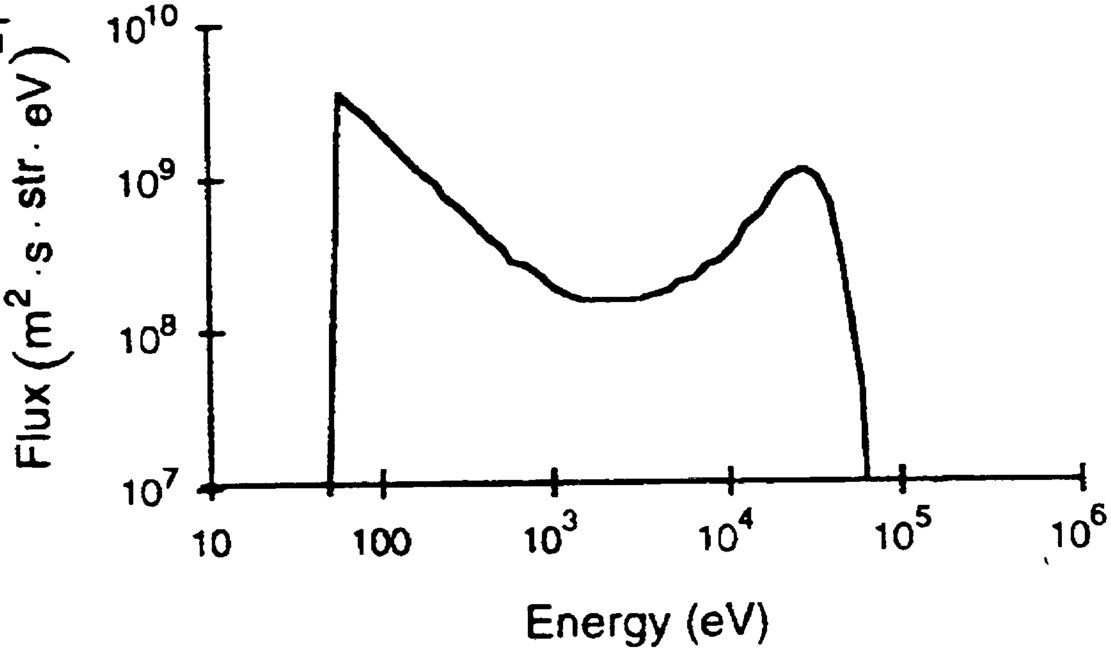

Figure 6. A severe charging environment. Fontheim distribution for A_p[Power law coefficient]$=3x10^{11}$ m^{-3}, $\alpha=1.1$, $E_{PL}=50$ eV, $E_{PH}=1.6x10^6$ eV, $n=6x10^5$ m^{-3}, $\Theta=8$ KeV, $A_G=4x10^4$ m^{-3}, $E_o=24$ KeV, $\delta=16$ KeV, from ref. 8.

The net current density to a surface due to environmental fluxes, j_{net}, is then

$$j_{net} = j_{en} + j_{ir} + j_p \qquad [2]$$

where j_{en} is net electron current density, j_p is photoelectron current density and j_{ir} is ion ram current density.

Table 4. Charging Current Densities

Source	Condition	Current density A/m^2
Photoelectrons	sunlit	5×10^{-5}
Ram ions	$n_i = 1\times10^{8}\mathrm{m}^{-3}$ (a)	1.2×10^{-7}
	$n_i = 3.55\times10^{9}\mathrm{m}^{-3}$ (b)	4.4×10^{-6}
	$n_i = 10^{10}\mathrm{m}^{-3}$ (c)	1.2×10^{-5}
	$n_i = 10^{12}\mathrm{m}^{-3}$	1.2×10^{-3}
Auroral electrons	'severe charging environment'	
	incident electrons	-1.58×10^{-5}
	secondary electrons (d)	3.3×10^{-6}
	backscattered electrons (d)	2.8×10^{-6}
	net electrons	-9.7×10^{-6}
	DMSP F7 11/26/83 49843UT	
	incident electrons	-1.05×10^{-5}
	secondary electrons (d)	4.9×10^{-6}
	backscattered electrons (d)	3.4×10^{-6}
	net electrons	-2.2×10^{-6}

notes:
(a) Depleted level, from DMSP F7 case
(b) Depleted level, from severe charging environment
(c) typical nighttime ionosphere and SS altitudes
(d) "typical" insulator (SiO_2 properties used)

Charging and Decharging Rates and Charging Levels

A one dimensional formulation is used to estimate charging and decharging of dielectric surfaces in this analysis. With the PC operating to control structure potentials, charging of a dielectric can be considered in terms of a capacitor model. The potential V on a surface element (unit area) is just $V = Q/C$, with Q the accumulated charge and C the capacitance. The charging rate is given by

$$dV/dt = (1/C)\, dQ/dt = j_{net}/C' \qquad [3]$$

where C' is the capacitance/m^2. Decharging of surfaces may occur via charge removal by net (positive) currents due to ram ions or photoelectrons according to the j_{net} factor in above formula, or by charge relaxation inside the dielectric via

$$V(t) = V_0 \exp(-t/RC) \qquad [4]$$

with V_0 the initial surface potential and R the dielectric resistance.

Equation [3] can be used with current density values from Table 4 to estimate charging rates of surface dielectrics under auroral charging conditions, and to estimate surface decharging rates post-passage. However, simply multiplying these charging rates by some assumed duration of auroral passage (say, 60 seconds) will give only an extreme worst case estimate for the anticipated charging level. This is because the auroral electron currents are a function of surface potential, and will be reduced as the surface charges negatively, and because three-dimensional effects such as ions pulled into the wake by the electric fields due to charging are ignored in this one-dimensional treatment. Also, this approach ignores the fact that some dielectric relaxation will occur during the charging process. This latter effect can be incorporated into the present one-dimensional treatment by considering equation [3] and interpreting j_{net} to include the leakage current, i.e., consider

$$dV/dt = I_n/C, \text{ with } I_n = I_o - V/R$$

where now I_o, the environmental current, is considered to be a constant. The solution to this equation, with $V(0) = 0$, is

$$V(t) = I_o R(1\text{-}\exp(-t/RC)) \qquad [5]$$

We may note in passing that, if $V(0) = V_i$, the solution is just

$$V(t) = I_o R - (I_o R - V_i)\exp(-t/RC)$$

Evidently the material properties, aside from secondary yields, which are important to charging behavior are those which determine C and R, in particular the (relative) dielectric constant, ϵ, the resistivity, p, and the thickness, d (in meters):

$$\begin{aligned} C &= \epsilon_o \epsilon A/d \\ R &= p\, d/A \quad => \quad RC = \epsilon_o \epsilon p \end{aligned} \qquad [6]$$

Note that RC is a material characteristic, independent of area and thickness.

It may be noted that while photoelectron and ion ram currents are truly surface currents, the auroral electrons may penetrate some distance into the dielectric materials (depending on their energies), so that internal dielectric charging is possible. Dielectric relaxation, on the other hand is essentially a bulk phenomenon and so can relax charge internal to the dielectric.

In order to estimate charging for ISSA it is necessary to identify values for the material properties for ISSA surface materials. Representative values were considered to be:

For the anodization,

$d = 1$ mil (1 mil = .001 inches = 2.54×10^{-5} m)

$\epsilon = 5$

$p = 10^9$ to 10^{12} ohm-m (values for Alumina)

For thermal blanket outer layers,

$d = 5$ mils

$\epsilon = 2$
$p = 10^{15}$ ohm-m (e.g., teflon)

With these values, the information in Table 4 and equations [3], [4] [5] and [6], the desired charging rates and some levels can be estimated.

Results Summary

From Table 4, it can be seen that the photoelectron current densities exceed the hot electron fluxes, so sunlit surfaces are unlikely to charge. Under typical daytime ionospheric conditions j_{net} is zero. The current densities due to ram ions and photoelectrons can easily match the hot electron fluxes, so again no charging is expected for ram surfaces in these conditions. Under typical nighttime ionospheric conditions ram ion fluxes are sufficient to prevent vehicular charging. But during ionospheric dropout conditions, vehicular and ram surface charging can occur. In addition, dark wake surfaces can be usually be expected to charge under auroral conditions.

Typical results for charging rates and levels during the two nighttime charging environments, for the representative materials considered are (note that all voltages are negative):

For anodization,

Ram surfaces: $dV/dt = 1 - 6$ V/sec
$V_{max}(60 \text{ sec}) < 25$ V, for $p < 10^{11}$ (leakage limited)
$V_{max}(60 \text{ sec}) = 90 - 190$ V, $p = 10^{12}$

Wake surfaces: $dV/dt = 5 - 10$ V/sec
$V_{max}(60 \text{ sec}) < 40$ V, $p < 10^{11}$ (leakage limited)
$V_{max}(60 \text{ sec}) = 190 - 290$ V, $p = 10^{12}$

e-folding relaxation time, $1/RC$, about 45 sec for $p = 10^{12}$

For 5-mil thermal blanket cover,

Ram surfaces: $dV/dt = 25 - 80$ V/sec (not leakage limited)

Wake surfaces: $dV/dt = 50 - 100$ V/sec (not leakage limited)

e-folding relaxation time, $1/RC$, about 10^4 sec.

The two charging environments are used to produce the estimated ranges. These results suggest that, with the PC operating, the anodization is thin enough, and its resistivity probably low enough, that significant charging is unlikely, i.e., the design is adequate for the 51.6° inclination orbit. On the other hand, dark insulation which is also in the wake can charge significantly, and does not decharge rapidly. The one dimensional treatment used here is inadequate for a good estimate of large final charging potentials, because three-dimensional effects will come into play. Clearly, the resistivity of surface materials is the key parameter in this problem: values of dielectric constant are in the range of 1 - 10 for most materials, whereas resistivity values can vary by orders of magnitude! It is recommended that a requirement on surface material resistivity be included in the ISSA specifications to the hardware providers, with any value greater than about 10^{11} requiring assessment to ensure that local discharges cannot upset critical circuits. It has been assumed throughout that the ISSA bonding requirements ensure that there are no large areas of conductor not referenced to structure at frequent area intervals.

Without a PC

Without an operating PC, the structure potential is not controlled and will be determined by the overall current balance between the whole system and the environment. Depending on the natural environment, surface material properties and system orientation relative to the velocity vector (and sun), both absolute charging (of the whole vehicle including the structure) and differential charging of various surfaces are possible. Accurate modeling of these effects is beyond the scope of the present effort. However, some rough estimates can be made. This analysis focuses on eclipse cases because the auroral zones extend to ISSA latitudes primarily at night when the system will be in eclipse. Additionally, the photoelectron current densities are large enough compared to hot auroral electron current densities that daylight events in which the entire vehicle charges significantly are unlikely.

In eclipse, the currents to the system during auroral activity are due to the precipitating electrons, which can impinge on all surfaces, and to ionospheric ions, which impinge on ram-facing surfaces only. there are basically two possible charging regimes either the hot auroral electron flux to the whole (uncharged) system exceeds the ion flux to ram surfaces, or it does not. If the net auroral electron flux exceeds the ion flux, the whole system will charge negatively. This "absolute" charging will occur rapidly because the vehicle-to-ionosphere capacitance is small. Rapid absolute charging may be followed by development of differential charging of surface insulation, with ram-facing insulation tending to charge positively relative to structure and wake-facing insulation negatively. Such differential charging will occur more slowly because of the larger capacitance of the surface layers. If, on the other hand, the net auroral electron flux does not exceed the ion flux, some surfaces (those in ram) will remain near plasma potential while others (wake) will charge negatively. This is a differential charging dominated situation, and will have corresponding rates. The structure potential for this case will be intermediate between the ram and wake facing insulation potentials. Because there is no doubt some exposed conductor facing into the ram direction, the structure potential is unlikely to experience large excursions from plasma potential in this case.

Time scales for differential charging are determined by the effective capacitance of insulating layers and will be of the order computed previously for the PC operating cases. The time scale for absolute charging can be estimated by using the Debye length as the effective "plate" separation in computing the capacitance of the system to the ionosphere. This gives an upper bound on the capacitance (and correspondingly a lower bound on the charging rate). The Debye length for a $3.55 \times 10^9/\mathrm{m}^3$, 0.2 eV plasma is about 5 cm which yields a capacitance per unit surface area of 1.6×10^{-10} F/m^2. An initial current density of -7.5×10^{-6} A/m^2 (obtained from the severe charging environment in Table 4, considering that half the surface is in ram and half in wake) yields an initial charging rate of about 5×10^4 V/sec. Thus, absolute charging occurs very rapidly, and large excursions of the structure potential from plasma potential can easily occur during the time of auroral passage.

To obtain some estimates of the absolute charging levels which can occur during auroral passages, a 1-D code called `suchgr` (ref. 8) was used. `Suchgr` computes the equilibrium potential of a sphere of user-specified radius and material surface properties in motion through a plasma environment. It does not compute differential charging, but distributes the ram ion current uniformly over the sphere, and so gives an indication of the absolute charging levels. The plasma environments considered are taken from Table 4. The material properties used were those for SiO_2, and the Mach number and current collection modes were chosen appropriate to ISSA's orbit. Calculations were done for several values of object radius (`robj`) to obtain an indication of the effect of this parameter since different parts of the ISSA vehicle are expected to have different effective radii from the plasma current collection perspective. Results are summarized in Table 5.

Table 5. Equilibrium potentials in volts predicted by `suchgr` for various environments and object sizes.

`robj(m)->`	-------->	1.0	2.5	5.0	10.0
Auroral <u>electrons</u>	Cold ion <u>density</u>				
"Severe Charging Environ."	1.0 E8/m^3	-566 V	-1590 V	-3230 V	-5948 V
	3.55E9	-56	-188	-466	-1030
	1.0 E10	-19	-63	-161	-401
	1.0 E11	-0.8	-0.8	-0.8	-0.8
DMSP F7	1.0 E8/m^3	-86 V	-282 V	-654 V	-1369 V
	3.55E9	-3.3	-11	-28	-68
	1.0 E10	-0.9	-1.0	-1.0	-1.0

Evidently, the cold ion density is a critical determinant of whether or not absolute charging will occur, given a hot electron spectrum. When the ion flux was depleted DMSP F6 and F7 saw significant charging, to -400 and -600 V, for a few seconds (ref 9) For the severe charging environment considered here, absolute charging occurs for cold ion densities of $10^{10}/m^3$ or less, but at $10^{11}/m^3$, no absolute charging is predicted (differential charging can of course still occur). Similarly, for the DMSP F7 environment considered here, no absolute charging is predicted for a cold ion density of $10^{10}/m^3$, but charging is expected for lower cold ion densities. Charging levels depend on both cold ion density and object size, as well as on the electron spectrum.

While the overall size of ISSA is on the order of 100 meters, the effective size for purposes of these charging level estimates is much less, probably about 1-2.5 m for truss segments and 2.5 - 5 m for modules. the solar arrays' effective size depends on angle of attack to the velocity vector, and could range up to 5 - 10 m in some orientations. The calculations summarized in Table 5 indicate that hundreds, even occasionally thousands of volts of absolute charging are possible during auroral zone encounters, with potentials in the hundred volt range likely. Because the cold ion density is such a critical determining factor for the occurrence of absolute charging, and lower cold ion densities are more likely during solar minimum, it is likely that absolute charging events will occur more frequently around solar minimum. This is consistent with the experience of the DMSP spacecraft, which saw most of their charging events, including the "record" -1.4KV event, during solar minimum periods (ref 10).

It is clear that much more detailed analysis is required to obtain better than order of magnitude estimates. However, it would appear that charging of the ISSA structure to the hundred volt range during auroral zone passage is quite possible with no PC operating. Fluctuations of a few hundred volts may raise concerns during docking and EVA activities, and may affect some payload instruments. It would seem advisable, then, to use the PC to eliminate such charging.

Conclusions

ISSA will experience auroral conditions in its relatively high inclination orbit. It can expect on the order of 80 events annually. Auroral conditions may last on the order of 5 minutes.

The plasma contactor can maintain the structure potential near ambient potential in auroral conditions, but surface charging of dielectrics can occur. Surface material bulk resistivities of less than 10^{11} ohm-meters will limit this surface charging. This would also control buried charging if a similar requirement were applied to thick dielectrics.

Auroral encounters without the PC operating will permit rapid charging of the entire vehicle. DMSP has charged to 1.4 KV negative. Docking and EVA concerns should be addressed, and this may effect some payload instrumentation.

References:

(1) "Handbook of Geophysics and the Space Environment", Ed. Adolph S. Jursa, Air Force Geophysics Laboratory, 1985.

(2) "Selected Geomagnetic and other Solar-Terrestrial Physics Data of NOAA and NASA", C. Abston, L. Morris, J. Allen, CD-ROM01, National Geophysics Data Center, Boulder, CO, 1987.

(3) "Professional Dynamic Auroral Oval Simulator User's Manual", Solar Terrestrial Dispatch, Lethridge, Alberta, 1993.

(4) "A Statistical Model of Auroral Electron Precipitation", D.A. Hardy, M.S. Gussenhoven, and E. Holeman, JGR, **90**(A5), pp 4229-4248, 1985.

(5) Oler, C., private communication, 1994.

(6) "Auroral Circle --- Delineating the Poleward Boundary of the quite Auroral Belt", C.I. Meng, R.H. Holzworth, and S.I. Akasofu, JGR, **82**(1), pp 164-172, 1977.

(7) "Potentials on Surfaces in Space," E.C. Whipple, Rep. Prog. Phys., **44**, pp 1197-1250, 1981.

(8) Spacecraft Surface Charging Handbook, V.A. Davis and L.W. Duncan, PL-TR-92-2232, Phillips Laboratory, Directorate of Geophysics, Air Force Materiel Command, Hascom Air Force Base, MA 01731-5000, 1992.

(9) "High-Level Spacecraft Charging in the Low-Altitude Polar Auroral Environment", M.S. Gussenhoven, D.A. Hardy, F. Rich, W.J. Burke, and H.C. Yeh, JGR, **90**(A11), pp 11009-11023, 1985.

(10) "Solar Cycle Dependence of Spacecraft Charging in Low Earth Orbit", T. B. Frooninckx and J. J. Sojka, JGR, **97**(3) pp2985-2996, 1992.

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Due to its high inclination orbit, International Space Station Alpha (ISSA) will occasionally experience surface charging by the high energy electrons of the auroral environment. This study looks at the frequency of these occurrences and recapitulates a charging model. ISSA should expect about 80 auroral encounters annually. If the plasma contactor is not run continuously, the vehicle may charge several hundred volts. Charge storage on standard space station coatings should not be a problem, but care must be taken that materials are not introduced inadvertently that cannot bleed off accumulated charge in a reasonable time. A conductivity requirement may be used to ensure surface materials do not charge to high voltages, or store charge for long periods of time.

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