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# A SPACECRAFT CHARGING CAPABILITY FOR SXTF

IRT Corporation
P.O. Box 81087
San Diego, California 92138

17 January 1979

Final Report for Period 10 October 1977—30 November 1978

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This report assesses the impact of including a spacecraft charging capability in the proposed Satellite X-ray Test Facility (SXTF). Three questions have been addressed: What is the nature of the environment to be simulated? What hardware is available for simulation of this environment? What is the impact on the design, construction, cost, and operation of SXTF? A set of recommended source hardware is presented.

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At a minimum, both low energy (tens of keV) and high energy (MeV) electron sources should be included as well as a UV source. Whether the electron sources should produce a polyenergetic output is to be determined.

Inclusion of low energy electron sources requires that the geomagnetic field be cancelled inside the tank. Incorporation of high energy electron sources poses several design and operational problems in regard to shielding for personnel safety, incorporation of a fail safe mode of operation to prevent damage to test object or equipment, and in a need to provide adequate space for the source(s) and shielding.

Distribution/
Availability Codes
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A

## CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

| TO CONVERT FROM | TO | MULTIPLY BY |
|---|---|---|
| angstrom | meters (m) | 1.000 000 X E -10 |
| atmosphere (normal) | kilo pascal (kPa) | 1.013 25 X E +2 |
| bar | kilo pascal (kPa) | 1.000 000 X E +2 |
| barn | meter$^2$ (m$^2$) | 1.000 000 X E -28 |
| British thermal unit (thermochemical) | joule (J) | 1.054 350 X E +3 |
| calorie (thermochemical) | joule (J) | 4.184 000 |
| cal (thermochemical)/cm$^2$ | mega joule/m$^2$ (MJ/m$^2$) | 4.184 000 X E -2 |
| curie | giga becquerel (GBq)* | 3.700 000 X E +1 |
| degree (angle) | radian (rad) | 1.745 329 X E -2 |
| degree Fahrenheit | degree kelvin (K) | $t_K$ = (t° f + 459.67)/1.8 |
| electron volt | joule (J) | 1.602 19 X E -19 |
| erg | joule (J) | 1.000 000 X E -7 |
| erg/second | watt (W) | 1.000 000 X E -7 |
| foot | meter (m) | 3.048 000 X E -1 |
| foot-pound-force | joule (J) | 1.355 818 |
| gallon (U.S. liquid) | meter$^3$ (m$^3$) | 3.785 412 X E -3 |
| inch | meter (m) | 2.540 000 X E -2 |
| jerk | joule (J) | 1.000 000 X E +9 |
| joule/kilogram (J/kg) (radiation dose absorbed) | Gray (Gy)** | 1.000 000 |
| kilotons | terajoules | 4.183 |
| kip (1000 lbf) | newton (N) | 4.448 222 X E +3 |
| kip/inch$^2$ (ksi) | kilo pascal (kPa) | 6.894 757 X E +3 |
| ktap | newton-second/m$^2$ (N-s/m$^2$) | 1.000 000 X E +2 |
| micron | meter (m) | 1.000 000 X E -6 |
| mil | meter (m) | 2.540 000 X E -5 |
| mile (international) | meter (m) | 1.609 344 X E +3 |
| ounce | kilogram (kg) | 2.834 952 X E -2 |
| pound-force (lbf avoirdupois) | newton (N) | 4.448 222 |
| pound-force inch | newton-meter (N·m) | 1.129 848 X E -1 |
| pound-force/inch | newton/meter (N/m) | 1.751 268 X E +2 |
| pound-force/foot$^2$ | kilo pascal (kPa) | 4.788 026 X E -2 |
| pound-force/inch$^2$ (psi) | kilo pascal (kPa) | 6.894 757 |
| pound-mass (lbm avoirdupois) | kilogram (kg) | 4.535 924 X E -1 |
| pound-mass-foot$^2$ (moment of inertia) | kilogram-meter$^2$ (kg·m$^2$) | 4.214 011 X E -2 |
| pound-mass/foot$^3$ | kilogram/meter$^3$ (kg/m$^3$) | 1.601 846 X E +1 |
| rad (radiation dose absorbed) | Gray (Gy)** | 1.000 000 X E -2 |
| roentgen | coulomb/kilogram (C/kg) | 2.579 760 X E -4 |
| shake | second (s) | 1.000 000 X E -8 |
| slug | kilogram (kg) | 1.459 390 X E +1 |
| torr (mm Hg, 0° C) | kilo pascal (kPa) | 1.333 22 X E -1 |

* The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s

** The Gray (Gy) is the SI unit of absorbed radiation.

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# 1. INTRODUCTION

Various parts of geosynchronous satellites may become differentially charged as a result of exposure to the ambient particle and photon radiation environment, both that naturally present, and that consequent to an exoatmospheric nuclear explosion. Such charging can affect reliable satellite operation or survivability in several important ways. Electrons in the keV range (∿ 5-30 keV) deposit charge on all exposed dielectric surfaces which generates high potentials on insulators and floating conductive surfaces. Because of anisotropies in the electron flux, discharging of solar illuminated surfaces by photoelectron emission, and shadowing, various satellite surfaces may become differentially charged. Higher energy electrons (∿ 1 MeV) can penetrate the satellite's skin and deposit charge in cables, other dielectrics and electronics. Such charging can generate sufficiently high potentials to cause dielectric breakdown or flashover. The resultant transient currents and electromagnetic fields can cause damage to or destruction of spacecraft dielectrics, or couple into onboard electronic circuitry causing upset, or in extreme cases, burnout.

Theoretical calculations predict, and experimental evidence exists to show that such precharging can enhance the SGEMP response to a flash x-ray pulse. Moreover, the x-rays may themselves trigger discharges (Ref. 1,2,3). Still to be defined is the magnitude of this synergistic effect (worst case) and its detailed dependence on x-ray fluence and spectrum.

Thus, it can be seen that a satellite's SGEMP response cannot be satisfactorily simulated unless the charge distribution on and in a satellite due to the charged particle environment is also simulated. Whether such environment needs to be simulated for a satellite SGEMP survivability test remains to be determined.

There is a second reason why it may be desirable to include a spacecraft charging capability in SXTF. There has been discussion that SAMSO will levy a spacecraft charging survivability spec on future geosynchronous satellites. This will mandate a need for system survivability testing. An SXTF containing a spacecraft charging capability will provide an attractive test option.

Because of the distinct possibility that a spacecraft charging capability will be incorporated into SXTF, the Defense Nuclear Agency has commissioned this study to address the following topics:

1. Define which aspects of the space radiation environment should be simulated.
2. Identify the technology available to carry out such simulation.
3. Assess the impact of incorporating a spacecraft charging capability into SXTF.
4. Identify areas which require further definition or need technology development.

The second section of this report describes the particle environment to be found in geosynchronous orbits. Both the natural and artificial components are not very well defined. However, available evidence indicates that a faithful simulation with regard to species, energy spectrum, fluence, and geometric distribution would be difficult. Therefore, a limited simulation of this environment judged to be most important in producing charging effects is likely to be included in SXTF. The means of simulating this environment is discussed in Section 3 of this report. In Section 4 we discuss the problems to be faced as a result of the incorporation of an electron spraying capability into SXTF. It will have a substantial impact on the design, construction and operation of SXTF. The most significant impact is the need for large amounts of radiation shielding for the MeV bremsstrahlung produced by the high energy source. A second consequence to be avoided is damage produced by a narrow high energy electron beam which may inadvertently strike either facility or test object components. Finally, Section 5 summarizes our principal findings, suggests candidate hardware and provides recommendations for further study and needed technology development.

# 2. PARTICLE ENVIRONMENT SPECIFICATION

## 2.1 NATURAL ENVIRONMENT

Geosynchronous satellites may become charged (with respect to ambient plasma potential) and various parts of such satellites may become differentially charged as a result of exposure to the particle radiation environment, including natural trapped, magnetospheric substorm events, and that following an exoatmospheric nuclear explosion. High potentials can be produced by such charging, so that dielectric breakdown or vacuum arcs (flashover) can occur. The resulting transient currents and electromagnetic fields can couple into onboard, electronic circuitry, causing circuit upset or, in extreme cases, component damage. In addition, spacecraft can suffer other damage as a result of arcs and discharges (e.g., contamination of surfaces, degradation of thermal blankets, and sensor anomalies). Spurious events and operational anomalies attributable to charging phenomena have been observed on many spacecraft to date (Ref. 4).

If the satellite is illuminated by the sun, the vehicle potential is usually maintained at plasma potential by the release of photoelectrons. Differential charging can occur on shadowed surfaces, however. Satellites have occasionally been observed to charge to a few hundred volts negative in sunlight. In eclipse, negative potentials of kilovolts (or even tens of kV) can be attained.

Most data on the low-energy ($< 50$ keV) charged particle environment at geosynchronous orbit have been obtained from experiments on ATS-5 and ATS-6. From this data, it is apparent that the particle environment to which a spacecraft is subjected during a mission is not only complex, but also highly variable with time and location. There is no known "typical" environment in the sense that a given energy spectrum could be expected to be encountered a certain percentage of the time. However, reasonable estimates can be made of the amount of time per year a given flux level is exceeded (Ref. 5,6), and the range of "average" energies can be specified. Data are scarce on anisotropies such as field aligned fluxes. A better definition of the natural particle environment to be found in geosynchronous orbit will become available in 1979 following the launch of the SAMSO P78-2 (SCATHA) satellite.

A few examples have been given in the literature of electron energy spectra and fluxes associated with common events at geosynchronous orbit (Ref. 6,7). The result of one such event (2/11/70) is shown in Figure 1. This was a fairly intense substorm occurring at the spacecraft location in the midnight-to-dawn sector. The spectral current density (A/cm$^2$-sr in a 0.1 keV energy interval), as derived from published data, is shown for two local times, 0900 and 1000. A spectrum for a quiet period (2/12/70) is also shown for comparison. The total fluxes were approximately 6.7 x $10^{-10}$ A/cm$^2$ and 6.3 x $10^{-10}$ A/cm$^2$ in 2π steradians for 0900 and 1000, respectively. *These substorm spectra represent* an example of an environment that can lead to spacecraft charging, though not the most intense likely to be encountered.

Some indications of maximum flux levels to be expected have been given in summaries of ATS-5 results (Ref. 6,7). It would appear that typical electron exposures are 0.6 nA/cm$^2$ and maximum exposures about 6 nA/cm$^2$. Average energies are typically about 6 keV, but reaching 20 to 30 keV at times. Proton (or heavier positive ion) current densities are normally a factor of 25 to 100 smaller than the electron current densities, and the average energies are twice to 2.5 times those of the electrons.

For representative spectra of high energy electrons (0.1 to 4 MeV), the AE-4 Trapped Electron Model (epoch 1967) can be utilized, with modifications as suggested by ATS-6 data (Ref. 8). Such a spectrum, as derived from the integral AE-4 spectrum for L=6.6 and ATS-6 data, is shown in Figure 2. The spectral current density in the region 100-400 keV has been reduced below AE-4 in order to more closely dovetail with ATS-5 low energy data. A new specification for the outer electron zone environment (AE-7) is currently in preparation (Ref. 9). It is substantially identical to AE-4 for electrons with energies less than 2 MeV. The model predicts significantly greater fluxes of electrons with energies above 2 MeV. However, this change is not such to invalidate any of the calculations or recommendations which are presented in this report as the enhanced nuclear electron environment is more severe than the natural.

The integral current density predicted by AE-4 for energies greater than 300 keV is 6 x $10^{-13}$ A/cm$^2$ in 2π steradians. Allowing for variations common

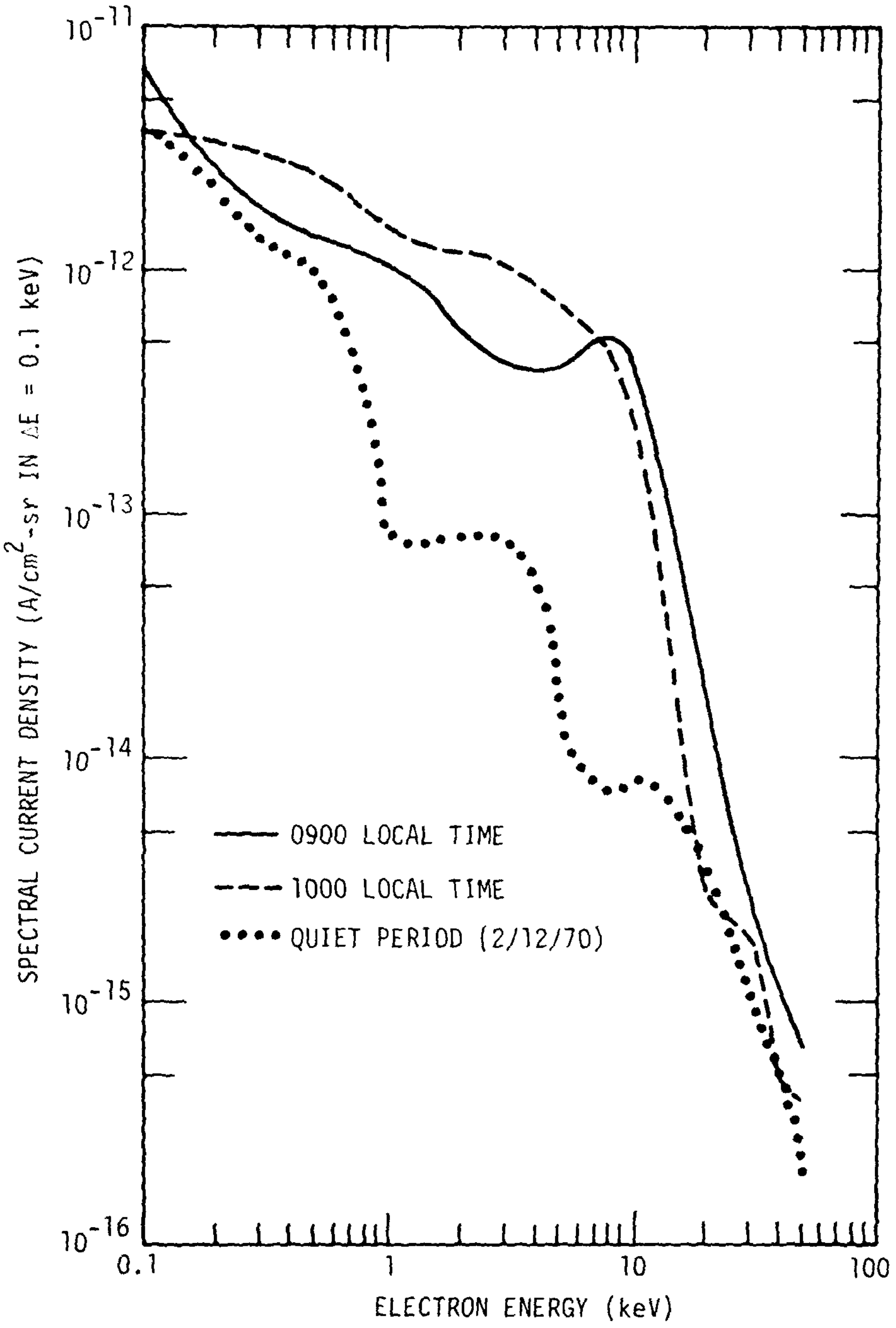

Figure 1. Representative substorm electron energy distribution at geosynchronous orbit

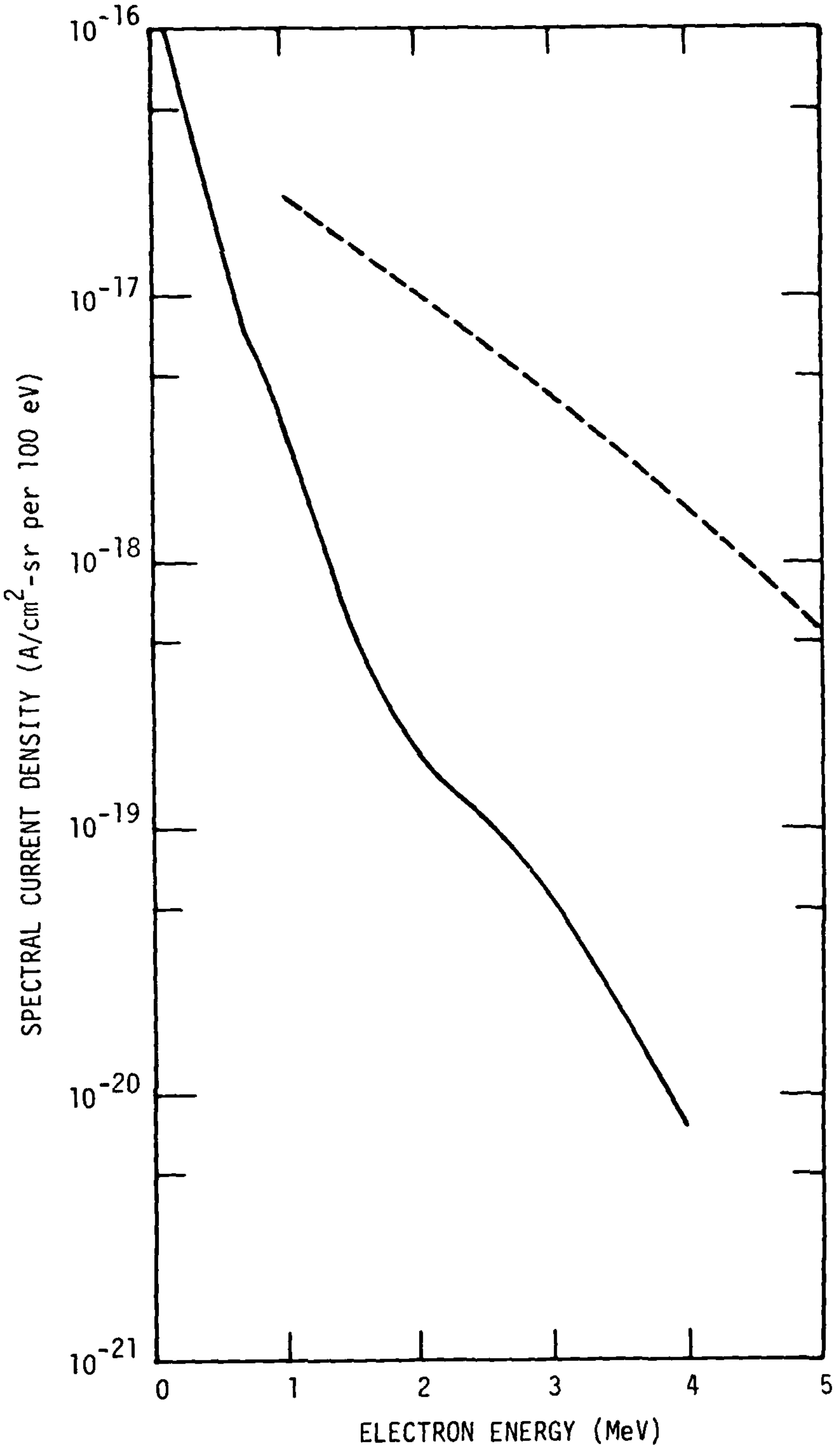

Figure 2. High energy electron energy spectrum for natural (solid line) and artificial (dashed line) environments

at high altitudes, at least $10^{-11}$ A/cm$^2$ would be required for simulation. As discussed below, considerably higher current densities would be necessary from the high energy electron sources.

## 2.2 ARTIFICIAL ENVIRONMENT

A high-altitude nuclear detonation can yield an enhanced charged particle environment at geosynchronous orbit. The resulting spacecraft charging can be quite severe. Spectrum changes and enhancement of fluxes may occur at all particle energies. Unfortunately, most present knowledge of the expected artificial environments rests upon theoretical calculations.

Changes to the high energy electron spectrum at geosynchronous orbit result from radioactive debris that emits beta decay electrons in the MeV range. Some of these electrons may be trapped within the magnetic field lines enclosed by the debris, others may not be trapped. The flux of such electrons at a satellite is highly dependent upon the altitude and location of the burst, but may be as high as 100 times the natural flux above 0.5 MeV (Ref. 8,10). The time scale for significantly enhanced flux is a few tens of seconds, with peak flux of trapped electrons at about ten seconds after the detonation, after which the flux decays over a period of several days to more than a year. The spectrum may be assumed to be approximately that of fission electrons. Such a spectrum (Ref. 11) is shown in Figure 2 for arbitrary flux level.

Recent theoretical work (Ref. 12) has indicated that a significant increase in low energy (< 100 keV) electron flux at geosynchronous orbit can result from a nuclear detonation. The basic mechanism is that of electron streaming to high altitudes due to turbulent coupling between the debris plasma and the natural background plasma. In addition to the dependence on burst altitude and location, the electron flux would depend upon the mass and orientation of the bomb casing just prior to detonation. An omnidirectional flux of about $10^{-6}$ A/cm$^2$ could result at geosynchronous orbit over a time scale of seconds. No information is availabile on the expected energy spectrum, but it may be assumed to be similar to that due to a substorm, with temperatures of $\sim$ 10 keV.

# 3. SIMULATION OF THE ENVIRONMENT

## 3.1 GENERAL CONSIDERATIONS

The results of Section 2 are summarized in Table 1. The energy ranges specified are those considered to be of most significance for spacecraft charging phenomena and the flux levels indicated are conservative upper limits.

Table 1. Charged Particle Environment of Importance to Spacecraft Charging

| Particles | Energy Range | Maximum Incident Flux (A/cm$^2$) |
|---|---|---|
| Natural low energy plasma substorm electrons | 2-30 keV | $10^{-8}$ |
| Artificial low energy plasma electrons | 2-30 keV | $2\times10^{-6}$ |
| Natural high energy electrons | 0.5-4 MeV | $10^{-11}$ |
| Artificial high energy electrons | 0.5-5 MeV | $10^{-9}$ |
| Natural positive ions | 5-50 keV | $5\times10^{-10}$ |
| Artificial positive ions | 5-50 keV | $10^{-7}$ |

Ideally the exact environment would be simulated, including the full distributions of particles in energy and angle. Such an exact simulation of the environment does not, however, appear feasible with presently available technology since available electron and ion sources all suffer from most or all of the following limitations:

- They are point sources, not distributed ones.
- They are nearly monoenergetic, i.e., they do not produce continuous spectra.

- High energy sources produce narrow pencil beams that must somehow be fanned out to illuminate a target as large as a satellite.

It appears, therefore, that an accurate simulation of both the natural and artificial environment would require a large number of sources of different energies deployed at a large number of points on the spherical surface of the SXTF vacuum chamber, and would raise the cost and construction difficulties substantially.

Since it appears difficult if not impossible to simulate the total environment, it is logical to ask which aspects of the total environment are most important for simulation. One cannot give a definitive answer to this question. Phenomenology studies to date have concentrated on the effects produced by either monoenergetic low energy or high energy electrons (Ref. 2, for example). The effect of ions, which would be confined to surface charging is unknown. Nor has the effect of charging by a distributed energy spectrum been studied experimentally. It is hoped that more will be learned from ongoing programs sponsored by DNA, SAMSO, and AFWL. For the present, it is clear that such a simulation might include the following components:

1. A low energy electron charging source to simulate components 1 and 2 of Table 1 (2-30 keV).
2. A high energy electron charging source to simulate components 3 and 4 (0.5-5 MeV).
3. A UV source to create photoemission which is an important factor in producing differential charging.

If possible some attempt might be made to obtain distributed energy spectra.

There are several reasons why one should distinguish between low and high energy electrons. First, they produce different effects on the spacecraft; the former, is responsible for surface charging while the latter causes problems internally. Second, it is most convenient to produce these interactions, with distinctly different sources. One simplifying factor is that the natural and nuclear environments comprise electrons of similar energies even if the energy distributions are somewhat different. Another factor shared by both is that they are not noticeably well defined (in contrast to the output of nuclear devices) so that overly elaborate simulations are probably pointless. This is especially true for the postulated low energy component of the artificial enhanced charged particle environment. Moreover, the natural environment, for which much more detailed data is available is highly variable; and the statistics of the variations in energy spectrum, flux, flux anisotropy, are not well known. A reasonable estimate,off by not more than a factor of four, can probably be made for all but components 2 and 6 of Table 1 which have not been detected experimentally. However, assuming that the environment to be simulated is that specified in this section, let us proceed to examine the simulation problem.

## 3.2 GEOMETRY

In the absence of more detailed data, it is reasonable to assume that the natural flux is isotropic. The flux incident on a satellite exposed to an exoatmospheric detonation will depend on the relative position of the detonation and the orbit of the satellite. To define the requisite number of sources, one can ask what is the minimum number needed to cover some maximum working volume uniformly. Flux anisotropies could be simulated by varying the output of some of the guns.

If the target is placed in the center of the spherical vacuum chamber, four electron guns are the minimum set that can illuminate the whole surface of a spherical target. If these are arranged in a tetrahedral array, and each gun illuminates the silhouette seen from its positon uniformly, the uniformity of surface coverage over the whole target is better than ±20%. This applies to any monotonically convex target. For targets of more complex geometry, such as satellites with deployed solar paddles, this minimum configuration will necessarily leave substantial areas of the satellite shadowed, that is to say the shadowed areas will see none of the four sources. Table 2 shows the five possible completely regular arrays of points on a spherical surface, the angle between each point and its nearest neighbors, and the number of each point's nearest neighbors. Clearly, the larger the number of electron guns distributed around the target, the better will be the simulation of an isotropic flux. How good does the simulation need to be? If the satellites are restricted to geometries not much more complex than those shown in Figure 3, a set of six electron sources, located on the intersections of three orthogonal diameters with

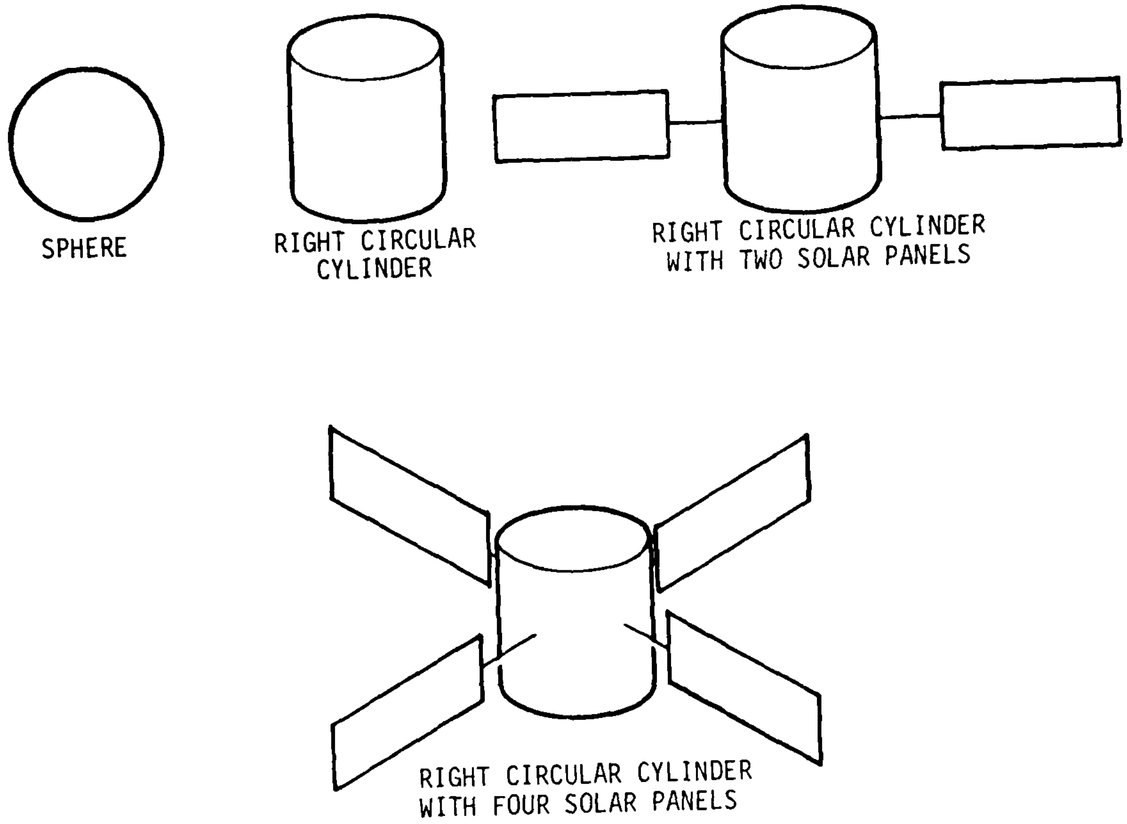

Figure 3. Representative satellite shapes

the spherical surface of the vacuum tank would illuminate the objects very nearly like an isotropic flux.

Table 2. The Regular Arrangements of Points on a Sphere

| Number of Equally Spaced Points | Angle Between Nearest Neighbors | Number of Nearest Neighbors |
|---|---|---|
| 4 | 109.47° | 3 |
| 6 | 90.00° | 4 |
| 8 | 70.53° | 3 |
| 12 | 63.43° | 5 |
| 20 | 35.97° | 3 |

## 3.3 DIFFERENTIAL CHARGING

Differential charging of various parts of the satellite is perhaps the most important effect of the low energy electron flux. This flux would, by itself, charge the whole satellite fairly uniformly. In the presence of sunlight, however, photoelectrons emitted from the surface will prevent the sunlit surfaces from charging up. These surfaces will be kept near the plasma potential by the balance between the arriving electron flux and the departing photoelectron flux. The flux of photoelectrons emitted will generally exceed the arriving electron flux, so the potential will adjust itself to the point where not all photoelectrons can escape, and the two fluxes are in balance. On the dark side, or where shadowed, there is no photoelectron flux, and so all electrically isolated surfaces can charge up. This differential charging of satellite surfaces can cause vacuum sparks, and dielectric breakdowns, and will effect the SGEMP response induced by an X-ray flash. A satisfactory simulation of surface charging due to the low energy electron flux must, therefore, include a means of simulating the differential charging that arises from the solar photoelectrons.

The most direct means of simulating this effect is to simulate the solar photon flux with suitable lamps illuminating one side of the test satellite. The full solar spectrum is not needed to simulate the effects on charging. However, the infrared and the red end of the visible spectrum make little or no contribution to photoelectron emission from satellite surface materials, only the blue and ultraviolet parts of the solar illumination make an appreciable contribution. These can be simulated with a small fraction of the lamp power input, cost, and thermal burden that would result from a simulation of the full solar spectrum. For the same power input, mercury capillary arc lamps, for example, radiate more than twenty times the power at wavelengths shorter than 200 nm than is radiated by the xenon arcs usually used in solar simulators. However, a solar simulator may be included in SXTF for illuminating solar cells which may be adequate to achieve photoelectron production, i.e., 1 sun AMO over a suitably large area.

## 3.4 LOW ENERGY ELECTRONS

Several alternative low energy electron guns may be considered for simulation of the low energy electron environment. These may be classified according to the primary electron source, method of acceleration, and method of distributing the electrons over a large target. Primary electron sources may be divided into hot and cold cathode devices. Hot cathodes may consist of tungsten filaments, thoria coated iridium filaments, oxide coated cathodes (usually a nickel substrate coated with a mixture of barium, strontium, and calcium oxides), dispenser cathodes (usually a porous tungsten matrix loaded with alkaline earth oxides), and lanthanum hexaboride cathodes. Dispenser and oxide coated emitters are very sensitive to contamination; they are "poisoned" very easily by traces of organic vapors, silicones, and many metal vapors, as well as by oxygen, sulfur, halogens, and water vapor. Their life expectancy is adversely affected if they are frequently exposed to air. Lanthanum hexaboride is somewhat less sensitive to poisoning than the alkaline earth based emitters, but is by no means immune. Tungsten and thoria coated iridium filaments, on the other hand, are highly resistent to all forms of poisoning, and especially in the case of tungsten, are simple and inexpensive to construct. Under the conditions to be expected in the SXTF vacuum chamber, both have life expectancies of thousands of hours. Thoria coated iridium is resistant to burnout if it is inadvertently kept heated when let up to atmosphere, but since this occurrence will presumably be prevented by the SXTF control system, the higher cost of thoria coated iridium would not appear to be jusitifed.

The main types of cold cathode emitters that merit consideration are multipactor sources, and field emitters. Multipactor sources depend on electrons being accelerated by an rf field across a gap between two plates and causing secondary electrons to be emitted. If the rf frequency is correctly chosen relative to the electron transit time, the electrons from one plate arrive at the other just as the field reverses, and at each passage across the gap, the number of electrons increases until equilibrium is established by space charge limitation. Electrons can be obtained through holes in one of the plates and accelerated. The *multipactor* source is somewhat sensitive to poisoning since its operation depends on the secondary electron emission coefficient of the plates which in turn is sensitive to surface contamination. It has the advantages of long life expectancy, ease of fabrication, the ability to be easily shaped to provide a beam of the desired geometry, and unlike hot cathodes, it emits no light. Its disadvantages are that it is not well developed and will require some R&D, it has some sensitivity to poisoning, and it requires an rf generator.

*Field emission sources* make use of the electric field concentration around sharp pointed needles. If the electric field at a surface is sufficiently large, electrons can quantum mechanically tunnel through the surface potential barrier and be emitted into space. To achieve the necessary large field gradient, the radius of the tip must be extremely small. The traditional method of making field emitters has been by electrolytically etching the tips of fine tungsten wires. This type of field emitter is difficult to fabricate, very delicate, and unsuitable for all but the most exacting applications. Recently, it has been found that carbon fibers are good field emitters. When they are cut or broken, they fracture forming very sharp points, and are immune to spark effects that could destroy metal field emitters. Field emitters are conceptually simple, require no heater or rf supply, and with carbon fiber, are easy and cheap to fabricate and are immune to poisoning effects. Field emitter guns suitable for spacecraft irradiation with electrons have not been constructed, however, and some R&D effort would be needed to develop them.

Electrons may be accelerated in relatively simple structures either by dc electric fields, or by rf fields. Dc acceleration has the advantage of simplicity, the electron gun can be a simple diode structure. A dc gun can, however, produce only a single energy beam. A gun using an rf accelerating field, or a combination of dc and rf can be designed to produce a spectrum of energies, although the degree of control of the spectral density function may be somewhat limited. Dc electron guns are well developed, and their design is fairly straightforward. Rf guns for low energy electrons are not so well developed and would require some R&D.

Most conventional electron guns are designed to produce narrow pencil beams. The SXTF requirement is for guns that can produce a broad beam to uniformly distribute electrons over a large target. There are essentially two approaches that can be used to meet this requirement, sweeping the beam over the target in a raster pattern, and designing the gun to directly produce a diffuse beam. With the raster method, it is possible to achieve very precisely uniform illumination of the target. It has the disadvantage that each point on the target sees a pulsating high dose rate rather than continuous bombardment, and the charging effects may not be the same. The raster method also requires suitable electronics to drive the sweep plates or coils. A diffuse electron gun, not requiring a raster sweep, was developed by IRT for the SKYNET tests (Ref. 2). The gun was of extremely simple construction, and performed well in those tests. A disadvantage of the diffuse gun is that electrons may be sprayed where not desired.

Total electron currents required from the low energy electron guns are of the order of 0.1 mA per square meter of satellite surface area, 20 mA per square meter if it is desired to simulate the postulated low energy component of the artificial environment. Thus, for typical satellites, tens of mA are required (hundreds of mA in the artificial environment case).

## 3.5 HIGH ENERGY ELECTRONS

The primary available sources of electrons in the 0.5-5 MeV energy range are rf accelerators (LINACs) and dc machines (Van de Graafs). A LINAC for this energy range is available from Varian Associates Radiation Division. Their Linatron 400 is designed as a bremsstrahlung x-ray source, but can be configured as an electron source. It can generate an electron beam of 220 μA average (180 mA peak with a 0.0012 duty factor) with a beam energy of up to 4 MeV. This machine costs approximately $250K, ± about 20% depending on configuration and options. The primary advantages of a LINAC are compact size and low cost. They suffer from the disadvantage of a pulsed, rather than continuous beam. If dose-rate effects are considered important, the use of a pulsed beam may not be a reasonable simulation of the charging effects of the natural environment.

Dc accelerators are available from two main manufacturers, High Voltage Engineering Corporation (Van de Graaf) and National Electronics Corporation (Pelletron). The sizes and operating characteristics of Van de Graafs and Pelletrons are similar, as are their principles of operation, the difference between them being differences of detail. Pelletrons are slightly more expensive than Van de Graafs, but NEC claims they are more reliable and require less maintenance. Typical Van de Graafs are HVE models KS3000 and KS4000 which cost $302,400 and $324,500, respectively. They can accelerate electron beams of up to 1000 μA to energies up to 3 and 4 MeV, respectively. Typical Pelletrons are NEC models 3UEH-HC and 3UEH which can accelerate electron beams of up to 300 μA and 100 μA respectively to energies up to 3 MeV. These machines cost $450K and $340K, respectively. These costs do not include the cost of some necessary accessories such as gas handling and storage equipment for the insulating gas ($SF_6$ for the Pelletrons and a $N_2$, $CO_2$, $SF_6$ mixture for the Van de Graafs), beamlines, bending magnets, etc.

All available high energy electron accelerators produce narrow pencil beams, and some means must be provided to distribute these beams over a large area target. The available methods for accomplishing this are scattering, lenses and raster systems. A scatterer is the simplest means of spreading out the beam, and has the additional advantage (in principle) of spreading the energy distribution of the beam so that it more nearly approximates the natural energy spectrum. Relatively thick scatterers have the disadvantage of producing an isotropic angular distribution and of high beam current requirements. Lenses do not appear usable since lenses of the requisite strength are not available for the beam energies involved. Electromagnet raster scanners are available for electrons of this energy range, but have the disadvantage that, despite the use of a dc beam, each element of the target surface is irradiated with a pulsed beam of small duty factor. IRT is currently designing and constructing a rastering system for AFWL to be attached to a TRW Van de Graaf for spacecraft charging tests on the FLTSATCOM qual model center body. Such a system could in practice be used in SXTF.

The total current requirement for a high energy electron source incorporated in SXTF cannot be simply obtained from the environment specification by multiplying by the appropriate areas. This situation arises because of the times required to reach steady charge state in the spacecraft internal dielectrics upon electron irradiation. In space, typical times (order of magnitude) for reaching steady state are 20 days for the natural environment and 1/2 hour for the artificial environment. In SXTF, however, irradiation times must be kept short, probably on the order of 1/2 hour, so the current density must be high enough to ensure that steady state is attained. One must determine that there are no dose rate effects on the final charge state produced. There is reason to believe that to a first approximation this is so (Ref. 3). The current required from the high energy electron source would then be about 50 μA per square meter of spacecraft area.

If a scatterer is used to distribute the beam and produce an energy spectrum, the current requirements are higher. The transmission through the scatterer may be about 30% and a large fraction of the current may not hit the spacecraft because of the angular distribution following the scatter. The latter fraction depends upon the location of the scatterer within the tank. Current requirements could be as high as 1 mA per square meter if a scatterer is used.

## 3.6 IONS

Although the positive ion fluxes encountered in the spacecraft environment are normally about a factor of 25 to 100 less than the electron fluxes, ions may contribute to spacecraft charging phenomena. Secondary electron emission coefficients for positive ions are large, especially for ion energies above a few keV, so that the ion current to the satellite is, in effect, magnified. If the satellite is negatively charged, the ions will be accelerated as they approach the satellite, and even ions with low initial energy can impact with sufficient energy for high secondary coefficients. Penetration of ions into spacecraft surfaces is less than for electrons, so that dipole layers can be formed in insulators, possibly influencing discharge characteristics.

The production of ion beams for simulation in SXTF would be similar in most respects to the production of low energy electron beams. Although there are many types of monoenergetic ion guns available for the 5-30 keV energy range, perhaps the simplest and cheapest would be a flood gun similar to that used for electron spraying in the SKYNET tests. Very few modifications would be required to that design for conversion to use with ions. The ion guns could then be mounted in clusters with the electron guns.

As the electron beam traverses the region between the tank wall and the spacecraft, positive ions are produced from the residual gas. Since the spacecraft (or parts of it) rapidly charges to a negative potential, all positive ions formed are attracted to it. (Secondary electrons formed in the gas ionization go to the walls of the tank). The energy of the ions bombarding the spacecraft is equal to the spacecraft potential minus the potential at the spot the ions were formed. A spectrum of ion energies can thus be expected. The magnitude of the ion current due to the residual gas depends upon the electron energy, the residual gas pressure, and the composition of the background gas. Secondary electrons, both off the satellite and as a result of gas ionization, will produce ions with higher efficiency than the main beam. Ion production of secondaries is especially strong if the satellite is outgassing. With residual gas pressures in the $10^{-5}$ to $10^{-6}$ range, ion currents may be 1/100 to 1/25 of the electron current, or even larger. Indeed, it will be difficult to charge the satellite unless the gas pressure is low enough. Detailed study of the effects of residual gas ionization is desirable, at least to the degree of determining the maximum permissible operating pressure. To handle the ion problem in the tank, it is recommended that a residual gas analyzer be incorporated.

# 4. FACILITY IMPACT

## 4.1 MAGNETIC FIELDS

In a vacuum tank as large as that of the SXTF, the geomagnetic field ($\approx 0.5$ gauss) must be largely excluded if low energy electrons from guns at the tank wall are to reach a target at the center. Figure 4 is a plot of the gyroradius of an electron as a function of energy for various value of B. Referring to Figure 5, if an electron passes along a trajectory that is a circular arc of radius r, and the gun, G, and target, T, are separated by a distance d, then the electrons, in order to hit T must be launched at an angle $\theta$ from the line connecting G and T, where

$$\theta = \sin^{-1}\left(\frac{d}{2r}\right) \quad . \tag{1}$$

$\theta$ can exist, therefore, and the electrons can reach the target if and only if $r \geq 1/2\ d$. In the SXTF, let us assume that we have an electron gun on the surface of the 30 m diameter vacuum tank and a target at its center and that B is perpendicular to d. d is, therefore, 15 m. Let us set $r = 1/2\ d = 7.5$ m. Referring to the $B = 0.5$ gauss plot of Figure 4, we see that the lowest energy electron that can reach the target has an energy of 10.5 keV. $\theta$ is 90°, so this electron is launched tangent to the spherical vacuum tank, and its path to the target is a semicircle. It is desirable that $\theta$ be kept reasonably small, say less than 30°, for electrons of the lowest energy of interest, say 5 keV, so as to simplify aiming. Setting $\theta = 30°$, $d = 15$ m, in Eq. (1) and solving for r, we get $r = 15$ m. Referring to Figure 4, we see that $B \approx 0.17$ gauss, about one third the geomagnetic field.

If a spectrum of electron energies is used, the magnetic field must be quite small, since different energy electrons have different trajectories in the field. Aiming problems become severe unless the geomagnetic field is reduced below 0.1 gauss. The presence of a magnetic field may also affect the SGEMP response by perturbing the orbits of x-ray generated photoelectrons which have energies comparable to those associated with magnetic substorm electrons.

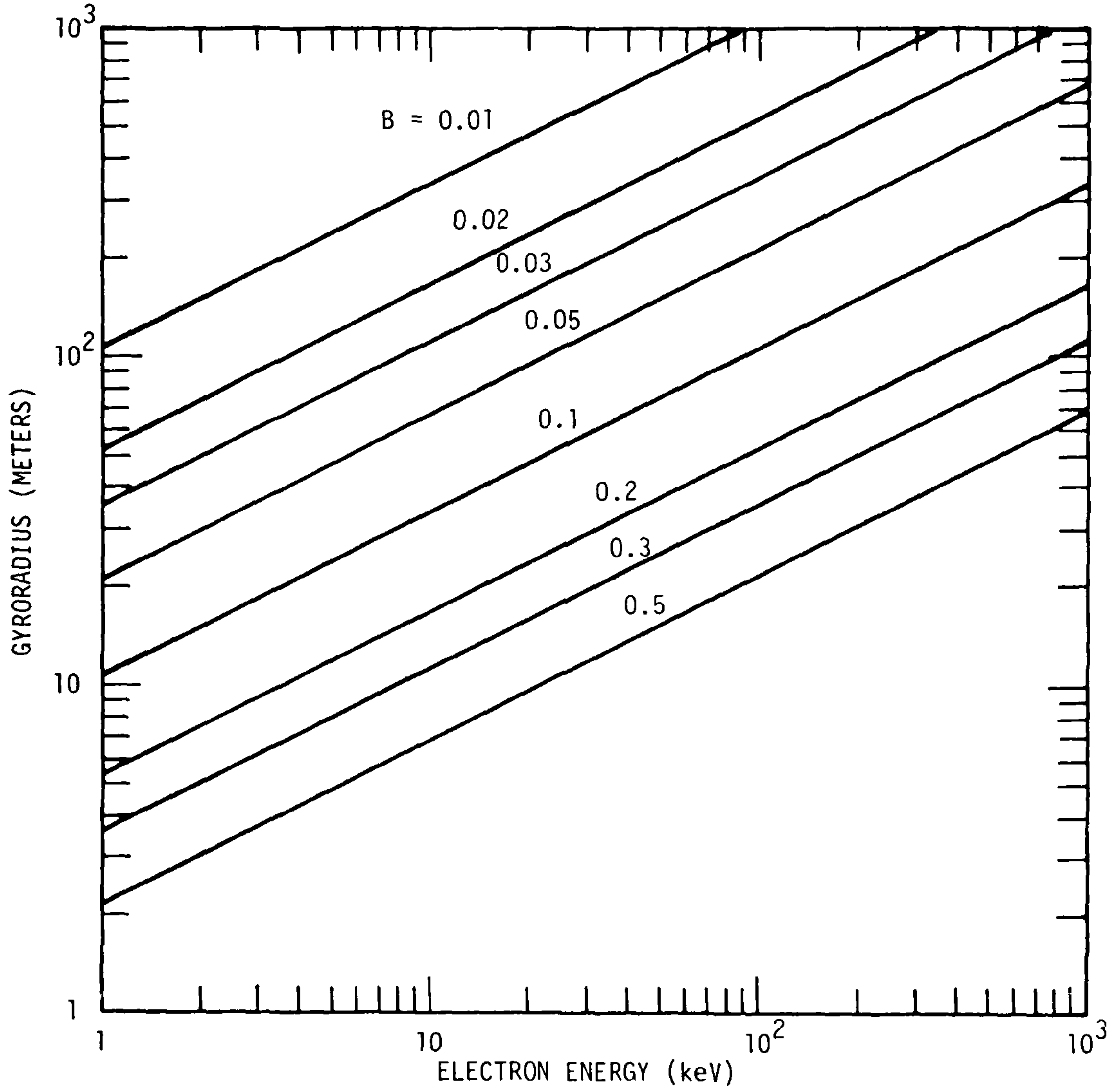

Figure 4. Electron gyroradius as a function of electron energy and magnetic field (gauss)

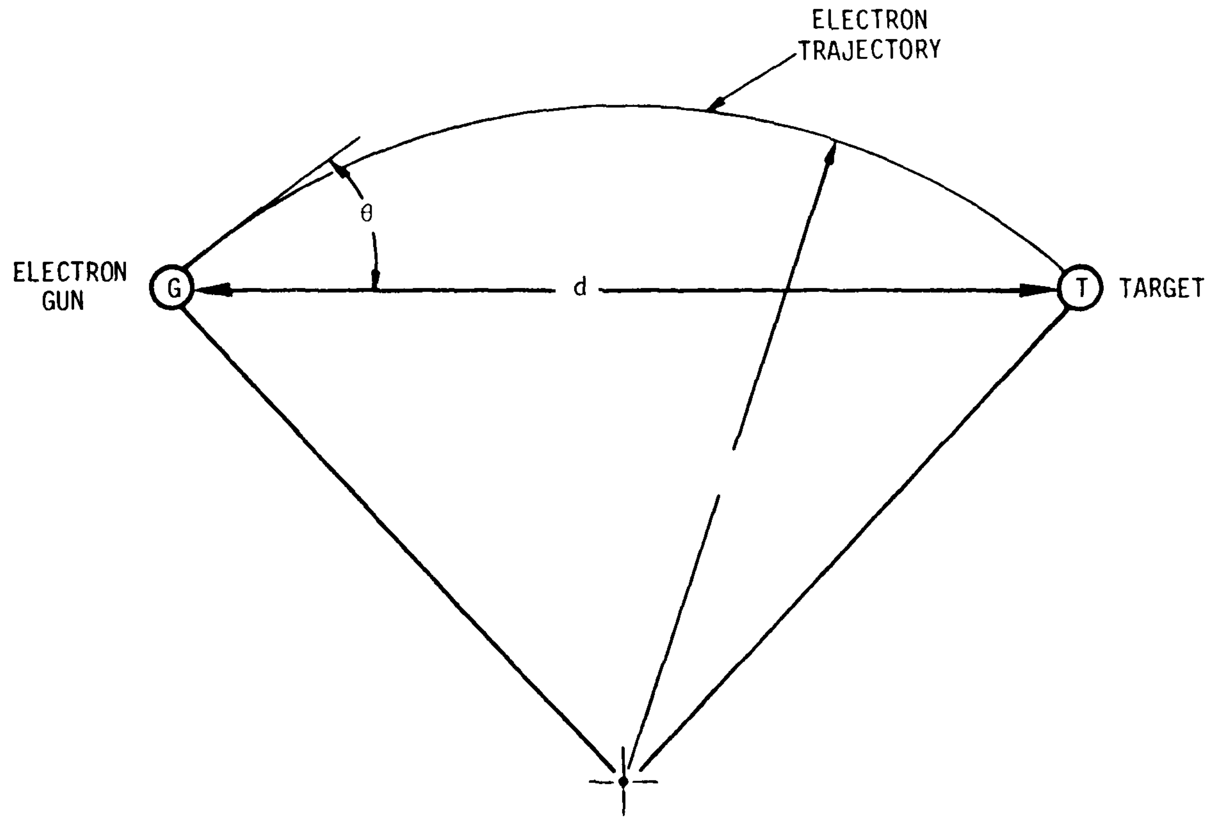

Figure 5. Geometry of electron trajectories in the presence of a magnetic field

The geomagnetic field may be excluded from the interior of the vacuum chamber by either of two methods, shielding with a material of high permeability, or cancellation with an applied opposing field. Let us look at each of these alternatives in turn.

Shielding might be accomplished by making the vacuum vessel walls of pure annealed iron (such as Armco magnetic ingot iron). This material has an initial permeability of $\mu \geq 500\ \mu_o$. If we have a thin spherical shell, and define a shielding factor, S, such that

$$S \equiv \frac{B_1}{B_2} \quad , \qquad (2)$$

where $B_1$ and $B_2$ are the induction outside and inside respectively, then

$$S \approx \frac{2\mu t}{\mu_o r} \ , \ t \ll r \quad , \qquad (3)$$

where t is the wall thickness and r is the radius. If we let $\mu/\mu_o = 500$, $r = 15$, and $t = 0.05$, we get $S = 3.3$. Because this factor is just sufficient under nearly ideal conditions, and because it is doubtful that the iron can be maintained in sufficiently stress-free condition during fabrication of a 30 m sphere, this approach does not appear promising.

Suppose we have a sphere covered with a current sheet such that the circular current elements are all concentric with one axis passing through the center. If we define an angle θ as the angle between the axis and a line between some arbitrary point on the sphere and the center, then the condition for a uniform field inside the sphere is $J = \frac{2}{3} J_o \sin\theta$, where J is the surface current density (in $Am^{-1}$) at any point on the sphere. The field inside is $\frac{2}{3} J_o$ everywhere, and the induction is $\frac{2}{3} J_o \mu_o{}^{-1}$. The total circulating current, I, is given by:

$$I = \int_o^{\pi} r \sin\theta d\theta = 2\ J_o r \text{ ampere turns.} \qquad (4)$$

The geomagnetic induction magnitude in California is $B \approx 0.5$ gauss $= 5 \times 10^{-5}$T. The field, H, is given by

$$H = \frac{B}{\mu}$$

The permeability of free space in SI units is $\mu_o = 4\pi \times 10^{-7}$ henry meter$^{-1}$, which yields $H = 39.8\ \mathrm{Am}^{-1}$. Setting $J_o = \frac{3}{2}H$, and $r = 15$ m, we get $I \approx 1791$ ampere. If the spherical surface were wound with a fifty turn coil as shown in Figure 6, the current required would be

$$i = \frac{I}{n} \ , \tag{6}$$

where $n = 50$, giving $i = 25.8$A. The length of this coil is given by

$$\ell = \frac{n\pi}{r} \int_{-r}^{r} \sqrt{r^2 - z^2}\ dz = \frac{n\pi^2 r}{r} \ , \tag{7}$$

which, for the numbers above, gives $\ell = 3701$ m. If this coil were wound with #10 wire, its resistance would be 12.13 ohms. Solving ohms law for voltage drop yields 435V and a power dissipation of 15555 watts.

If the SXTF vacuum chamber were made of a nonmagnetic material, say a 300 series stainless steel, the coil axis should be aligned as precisely as possible parallel to the local geomagnetic field vector, and the coil current adjusted to cancel the field inside. The presence of doors and other apertures in the vacuum wall poses a difficulty with this approach. If the turns are diverted around the apertures, some of which are quite large, this will result in local field perturbations. One way of minimizing these perturbations is to select the locations of the largest apertures as near as possible to the poles of the winding where the surface density of turns is a minimum, and as far as possible from the equator, where the density is a maximum. Another approach is to avoid diverting the turns any more than absolute necessary. At the x-ray source, for example, the turns might be threaded between individual x-ray source modules rather than being diverted around the whole source assembly. At the main entrance doors, the turns might go straight across the doorway. They could have plugs and sockets on one side of the doorway to enable them to be disconnected to unblock the passage.

## 4.2 RADIATION SHIELDING

An electron source of 1-5 MeV energy is capable of producing a large amount of hazardous radiation (bremsstrahlung), even at low beam currents. Any region that can under any circumstances be struck by a portion of the electron beam must be considered as a potential source of such radiation. The purpose of this section

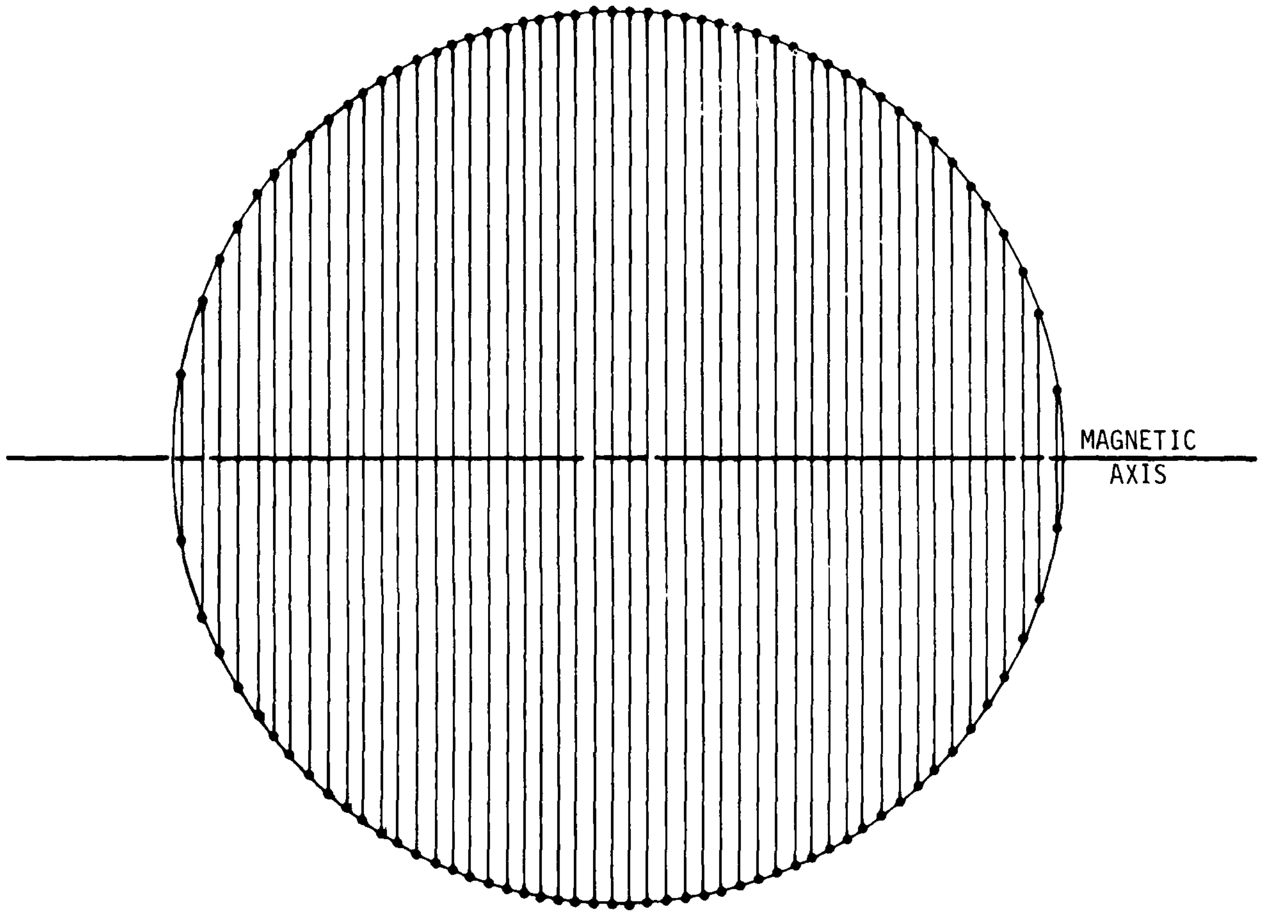

Figure 6. Coil geometry

is to estimate some possible shielding requirements for a high energy electron source installed in SXTF.

Some radiation sources that must be considered include:

- Collimators and walls inside the electron source.
- The satellite under test.
- The cold wall.
- The damper and associated components.
- The tank wall.
- Cables, platform, etc., inside the tank.

These targets are, of course, of different materials and thicknesses and will thus have different efficiencies for bremsstrahlung production. For the present study, it is sufficient to calculate a representative normalized dose rate for the worse case circumstances, e.g., the situation where the collimated beam hits the tank wall, a collimator in the source, the satellite or other internal tank instrumentation.

For order of magnitude calculations of dose rate, certain simplifying assumptions can be made. The entire bremsstrahlung intensity can be considered to be concentrated at one third the initial electron kinetic energy. The photon angular distribution varies with the initial electron energy, but it may be assumed that half the photons are emitted within a cone of half-angle $\theta$ about the forward electron beam direction, and that the photons are uniformly distributed within this cone ($\theta$ = 20°, 25°, 30° for $T$ = 5 MeV, 3 MeV, 1 MeV respectively).

Considering, then, a thick steel target and a collimated electron beam, the following dose rates are calculated at 1 meter radius for 1 mA beam current:

| T (MeV) | D(rads/sec at 1 m) |
|---|---|
| 5 | 117 |
| 3 | 32 |
| 1 | 15 |

(It should be noted that actual dose rate could be somewhat higher in the direction of the electron beam.) At 10 meters distance these dose rates are reduced a factor of 100. As an example of potential shielding requirements, a 3 MeV - 1 mA electron beam could be chosen, for which the dose rate in the above approximation would be 0.32 rads/sec at 10 m, or 1150 rads/hr. An attenuation factor of $5 \times 10^5$ would have to be provided in order to reduce the dose rate to ∿ 2 mRad/hr. Approximately 7 inches of lead, or about 5 feet of concrete, would be required for this degree of attenuation. As the beam would not be allowed to strike the side of the tank indefinitely, the actual amount of shielding required is somewhat less.

Thus, some shielding must surround the tank, and the source must be fully shielded. The tank shielding could be thinner in some directions, especially if effective use is made of controlled areas. Shielding requirements become most severe if a scatterer is used for spreading the beam in angle and energy, or if several sources are necessary for an isotropic illumination.

## 4.3 MISCELLANEOUS

### 4.3.1 Stray Electrons

It will be virtually impossible to avoid missing the satellite with some of the electrons. In addition, secondary electrons will move toward the walls as the satellite charges to a negative potential. Any dielectric surfaces or coatings can then charge up and create stray fields in the tank. It is difficult to predict whether or not this could be a serious problem.

A much more serious problem will arise if the collimated LINAC beam impinges on the satellite or test electronics. A 3 MeV electron has a range of 1.46 $g/cm^2$ or 0.54 cm in Al and about 1 mm in Pb. While it will be possible to shield test electronics for high energy electrons, such shielding is not possible for the satellite. Such a beam could deposit $\sim 2.10^8$ rads(Al)/sec with catastrophic consequences. Therefore, any high energy beam transport system must have a fast acting, fail safe mode of operation.

### 4.3.2 Source Placement

The recommended low energy electron sources (Section 5.1) are sufficiently compact that they would probably not pose any severe placement or mounting problems. For example, some of the damper supports might also serve as supports for gun clusters. Tank and cold wall penetrations must, of course, be provided for control and power cables. The design of the platform must be coordinated with the gun placement scheme.

Installation of one or more high energy electron sources would result in substantial facility impact. In the case of an HVE KS-4000 accelerator, an area of about 35' x 18' x 12' is required for horizontal mounting, 42' x 27' x 18' for vertical mounting (not including shielding). Placement of the source underground would be advantageous for economy of shielding. Any underground location other than below the tank may lead to long beam lines with consequent cost of beam line components and shielding. However, it would be difficult to find a suitable location above ground in SXTF unless a much smaller (< 1 MeV) accelerator is chosen.

If a scatterer is used, it should be mounted fairly close to the satellite. The scatterer must be water-cooled, so that the unit together with its supporting structure is of sufficient size to possibly affect the SGEMP tests through reflections, secondary emission, etc.

Provision for radiation monitoring must be installed (in occupied areas, etc.) if high energy sources are to be used.

### 4.3.3 Heat Load

An electron beam of 3 MeV, 150 μA represents a power of 450W. Such a beam, if stopped in the satellite, could under some circumstances create a heat load problem. Hopefully the satellite thermal control system could accommodate an extra load of this magnitude.

# 5. SUMMARY AND RECOMMENDATIONS

## 5.1 SUMMARY

This report has attempted to answer three questions related to providing a spacecraft charging capability for SXTF. These are:

1. What is the nature of environment to be simulated?
2. What hardware is available for the simulation of this environment?
3. What is the impact on the design, construction and operation of SXTF?

A strawman set of recommended hardware and an identification of action items is presented. This report assumes that it is desirable to incorporate a spacecraft charging capability into SXTF. It does not deal with the question of necessity. Whether it is necessary to consider precharging effects in performing an integrated system test to determine satellite SGEMP survivability will only be determined after the spacecraft charging/SGEMP phenomenology programs being carried out under DNA and AFWL sponsorship are completed. Even if such a capability is not important for SGEMP, the inclusion of this capability may be mandated if SAMSO levies a S/C survivability requirement on DOD satellites.

As discussed in Section 2, the environment to be simulated has two sources (q.v. Table 1, Section 3.1): One is a natural component comprising both low energy plasma substorm electrons and positive ions, with energies of tens of keV, and a much weaker high energy trapped electron pendant with characteristic energies of hundreds of keV to several MeV; the second principal component is the particle environment typical of an exoatmospheric nuclear detonation which also comprises both electrons and ions. The two differ in intensity (the nuclear being of an initially higher intensity which decays) and also energy spectrum. The presence of solar UV radiation also plays an important role in charging. In developing the specific hardware implementations discussed in Section 3, and summarized in Section 5.2, four factors have been taken into account. These are:

1. Particle Species. As a minimum the facility should contain low energy and high energy electron sources. Insufficient evidence is available as to a need for ions, although the inclusion of such a capability presents no great difficulties.
2. Energy Distribution. No detailed information is available on the necessity for a detailed simulation of particle energy distribution. What is known is that the low energy and high energy electron components produce different charging effects (i.e., surface or interior). Providing a distributed energy spectrum is not too difficult for low energy case, but is much more so for the high energy electrons.
3. Geometry. A reasonable simulation of the natural space environment requires isotropic coverage of the satellite. This is relatively easy to achieve for the low energy electron source but again will be difficult for the high energy component. Given a multisource capability, anisotropic exposures, perhaps more typical of the artificial environment, could be achieved.
4. Fluence. Provided that dose rate effects are not important in reaching charge equilibrium, one would like to charge the satellite as rapidly as possible. This would dictate charging times of the order of 1/2 hour based on the capabilities of available particle sources. This interval is comparable to predicted times for attaining equilibrium charging of interior spacecraft dielectrics by the enhanced nuclear charged particle environment.

Based on these considerations, the SXTF charging capability should include as a minimum:

1. A set of low energy sources ($2 < E < 30$ keV) capable of providing isotropic coverage.
2. At least one high energy source (up to 5 MeV) capable of providing reasonably uniform illumination of one side of a satellite by rastering or scattering.

5. A set of UV sources capable of providing an amount of UV fluence comparable to that produced by the sun. From a spacecraft charging point of view, this need not be the same source as that required to power solar cells.

The incorporation of a spacecraft charging capability will have a substantial impact on the design, construction, cost and operation of the facility. Major items include:

1. A need to provide an external solenoid to cancel the earth's magnetic field inside the tank. This is needed to prevent the trajectories of low energy charging electrons (and emitted photoelectrons) from being distorted by the geomagnetic field.
2. Considerable radiation shielding to reduce the level of bremsstrahlung radiation produced by the high energy electron sources to meet radiation safety requirements. The shielding problem becomes more severe as the maximum electron energy simulated increases.
3. An operational design for the high energy electron sources that is fail safe. In the case of malfunction, the satellite and other facility equipment must not be damaged by too long an exposure to the direct beam. A 3 MeV, a 1 ma electron beam will deposit a dose of several hundred Mrad (Al) per second.
4. A possible need to include significant space around or under the tank for inclusion of one or more high energy electron sources along with associated maintenance areas and shielding.

## 5.2 HARDWARE IMPLEMENTATION

### 5.2.1 Low Energy Electron Sources

Regardless of the electron guns used, it has been shown to be necessary to minimize the magnetic field inside the SXTF vacuum chamber so that the low energy electron paths have sufficient large radii of curvature to make a simulation possible. The recommended means of accomplishing this is to cancel the earth's field with an equal and opposite field of a spherical solenoid wound on the vacuum chamber surface. It is also recommended that, whenever possible, the turns of this winding go straight across all vacuum chamber ports and openings rather than being diverted around them so as to minimize the resulting local field perturbations. The treatments necessary to accomplish this will vary from one port to another depending on the size and shape of the port, its intended use, and its location and orientation relative to the solenoid axis.

The recommended electron guns are simple tungsten filament diode flood guns similar to those that were developed for the SKYNET tests. An example is shown in Figure 7. These guns are simple, cheap, and reliable, and they produce beams sufficiently diffuse to uniformly bombard a large target without benefit of raster sweeps or other special devices. It is recommended that these be mounted in clusters of at least four guns, three operated at three different energies in the low energy range, and one serving as a spare. Because the large size of the SXTF vacuum chamber may render access to the gun clusters difficult and costly, it may be worth considering the inclusion of more spares. A cluster of seven guns in a hexagonal array on a circular flange could be manufactured for less than $5,000 (guns only, not including power supplies). It is recommended that six clusters be installed at the interactions of three mutually orthogonal diameters with the spherical vacuum chamber surface. This array can give a good simulation of an isotropic flux at the center of the chamber, and any desired anisotropy may be simulated by varying the relative outputs of the various guns.

### 5.2.2 Ions

It is not yet clear whether it is necessary to simulate the ion portion of the environment. Adding ion guns to the electron gun clusters at any time would be straightforward and inexpensive, so that a decision on this matter should await results of spacecraft charging technology programs, and a study on residual gas ionization (Section 5.4).

### 5.2.3 UV Illumination

The differential charging effects that are so important to satellite survivability cannot be simulated by electrons alone. The photoelectrons emitted by the satellite are as important as the incident electron flux in determining the final charge distribution. It is not necessary to simulate the full solar spectrum for this purpose, however, since only the blue and the UV cause the emission of significant fluxes of photoelectrons. Whether or not to simulate the full solar spectrum will, therefore, be dictated by other considerations, but it is recommended that the UV spectrum be simulated with lamps, such as mercury arcs, that are rich in UV and

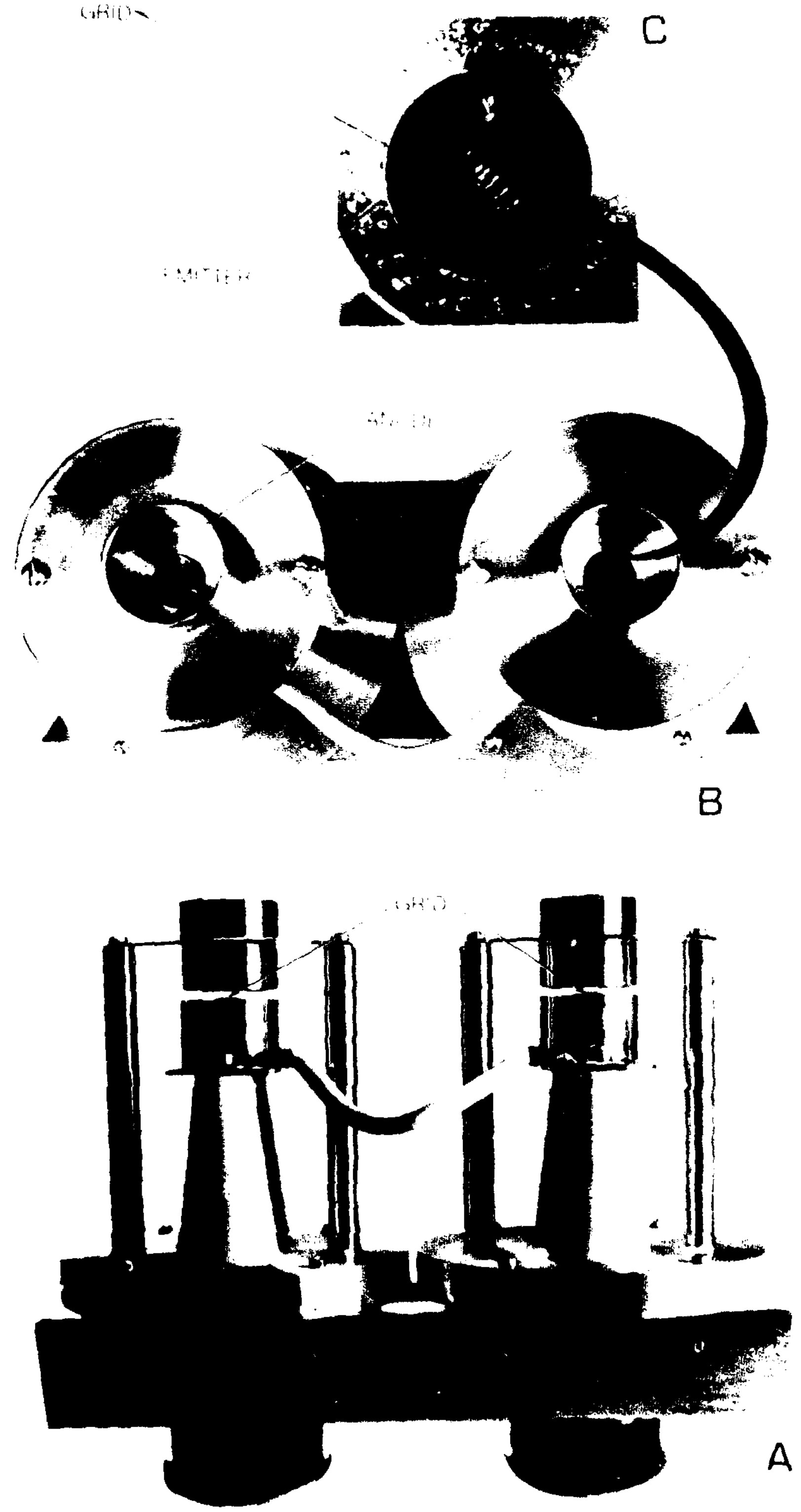

Figure 7. Electron guns (View C is an enlarged detail of View B to show the emitter and grid)

that such simulation approximate a plane wave front large enough to cover one side of the satellite.

### 5.2.4 High Energy Electrons

The most suitable accelerator for full simulation of the high energy electron environment would appear to be a machine with the capabilities of the High Voltage Engineering Model KS4000 Van de Graaf. The least expensive scheme for achieving an energy distribution and full target coverage would be a raster system with slow energy sweep (cycle/minute). It is by no means clear, however, that this would provide a valid simulation for the effects of the high energy environment. An appropriate energy distribution and full target coverage (from one side) can be produced with an area-weighted scattering filter, but the problems of shielding, cost, and placement must be overcome. Target coverage from more than one side will, of course, require more than one accelerator. This would cause severe design problems from the point of view of needed space and shielding and would have a substantial cost impact.

To minimize required shielding, it is recommended that the accelerator(s) be located underground with beam lines to the tank. The directions of the beams should be toward unoccupied areas. The strawman tank design should be evaluated to see if space can be made available by arrangement of items in the tank pit or by its enlargement.

## 5.3 COSTS

Approximate costs for a low energy electron gun system as recommended above can be identified:

| | |
|---|---|
| 6 gun clusters @ $5K/cluster | $ 30K |
| 20 power supplies @ $2K | 40K |
| Instrumentation and installation | 30K |
| TOTAL | $100K |

An ion beam system would be about the same magnitude in cost.

The cost of a high energy electron source is more difficult to estimate at the present time. Some representative figures are:

| | |
|---|---|
| Accelerator | $325K |
| Beam line components | 75K |
| Instrumentation and gas handling | 50K |
| Scatterer or raster system | 25K |
| TOTAL | $475K |

Shielding and installation costs depend upon location of the source and whether or not a scatterer is used for beam spreading. Such costs can be expected to exceed $1 million for a single accelerator. The Air Force Weapons Laboratory is planning to interface the TRW Van de Graaf to several vacuum chambers for a series of ECEMP experiments. It is recommended that their program be monitored as an aid to better defining the need, cost and problems involved in performing high energy electron/x-ray survivability tests.

## 5.4 AREAS FOR INVESTIGATION AND DEVELOPMENT

Before a detailed hardware design is produced the following questions should be addressed:

### 5.4.1 Environment Definition

The more faithful a simulation of the radiation environment required from the point of view of energy spectrum, type and uniformity of coverage, and dose rate, the more costly and difficult. Even a reasonably good simulation of the space radiation environment is probably impossible. Moreoever, some aspects of this environment, i.e., low energy electrons and ions associated with a nuclear explosion have never been experimentally observed, only predicted.

It is recommended that ongoing technology programs be monitored and perhaps directed to provide answers to questions such as:

1. How important is a faithful simulation of the energy spectrum of the charging environment?
2. Are there significant dose rate effects which should be taken into account in assessing the result of a spacecraft charging simulation. This has practical aspects not only in relation to charging times but also whether the use of rastered or pulsed beams is permissible?
3. How important is it to provide uniform satellite coverage? To provide such coverage will be difficult for high energy electrons.

Since the phenomenology of charging is reasonably well understood, some of these problems can be attacked analytically using transport codes modified to take into account the motion of deposited charge. Such codes have already been developed for cable studies. Discharge phenomenology, especially in concert with SGEMP effects, is less well understood. Answers will hopefully be provided by current AFWL, DNA, and SAMSO programs.

### 5.4.2 Low Energy Electron Sources

Although the electron gun system recommended in Section 5.2 should provide an adequate simulation, some improvements are possible. For example, field emitting electron guns potentially have some important advantages over hot cathode guns. Unlike tungsten filaments, field emitters produce no optical radiation, so they will not illuminate the dark side of the target in differential charging experiments. Carbon fiber field emitters are also potentially longer lasting than filaments. They are not, however, well developed for this application. A small R&D program to experimentally explore the possibilities of field emitting guns is, therefore, recommended.

Rf accelerators have the potential advantage of being able to produce continuous energy spectra rather than approximating the natural spectrum with a few discrete energies. As in the case of field emitters, however, this potential advantage is somewhat speculative since these accelerators are not well developed for low energy electrons. The potential advantages are sufficient that an R&D effort is to be recommended. It is believe that an rf accelerator could be designed to produce a beam with a broad continuous energy spectrum in a divergent beam that could uniformly bombard a large target without a raster sweep.

### 5.4.3 Positive Ions

It was pointed out in Section 3.6 that a considerable amount of ionization is going to be produced from the background gas in the SXTF tank when the low energy electron sources are operating. A detailed study should be made of the characteristics of this ionization and associated phenomena before any decision is made on incorporating ion sources into the facility.

### 5.4.4 High Energy Sources

A detailed study must be made of the shielding and other protective devices required if high energy sources are to be used in SXTF. This study should include investigation of structural requirements and constraints, and possible radiation effects of high energy electrons and bremsstrahlung on the satellite internal surface and test equipment. Other details on the use of high energy electrons should be investigated only after these studies are completed. An important unanswered question is the manner in which a distributed energy spectrum is to be produced. While it is possible to do this by a scatterer, this presents practical difficulty, not the least of which will be a perturbation of the electromagnetic boundary near the satellite. No practical scheme presently exists for rapidly rastering the energy of a high energy electron source.

### 5.4.5 Diagnostics

Means must be developed for in situ measurement of the electron beam characteristics, especially currents, energies, and coverages. The diagnostics should allow monitoring of these parameters during tests.

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