Poster

The Feasibility Of Multipole Electrostatic Radiation Shielding

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The Complementary Nature of Passive And Active Shielding

- Passive shielding may be the only practical solution for galactic cosmic radiation (GCR).
- Active shielding may effectively control the solar particle event (SPE) dose, thus removing the need for a storm shelter and reducing spacecraft mass.
- Whereas passive shield requirements are largely fluence-driven, active shielding is cutoff-energy-driven, and so the two approaches are complementary as illustrated in Fig. 1.

Complementary Roles in Shielding

(Conceptual Plot, Only)

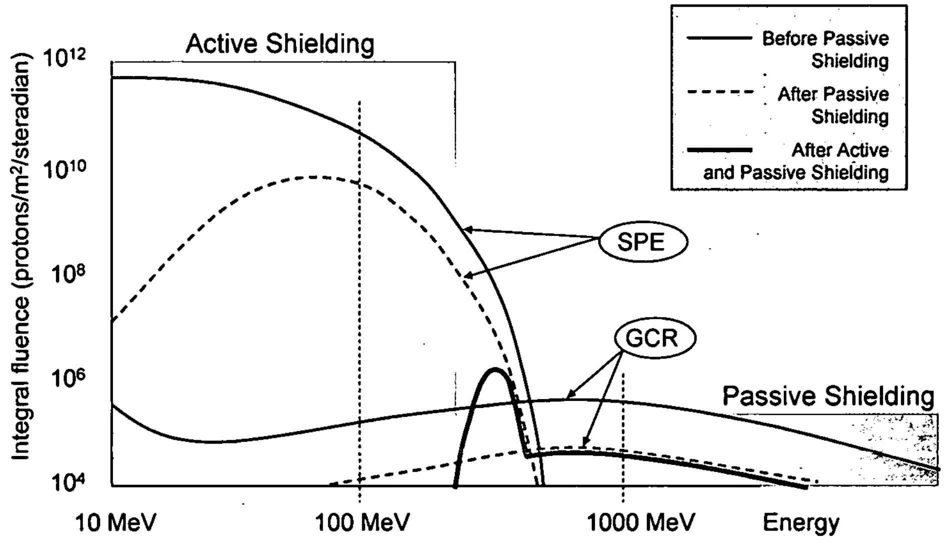

Figure 1. Active shielding effectiveness is 100% up to the cutoff energy. Passive shielding effectively reduces flux over a much broader spectrum. The complementary roles naturally align with the differences in the SPE and GCR spectra. This suggests that an optimal solution should leverage both types of shielding.

The Problem with Storm Shelters

- Psychologically and physiologically distressing to the crew (4 – 5 day gradual SPE)
- No protection for the spacecraft itself; radiation damage to critical electronics may result in loss of mission and life
- Single-event effects may require quick crew response to maintain spacecraft integrity.
- The storm shelter approach limits accessibility of the spacecraft *at the precise time when the spacecraft needs the most attention.*

A New Concept: Multipole Electrostatic Shield

A multipole expansion of the electrostatic fields may be exploited to deflect both the negatively- and positively-charged particles at the relevant energies for protection during an SPE. See figures 2 and 3.

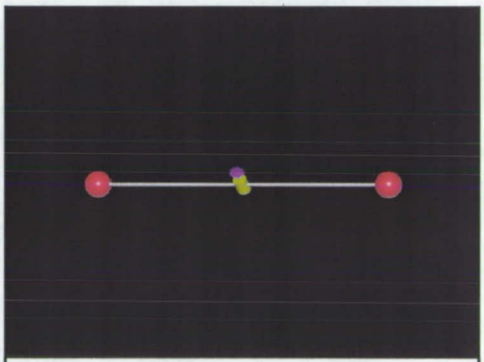

Figure 2. Possible active shield configuration as a linear quadrupole. The two “outriggers” have negative charge and the spacecraft positive.

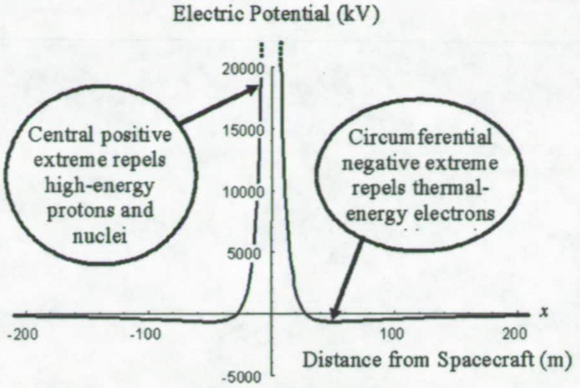

Figure 3. Potential field around the spacecraft deflects both positively- and negatively-charged particles.

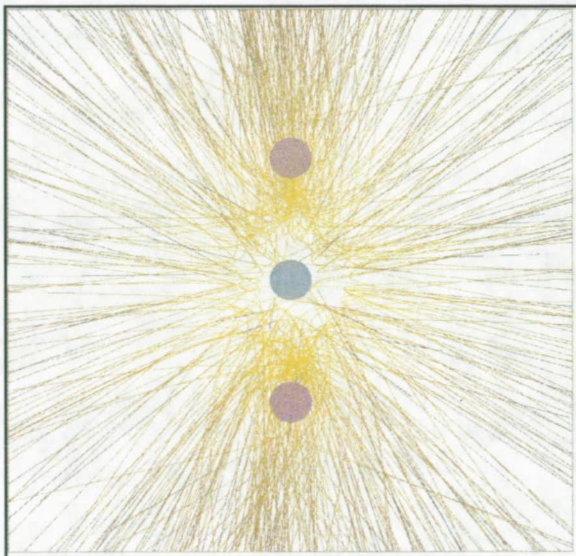

Figure 4. Ray tracing simulation of protons below cutoff energy. All are deflected from the spacecraft.

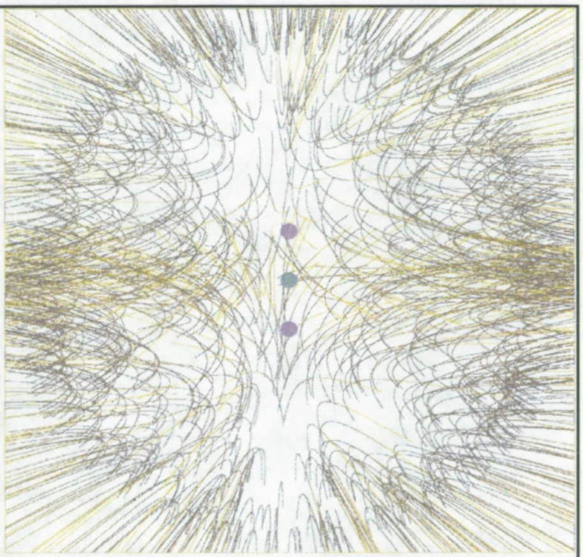

Figure 5. Ray tracing simulation of electrons at solar wind energy. All are deflected by the monopole component.

Shielding Efficiency

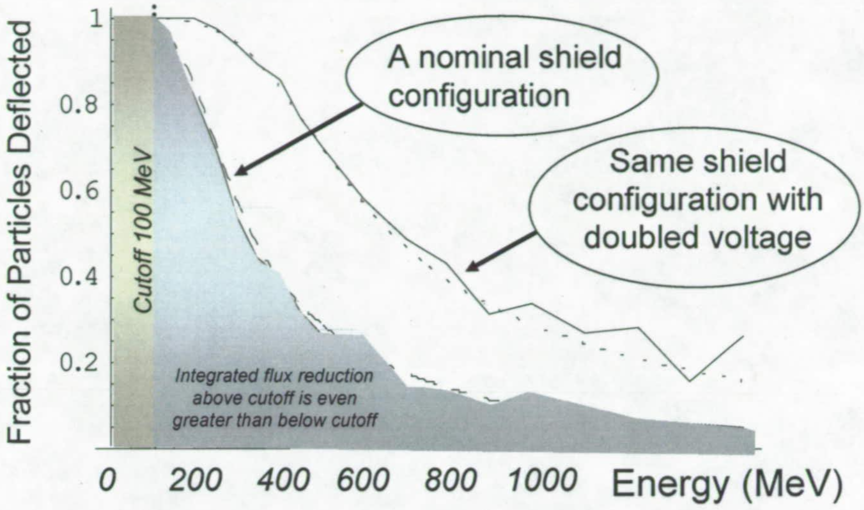

Figure 6. Shield efficiency, defined as the fraction of protons deflected from the spacecraft at a given energy. Efficiency is 100% below the cutoff energy and still significant above cutoff. Simulations have confirmed that the curve is horizontally scalable with the shield voltage.

Practical Concerns

1. **Voltage:** ~100 MV. The vacuum breakdown in space is 20 to 30 times higher than in the earth's atmosphere, allowing proportionately higher voltages for a charge pump of given geometry.

2. **Energy:** ~3 MJ = the chemical energy in 3 ounces of automotive gasoline.

3. **Force:** ~ 16,000 N (3600 lbf.). Manageable with aerospace structures.

4. **Ultraviolet light:** candidate materials are currently under development; this appears readily solvable.

5. **Ion engines:** currently use only about 20 kV to drive their exhaust. This poses the most difficult integration issue.

Handout

THE FEASIBILITY OF MULTIPOLE ELECTROSTATIC RADIATION SHIELDING

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BACKGROUND: PASSIVE SHIELDING AND STORM SHELTERS

Although passive shielding appears to be the only workable solution for galactic cosmic radiation (GCR), active shielding may play an important augmenting role to control the dose from solar particle events (SPEs).

It has been noted that, to meet the guidelines of NCRP Report No. 98 through the six SPEs of 1989, a crew member would need roughly double the passive shielding that is necessary to control the GCR dose [1]. This would dramatically increase spacecraft mass, and so it has been proposed that a small but more heavily shielded ***storm shelter*** may be used to protect the crew during SPEs.

THE PROBLEM WITH STORM SHELTERS

Since a gradual SPE may last 5 or more days, staying in a storm shelter may be psychologically and physiologically distressing to the crew.

Storm shelters do not provide shielding for the spacecraft itself against the SPE radiation, and radiation damage to critical electronics may result in loss of mission and life.

Single-event effects during the radiation storm may require quick crew response to maintain the integrity of the spacecraft, and confining the crew to a storm shelter prohibits their attending to the spacecraft ***at the precise time when that attention is needed the most.***

AUGMENTING PASSIVE WITH ACTIVE SHIELDING

Active shielding cannot protect against GCR because the particle energies are too high.

Although lower energy particles are easier to stop in a passive shield, such shielding is more satisfactory against *GCR* than against *SPE* radiation because of the tremendous difference in their initial fluences. Even a small fraction of the SPE fluence penetrating the passive shielding may result in an unacceptably high dose.

Active shielding is more effective than passive shielding against SPE radiation because it offers *100% shielding effectiveness* up to the cutoff energy, and significant shielding effectiveness beyond the cutoff as well. Ray tracing simulations (performed with the shield configuration introduced below) produces the Shielding Effectiveness curve shown in Fig. 1.

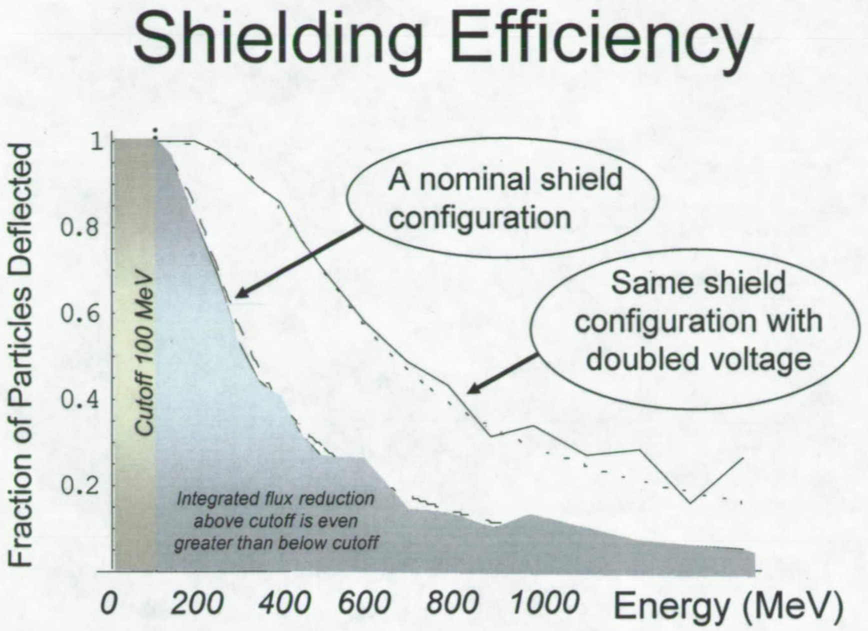

Figure 1. Caption…

Therefore, *combined* active and passive shielding is the natural solution to the total radiation problem, as illustrated in Fig. 2.

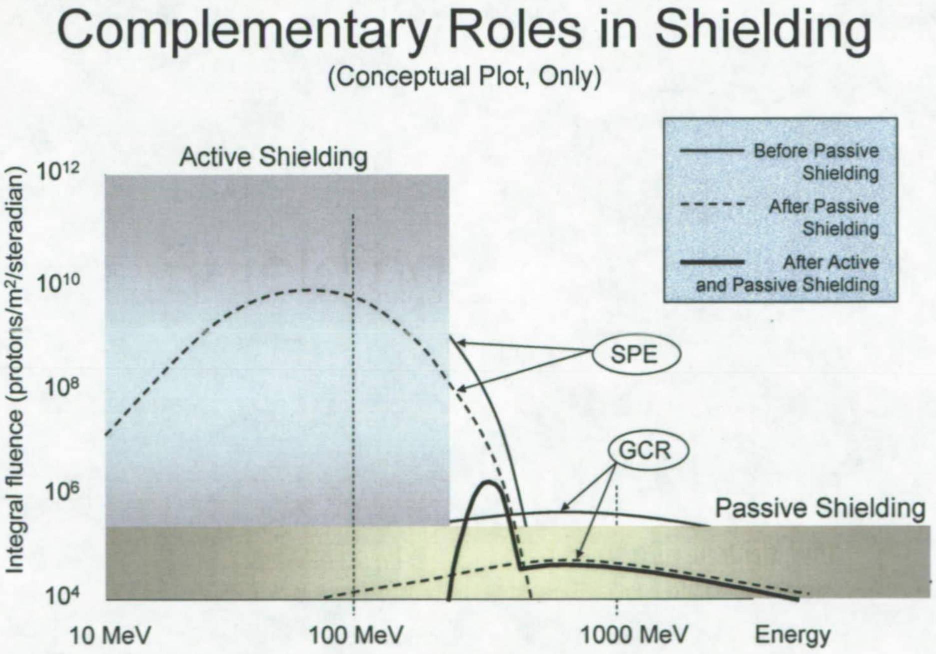

Figure 2. Caption…

THE PROBLEM WITH ELECTROSTATIC SHIELDS

An outwardly-repulsive radial field sufficiently strong to deflect energetic protons and nuclei will inadvertently attract a much-larger flux of thermal electrons, imparting to them sufficient energy to generate a critical bremsstrahlung hazard.

Shells of charge on conductive grids must be large to avoid vacuum breakdown, and are too massive and require excessive structural support.

Therefore, it has been generally concluded that electrostatics is not a practical or mature approach for shielding.

A NEW CONCEPT: MULTIPOLE ELECTROSTATIC SHIELD

A multipole expansion of the electrostatic fields may be exploited as a lightweight, reliable method to deflect both the negatively- and positively-charged particles at the relevant energies for protection during an SPE [2].

For example, a linear quadrupole may be created around the spacecraft by deploying and negatively charging two metallized polymer balloons that self-inflate under the Coulomb force (see Fig. 3). The quadrupole near-field produces a positively-repulsive zone around the spacecraft. A weaker but slowly decaying monopole term repels thermal electrons from a large region around the spacecraft (see Fig. 4).

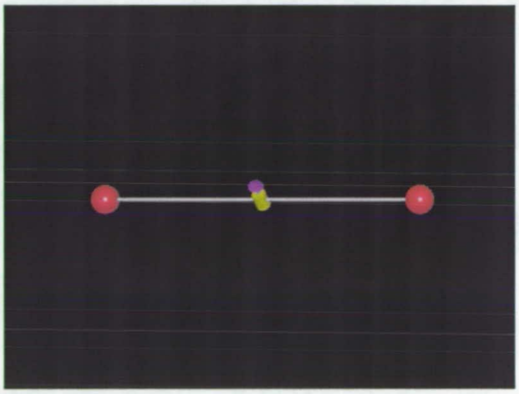

Figure 3. Caption…

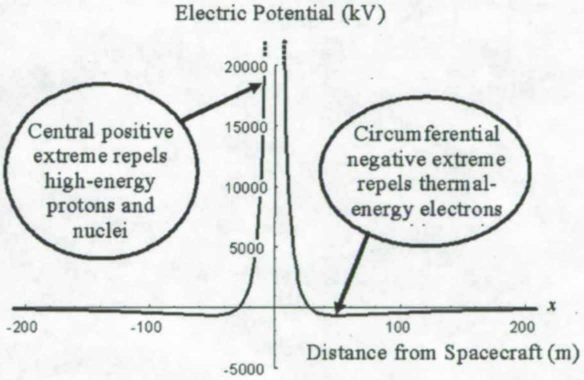

Figure 4. Caption…

Ray tracing simulations have been performed, and they demonstrate the success of this concept as shown in Figs. 5 and 6. The shield efficiency of Fig. 1 shows the deflection of an isotropic flux of protons at the relevant energies.

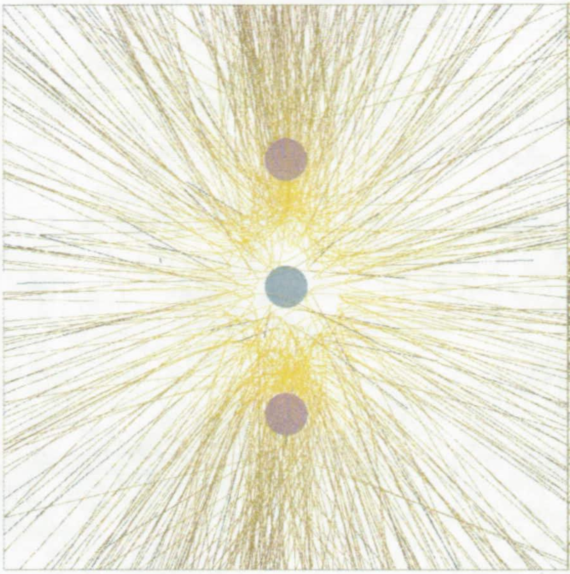

Figure 5: protons…(more caption)

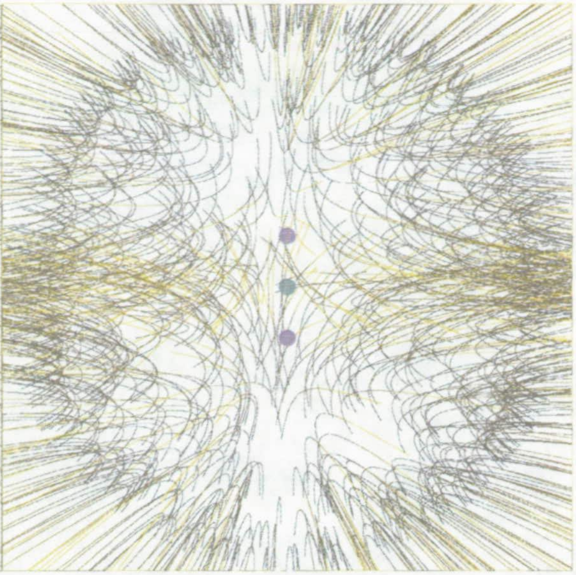

Figure 6: electrons…(more caption)

PRACTICAL QUESTIONS

Several practical questions have been addressed:

1. The necessary voltage (100 MV) seems feasible because ½ MV is easily achievable with a small charge-pump in the Earth's atmosphere, whereas the vacuum breakdown in space is 20 to 30 times higher. Daisy-chaining multiple charge pumps may easily achieve 100 MV.

2. The energy stored in such a system is approximately 3 MJ, which is the chemical energy in 3 ounces of automotive gasoline.

3. The forces between spheres is on the order of 16,000 N (3600 lbf.). This is manageable with aerospace structures.

4. The ultraviolet light from the sun may eject electrons from the negatively-charged sphere (see Fig. 3), which will then be accelerated from the negative to the positive sphere, rapidly discharging the system. However, the Kennedy Space Center has been developing novel candidate materials that mitigate UV concerns.

5. Ion engines currently use only about 20 kV to drive their exhaust. Therefore, it may be difficult to integrate an ion engine with an electrostatic shield. One strategy is to deactivate the shield unless an SPE occurs, and then to reactivate it and let the spacecraft coast (no ion thrusting) for its duration.

REFERENCES

[1] Townsend, L.W., and J.W. Wilson (1996) *Strategies for Mars: A guide to human exploration.* Science and Technology Series, v.86 (Univelt: San Diego, 1996).
[2] Metzger, P.T., Lane, J.E., and Youngquist, R.C. (2004) *Proc. 2004 IEEE Aerospace Conf.* (to be published).

Rapporteur Slides

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The Problem with Storm Shelters

- Psychologically and physiologically distressing to the crew (4 – 5 day gradual SPE)
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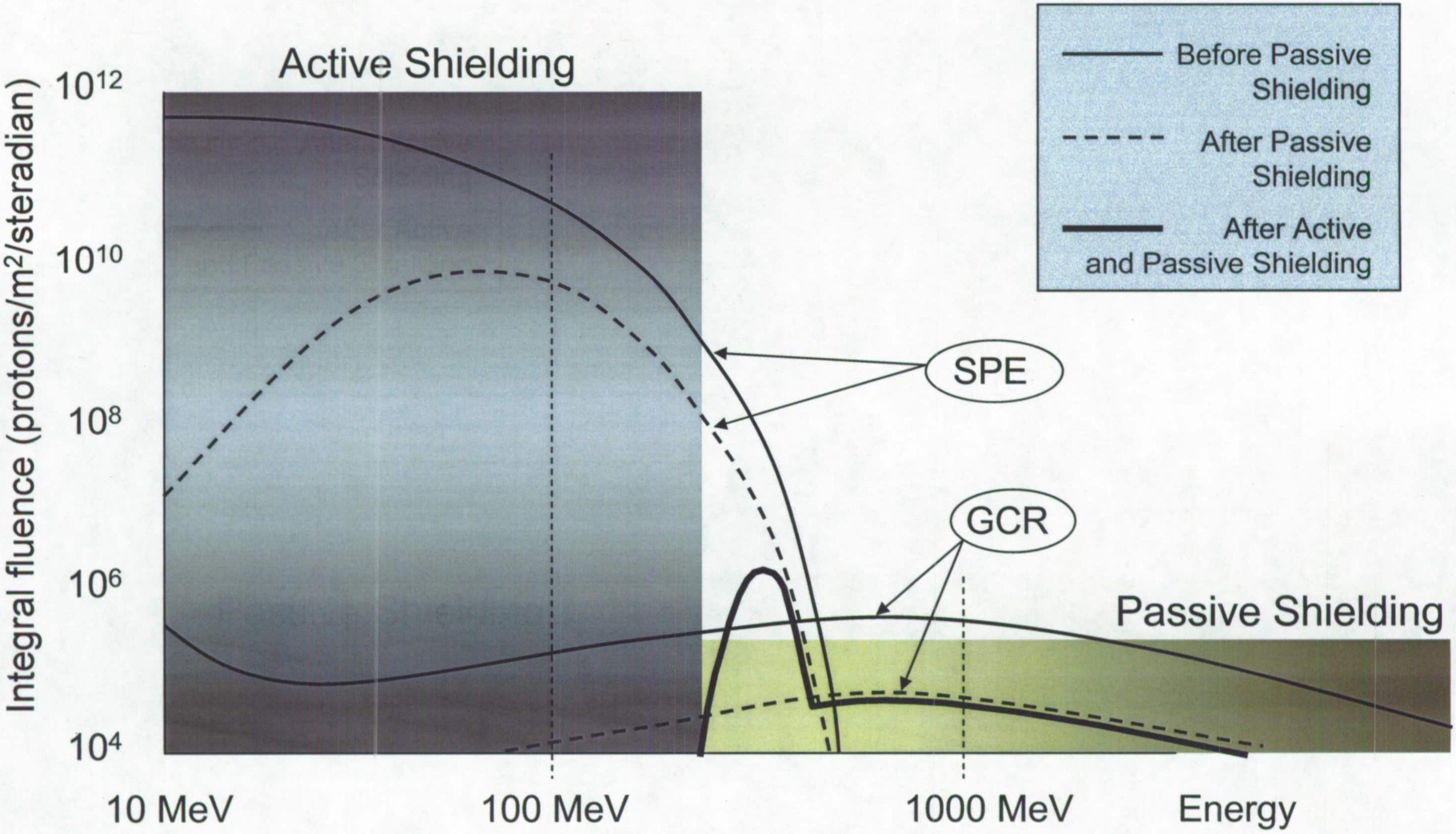

Caption for previous chart:

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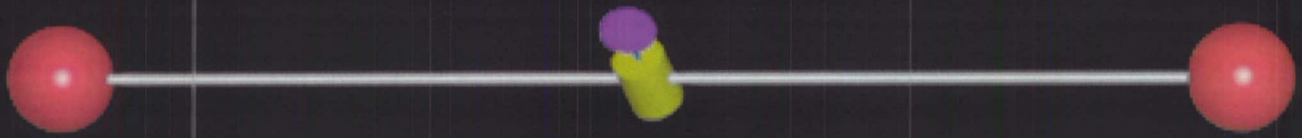

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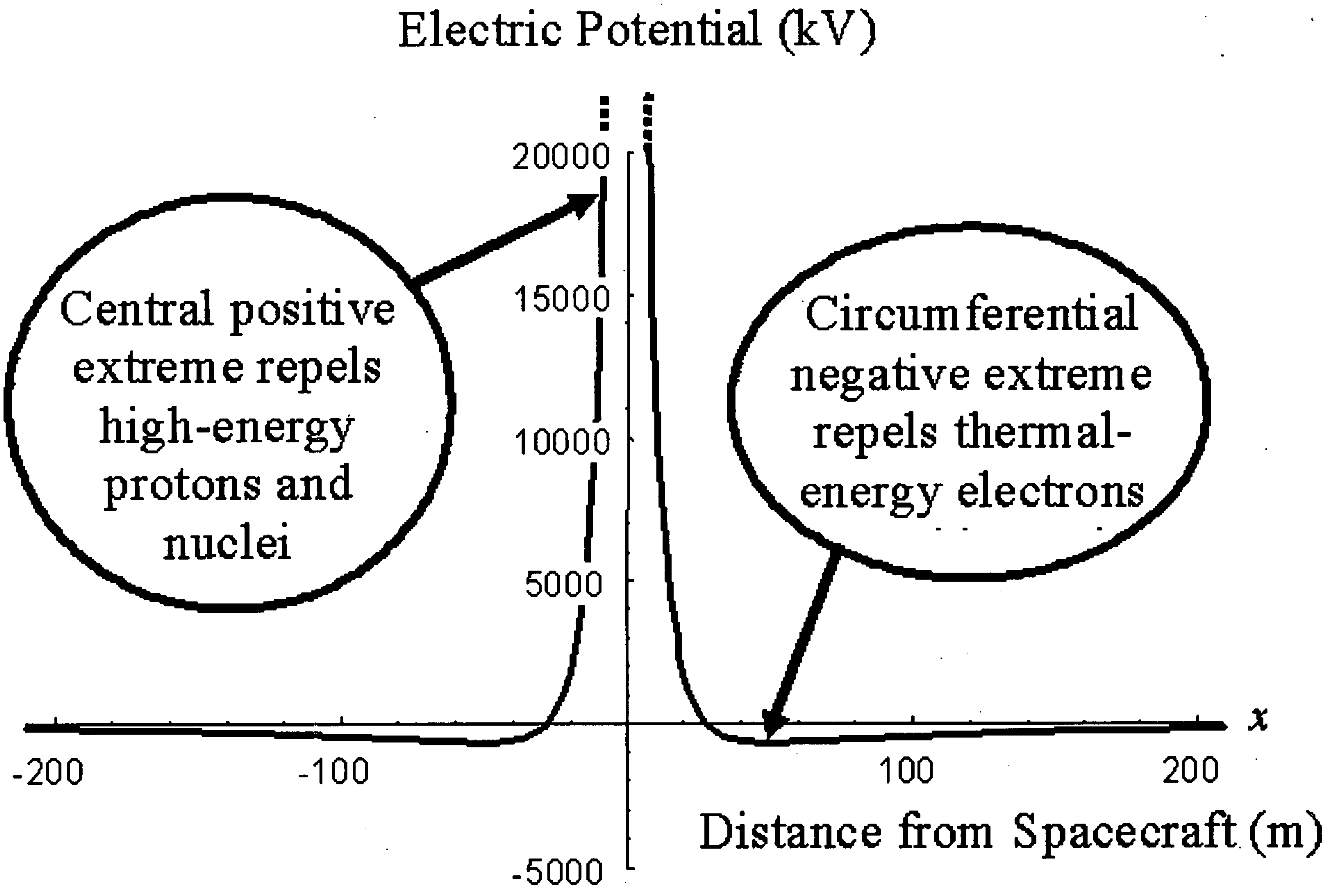

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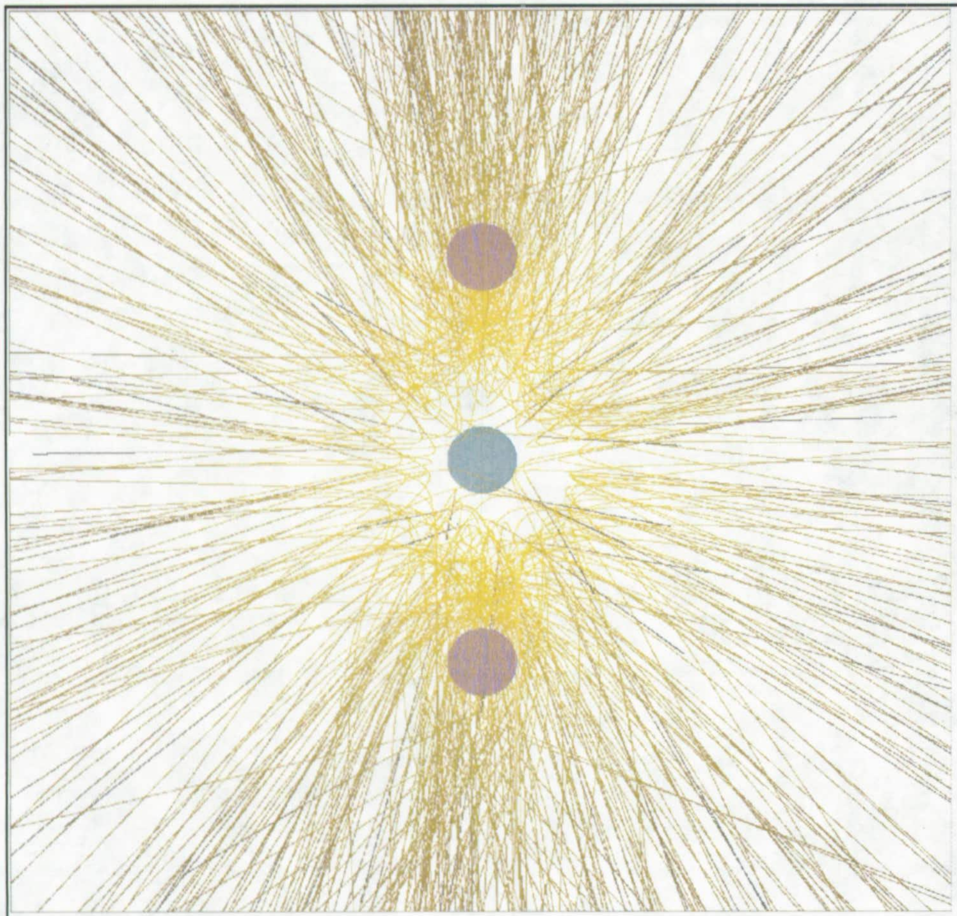

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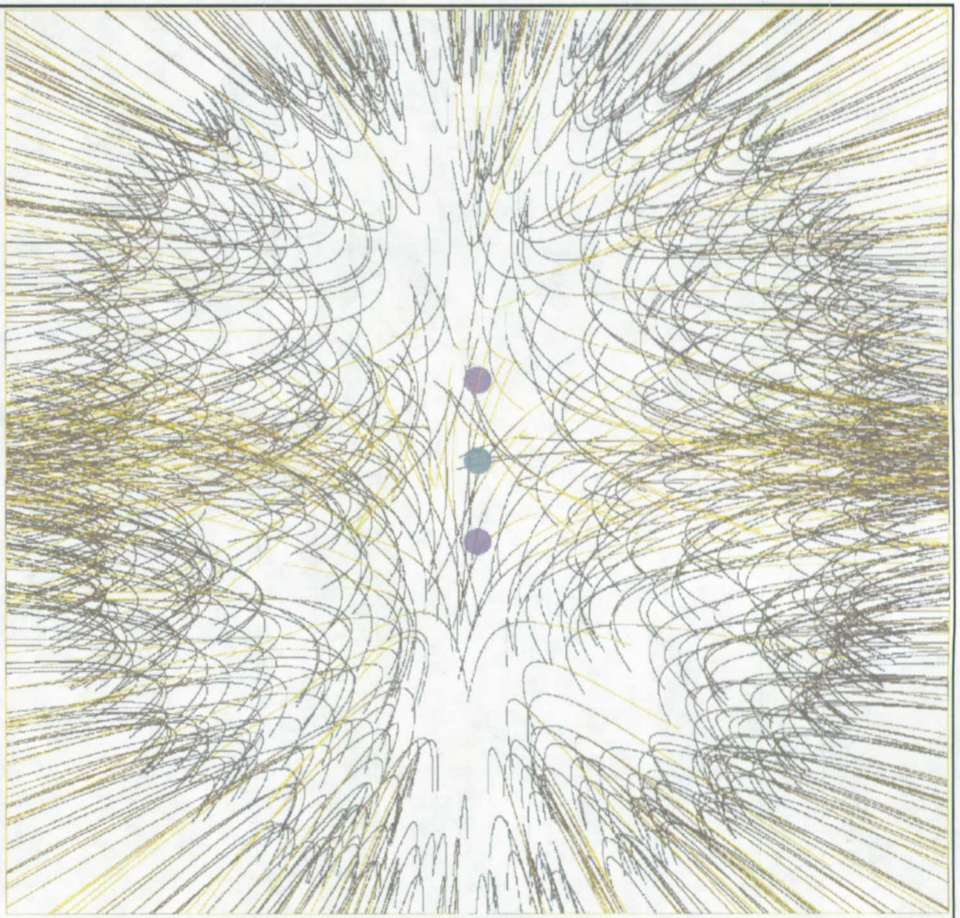

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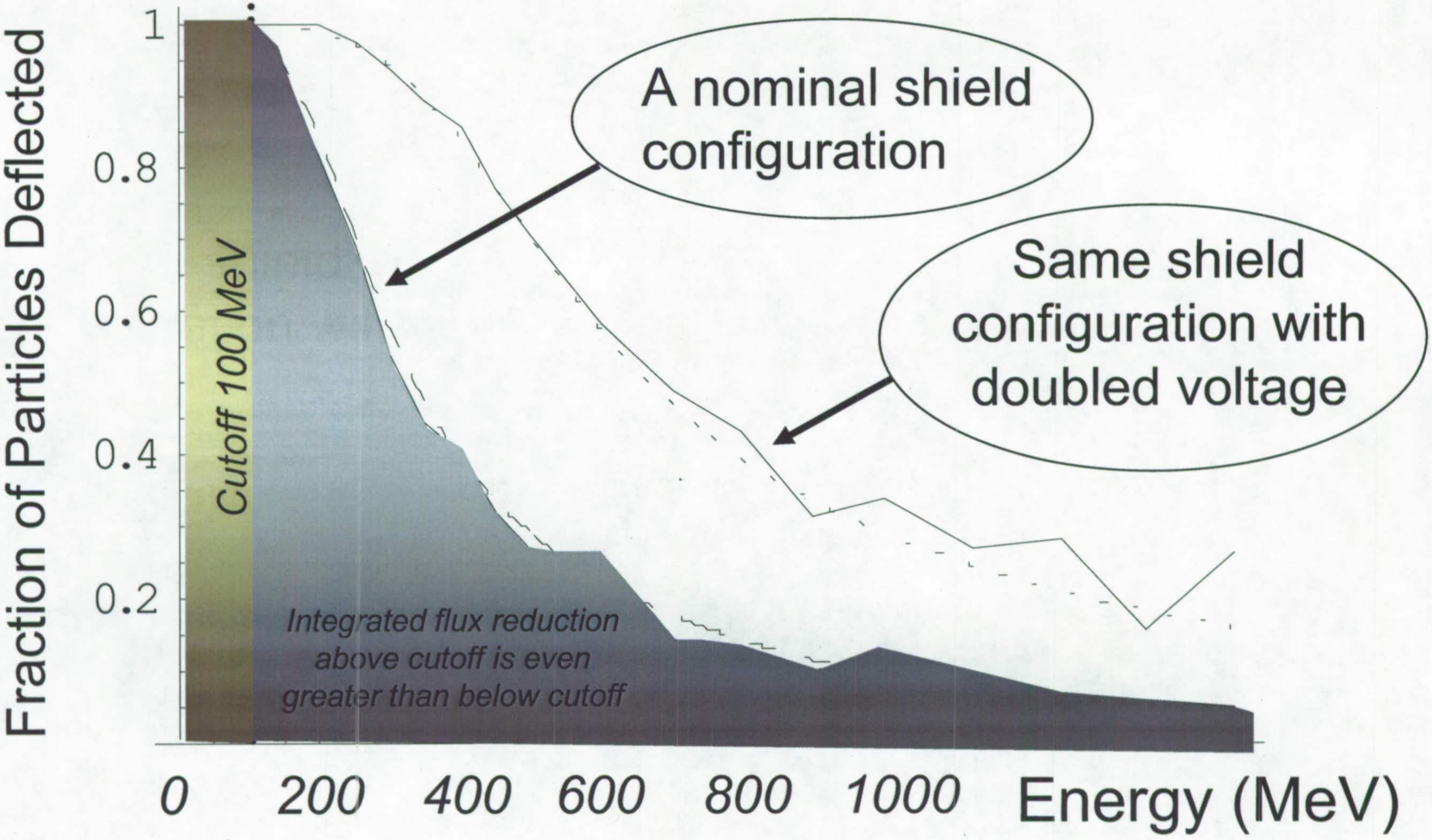

A nominal shield configuration

Same shield configuration with doubled voltage

Feasibility Issues

- **Voltage:** ~100 MV. The vacuum breakdown in space is 20 to 30 times higher than in the earth's atmosphere. Achievable by daisy-chaining 7 -10 charge pumps along an insulating truss.
- **Energy:** ~3 MJ = the chemical energy in 3 ounces of automotive gasoline.
- **Force:** ~ 16,000 N (3600 lbf.). Manageable with aerospace structures. Reduces as the inverse square of spacecraft length.
- **Ultraviolet light:** candidate materials are currently under development; this appears readily solvable.
- **Ion engines:** currently use only about 20 kV to drive their exhaust. This poses the most difficult integration issue, although possible solutions exist.