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Satellite Power System (SPS) Military Implications

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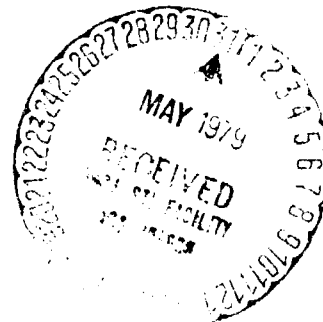
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DOE/NASA
Satellite Power System
Concept Development
and
Evaluation Program

Satellite Power System (SPS) Military implications

October 1978

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PREFACE

This paper documents the findings of a survey to determine the military implications of the Satellite Power System and to identify worthwhile study tasks that could be completed during fiscal year 1979.

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EXECUTIVE SUMMARY

This study was conducted to examine military implications of the NASA Reference Satellite Power System (SPS)* and to identify important military-related study tasks that could be completed during fiscal year 1979. Primary areas of investigation were the potential of the SPS as a weapon, for supporting U.S. military preparedness and for affecting international relations. In addition, the SPS's relative vulnerability to overt military action, terrorist attacks, and sabotage was considered.

The SPS could act as an electronic warfare weapon and, with modification, as a marginally effective energy-beaming weapon. The system could support military preparedness by providing energy for a strong and stable U.S. economy and by providing a powered platform for military systems, system segments, and operations.

The SPS would be vulnerable to military action, terrorism and sabotage unless hardened against these attacks by design, security, and a self-defense system. Because space is an international resource, military use of the SPS, even to protect itself, may have an adverse impact on the relations of the United States with other nations.

Tasks identified for completion in fiscal year 1979 include (a) a detailed vulnerability study, (b) evaluation of an SPS self-defense system concept, (c) determination of the effect of SPS flexibility to deliver different sized electrical loads on the ability to gain SPS support from individual nations, and (d) investigation of the effect of SPS deployment schedule on obtaining needed agreements, providing security, and controlling risks of armed conflict. A fifth and long-term task would consist of a worldwide survey identifying military implications of the SPS that result from the specific requirements of potential SPS power customers.

*See table 2.1.

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GLOSSARY

cm	centimeter
COTV	Cargo Orbital Transfer Vehicle
DC	Direct Current
DOD	Department of Defense
DOE	Department of Energy
G	Gain
GEO	geostationary earth orbit
GHz	gigahertz
GW	gigawatt
HLLV	Heavy Lift Launch Vehicle
Hz	hertz
kg	kilogram
km	kilometer
kW	kilowatt
LEO	low earth orbit
m	meter
mm	millimeter
MPTS	Microwave Power Transmission Subsystem
mW	milliwatt
MW	megawatt
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
OPEC	Organization of Petroleum Exporting Countries
PLV	Personnel Launch Vehicle
POTV	Personnel Orbital Transfer Vehicle
PTS	Power Transmission Subsystem
RFI/EMI	radio frequency interference/electromagnetic interference
R&D	research and development
SPS	Satellite Power System
W	Watt
μm	micrometer
λ	wavelength

I. INTRODUCTION

The U.S. Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) are investigating a potential new source of energy called the Satellite Power System (SPS).^{1/} The SPS concept involves placing in orbit around the earth satellites equipped with large solar arrays. The arrays collect solar radiation from the sun (approximately 99 percent of the time), which is then converted to electromagnetic radiation and beamed by a transmission system located on the satellites to receiving/conversion stations on the ground. The receiving equipment at the conversion station changes the electromagnetic radiation to electricity that can be fed directly into the utility network. The satellite and receiving antenna/rectifier (rectenna), for the current NASA^{2/} reference system using solar cells, and microwave power transmission subsystems are approximately 50 and 100 sq. km in size, respectively. The system is designed so that each rectenna will provide power to the utility grid. The scope of the concept can be placed in perspective by considering that the generating capacity of these satellites would be equal to all the electrical power generated in the United States in 1975. Projected energy demand at the turn of the century, as well as basic economics, indicate that at least 60 satellites will need to be programmed. Such a system is anticipated to have far-reaching impacts on society.

The SPS will have many features in common with systems of past and current space programs and will build on the technology that these programs have created. System development, production, and deployment will be costly processes, and SPS relative productiveness will be relied on to place it within the cost feasibility range. Lightweight structures and equipment and reliable operation, made possible by the favorable environment of space and design for the market, may hold the secrets to the needed cost control. If it is believed that the SPS will fulfill its postulated role by becoming a supplier of a significant part of the total energy consumed in the United States at some time during the first half of the twenty-first century, then SPS development, production, and deployed assets are valuable to both civilian and military segments of our nation now and in the foreseeable future. Furthermore, if the United States decides to depend on the SPS for so great a part of its total energy supply, the system must be secure. Some believe that the SPS cannot be defended successfully, but that if it could be, this defense would cost more than the SPS.

The investment of materials, effort, and money to fill the energy gap in the time available will be large but finite. Spending a large part of these resources on the development and deployment of a system that is superior from the standpoints of technological, economical, and environmental risks and yet is militarily indefensible actually may be squandering the resources. What is worse, however, is that these resources (and valuable time) then are denied to the alternative "runner-up" energy system concept that (though inferior in some respects) is acceptable and militarily defensible. This study has been performed to determine what role, if any, the SPS has in the U.S. military posture. Tasks included the following:

- Investigation of the SPS potential as a weapon or other supportive element of U.S. military preparedness;
- Investigation of the potential for impacts on international relations;
- Investigation of the relative vulnerability to overt military action, terrorist attacks, or sabotage; and
- Identification of questions needing further study.

II. SURVEY OF RELEVANT LITERATURE AND RELATED WORK

The survey for unclassified relevant literature and information on related work has included a Defense Documentation Center search, a search of the open literature, and conferences and contacts with representatives of the Department of Energy (DOE), the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and industrial organizations and individuals acting in a private capacity. During this survey it was learned that several efforts have included the consideration and documentation of the general topic of military activities in space. Examples include references 3, 4, 5, 6, and 7. However, with the exception of reference 6, no effort has been made to summarize this work because these reports and papers are readily available. Some of the pertinent information contained in reference 6 concerning laws and treaties is summarized by Mr. Leonard David in appendix A.

The potential of the Satellite Power System (SPS) to function as a weapon, support U.S. military preparedness, and affect international relations and SPS vulnerability, are discussed in the following paragraphs.

2.1 WEAPON AND MILITARY PREPAREDNESS IMPLICATIONS

Civilian space systems, like military space systems, are based on current technology; therefore, the systems provided by NASA and DOD would be expected to have many common features, several of which could implicate the SPS militarily. In 1958, shortly after the Sputnik launch, NASA^{8/} was formed from the old National Advisory Committee for Aeronautics (NACA) and from selected individuals and groups performing DOD space-related work. Projects transferred to NASA included project Vanguard and certain lunar probes and rocket engine programs. The formation of joint committees of NASA and military personnel to pursue common objectives and the free movement of workers (even the astronauts) between military and NASA space projects tend to promote similarities between NASA and military space efforts and equipment. Therefore, it does not seem inappropriate to consider the question of military implications of a civilian space system.

2.1.1 Weapon Implications

Use of the SPS as a weapon is a major concern. U.S. citizens as well as foreign governments and their citizens will want to know whether the power transmission beams can operate as weapons and what assurances can be provided that this 5 gigawatts of power will not be used as a weapon. The weapons implication of the NASA reference SPS (table 2.1) is examined.

Table 2.1 Summary of SPS Reference System Concept

Generating Capacity

- 5 GW DC output per SPS unit at the utility interface

Operational Characteristics

- Flat solar array with transmitting antenna on one end
- Power collection at GEO

Energy Conversion

- Photovoltaic—single-crystal gallium aluminum arsenide or single-crystal silicon

Power Transmission

- Microwave, phased-array transmitting antenna, klystron power amplifiers and slotted waveguide radiating elements

Structural Material

- Graphite composite

Rectenna

- Subarray panel with $\sim 8 \text{ km}^2$ active element area

Space Construction

- Construction at GEO

Space Transportation

- Heavy Lift Launch Vehicle (HLLV)—two-stage, vertical launch, winged, horizontal land-landing, reusable vehicles with 400 metric ton payload to low earth orbit
- Personnel Launch Vehicle (PLV)—modified Space Shuttle orbiter with passenger module
- Cargo Orbital Transfer Vehicle (COTV)—independent reusable electric-powered vehicle
- Personnel Orbital Transfer Vehicle (POTV)—two-stage, reusable chemical fuel vehicle

Earth Launch Site

- Kennedy Space Center pending further study

2.1.1.1 Microwave Power Transmission Subsystem (MPTS)

The MPTS is the transmission subsystem used in the current NASA reference SPS concept. The system, to be constructed and deployed in geostationary earth orbit (GEO), will be powered by a solar cell array having a platform of approximately 55 sq. km. Table 2.2 provides MPTS details^{2/} from which the following observations can be made:

- The system radiates a large amount of power.
- Power density at its highest level near the center of the antenna is a relatively low 2.2 W/cm^2 (approximately 16 solar constants), from which workers near the antenna can be shielded for short periods of time. (Figure 2.1 is a plot of maximum power density versus distance from the antenna toward the ground receiver.)
- There should be no trouble designing spacecraft that can travel in this beam with passengers aboard. Spacecraft or satellites not designed for this radiation field could overheat when moving slowly through it^{a/} resulting in temporary disability or permanent damage to their electronic systems.

Two possibilities exist for weapon use. First, the beam could be defocused and noise introduced to render selected communications ineffective (an electronic warfare weapon). Second, the beam could be directed at ground targets or scanned in a manner to follow spacecraft until overheating occurs, and/or until electronic failure disables the craft or produces a mission abort.

2.1.2 U.S. Military Preparedness Implications

The energy problem of the DOD was defined in the January 1977 U.S. Navy Energy Plan^{9/} as follows:

The most serious and pervasive threat to long-term national stability is the growing world inadequacy of assured energy resources to support world needs. National security depends on maintaining a worldwide balance of the distribution of energy resources. National security objectives can be achieved only if the United States is thoroughly prepared to meet essential industrial and military energy requirements. Attaining these objectives, deterring armed conflict, producing modern weapons systems, and maintaining the overall readiness of the U.S. military are all keyed to uninterrupted energy supplies.

^{a/} A radiation level as high as 1.5 W/cm^2 is permitted for aircraft. High speed aircraft flying at low altitude are able to dissipate radiation loads several times this value. (In space there is no air flow across spacecraft surfaces to cool them. Therefore, the radiant heat of the beam must be rejected by the use of reflective surfaces and/or absorption and reradiation.)

Table 2.2 Microwave Power Transmission Subsystem Parameters

- Frequency = 2.45 GHz
- Wavelength = 12.2 cm
- Output Power to Power Grid = 5 GW
- Transmit Array Size = 1 km in diameter, 13.4×10^6 kg mass
- Power Radiated from Transmit Array = 6.85 GW
- MPTS Efficiency = 61.1 percent
- Phase Control System: An active retrodirective array with a pilot beam reference for providing phase conjugation. This system includes:
 - Phase Lock Loop Around Each Tube for Phase Stability and Noise Suppression
 - Double Sideband, Suppressed Carrier Modulation (Two-Pilot Frequencies)
 - Coding of Pilot Beam for Security and Pilot Discrimination
 - Ground Safety Control System (Ground Sensors for Interpreting Beam Shape)
 - Power Density Levels
 - Center of Transmit Antenna = $22 \text{ kW/m}^2 = 2.2 \text{ W/cm}^2$
 - Edge of Transmit Antenna = $2.4 \text{ kW/m}^2 = 240 \text{ mW/cm}^2$
 - Center of Rectenna = 23 mW/cm^2
 - Edge of Rectenna = 1 mW/cm^2
 - Rectenna Size = 10.0 km x 12.4 km
 - Beam Diameter = 2.8×10^{-4} rad
 - Pointing Held to $\pm 2.8 \times 10^{-6}$ rad

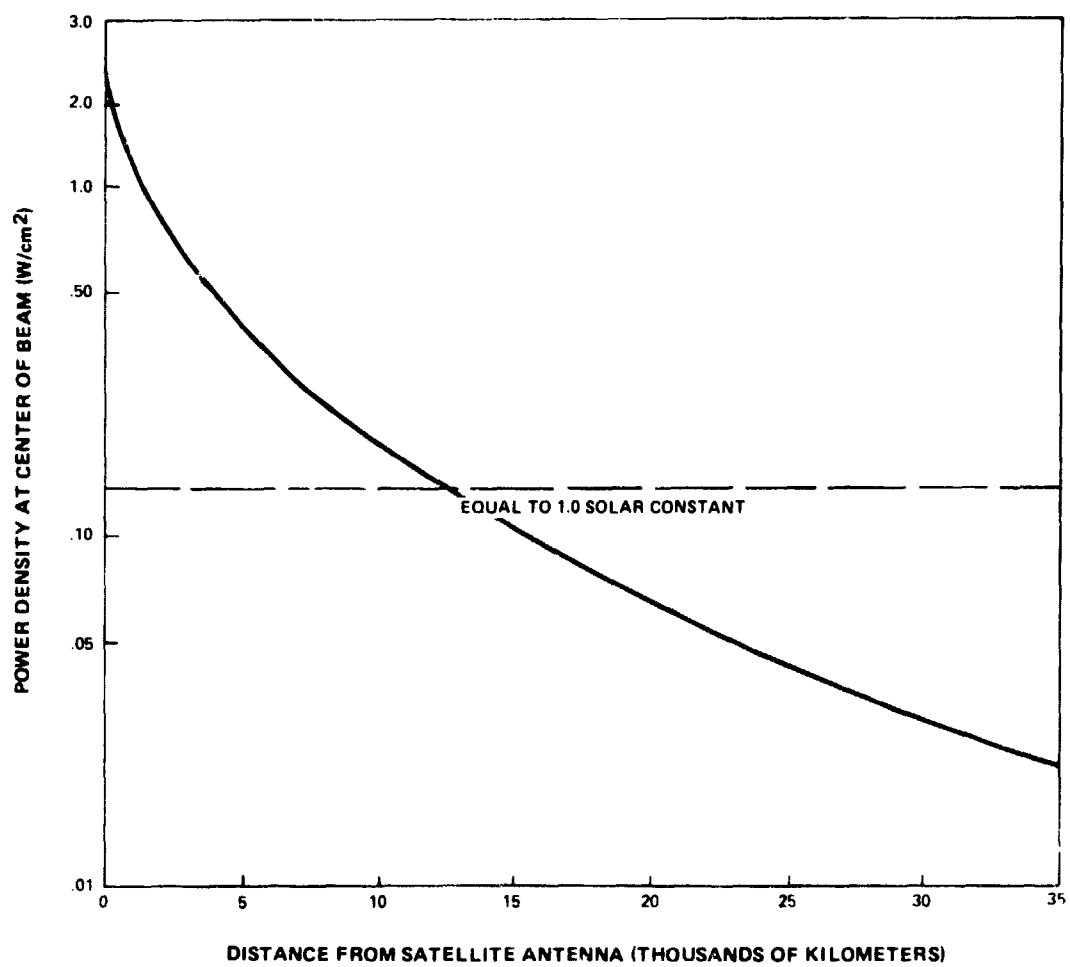


Figure 2.1 Power Density at Center of Microwave Beam Versus Distance From the Antenna

The major U.S. military preparedness implications of the SPS result from its ability to supply energy. The embargo on the export of petroleum products to selected countries in October of 1973 by the OPEC nations, and the realization that petroleum is a limited resource, have placed a high national priority on energy and energy-related issues. Objectives have been established to:

- Conserve energy;
- Increase domestic oil and gas production while reducing the use of oil and gas;
- Convert oil and gas electric plants to other fuels, such as coal, hydro, nuclear, solar;
- Develop the inexhaustible energy resources;
- Reduce oil imports; and
- Develop a billion barrel petroleum reserve.

The embargo has pointed out to the military the necessity of having a reliable source for each form of energy or fuel that it uses and has caused accelerated energy planning. Military bases, for example, have introduced programs to supply much of their own energy requirements and to reduce their dependence on outside sources.

These basic energy availability and use issues implicate the SPS in U.S. military preparedness. Many in the military community who have surveyed the problem believe that the United States will begin to be affected by the fuel shortage by 1985 or 1990; costs are already reducing fuel availability to some of the population. The power expected from the SPS cannot relieve these early shortages directly, but its imminence may encourage a freer flow of oil into the market, thereby keeping a bad situation from becoming intolerable.^{b/}

If the SPS comes on line, its power can begin to be used in the following ways:

- Strengthen the civilian/industrial sector, allowing more effective support to the military in the areas of technology, production, and capital;
- Free larger quantities of portable fuels required for military mobility (and mobility related stockpiling);

^{b/} Dr. William Shurcliff has pointed out that the encouragement of a freer flow (and use) of oil, with the prospects of an SPS that in fact does not come on line, could hasten and intensify the ultimate energy bind.

- Provide electricity to military ground installations through the utilities; and
- Supply markets that will strengthen mutual security bonds and reduce tensions.

The current plan is to deploy two 5-GW SPS units each year starting in the year 2000 and running through the year 2030 for a total SPS output of 300 GW. This is equivalent to the 1975 electrical power generating capacity in the United States and from 7.5 to 10.0 percent of the expected U.S. power requirement in 2030. (Other scenarios have projected the SPS deployment rate at two times to approximately four times this rate.)

Any growing dependence of the United States on an unfolding and successful SPS for power, coupled with the constant dependence of military preparedness on an economically and industrially strong United States, will implicate the SPS in U.S. military preparedness. However, the implication goes farther; the SPS must be protected by either the U.S. military or a military/quasi-military force in which the United States plays a part commensurate with its potential for loss.

2.1.3 Platform for Weapons

The NASA 5-GW SPS reference design is driven by a solar cell array with an area of approximately 50 sq. km.^{2/} This array is supported by a platform that is 10,400 m long, 5,200 m wide, and 470 m thick—a volume of approximately 25 cu km. Materials used in this platform and its design combine for an extremely lightweight structure having the appropriate stiffness for SPS functions. This platform, as well as SPS construction/maintenance facilities and personnel living quarters would seem from a cursory examination to be ideal assets for beginning any necessary SPS military operations. Military housing and work areas could be integrated into the SPS solar array platform by modifying and beefing up structures as required. The array could be extended to supply any added quantities of electricity needed by the military unit. During times of conflict^{c/} the array would be a prodigious source of power that could be preempted from the private sector and used to power weapons. The functions of such a military outpost could include security, supply, maintenance, repair, personnel, and training.

Security would encompass activities involving the maintenance and use of defensive/offensive equipment needed to protect the SPS. Systems could include

^{c/} During a national emergency (declared by the president) civil and commercial satellites would be subject to control by the Department of Defense. See appendix A, PRM-23.

visible/infrared/radar sensors for reconnaissance, surveillance, and search/track/-pointing; radiation/particle weapons; projectiles and missiles; communications/command/control; data-handling electronics; and electronic warfare/countermeasures equipment. A recent study by McDonnell Douglas Astronautics Company^{10/} investigated the evolutionary development of a space station to support people and equipment engaged in peaceful pursuits. Many of the same problems they encountered would need to be solved in developing and equipping the SPS military outpost. The shuttle transportation system is used to support the McDonnell Douglas space station concept.

Major technologies (including surveillance, detection, track, pointing, and laser weapons^{d/} and missiles) for beginning any needed self-defense system for the SPS and for deploying other weapons at the SPS space site are progressing steadily. However, before an appropriately equipped operational SPS self-defense system can be defined, an understanding of the threat, the output of operational analyses involving this threat, and the feel of experience may need to be combined for an extended operational shakedown of potential system elements. This suggests the possible usefulness of early experience with a system that may supply only modest amounts of power compared to the 5 GW of the NASA reference system.

2.2 IMPACTS ON INTERNATIONAL RELATIONS

2.2.1 SPS Security/Weapons

The potential value of the SPS to our industrial capability and national economic system arises from the fact that by 2030 the SPS may be filling a significant part of the U.S. electrical power needs. Any attack on this high-valued asset by a major force would be considered an attack that flies in the face of the U.S. strategic deterrent force. Such an attack could mean that strategic deterrence had failed^{3/} and would lead the United States into decisions and actions involving the very weapons and forces that should have prevented attack but did not. These risks to the SPS and to strategic deterrence might be ameliorated by internationalizing the system and/or by reaching agreements declaring the SPS off-limits for military action. SPS strengthening (which may include a self-defense system) could be made a part of the SPS to discourage and defend against small, unsophisticated attacks.^{4/} In the beginning, it will be difficult to determine

^{d/} Information from the DARPA high-energy-laser space defense program would be helpful in projecting laser weapons capabilities and in defining approaches.

what the extent of any SPS defense system should be. It could start small and expand to fit the need as requirements are developed. At present, space law contains nothing to prevent the United States from stationing parts of its strategic deterrent system (and forces) at the SPS space site, as long as these parts do not include nuclear weapons or weapons of mass destruction.^{11/} Growth of a defended SPS may tend to be limited by the fact that as the military capability increases, the value of the already high-valued target becomes even higher.

2.2.2 Agreements/Disputes

World communications have progressed to the point that populations in all parts of the world are becoming aware of resources, (such as solar flux, electromagnetic spectrum, and geostationary orbit) and want to share in their exploitation. The electromagnetic spectrum and the geostationary earth orbit are limited resources. The breadth of the useful electromagnetic spectrum, limited by equipment performance, has increased significantly with the widespread development of ultraviolet, visible, and infrared systems. However, in many regions of the spectrum, particularly the microwave region, bandwidth is a carefully controlled, highly coveted commodity. In the allotment of bandwidth, extreme care is exercised to ensure that the assignment is in the public interest and will not be used in a manner that interferes with equipments on the same band or operating in other bands. For this reason, the use of any frequency/bandwidth used by the SPS will likely need to be cleared through an international organization.

The geostationary orbit, because of its special characteristics, is a limited resource (there is only one around the earth). The number of slots available in this orbit for communication satellites, if collisions are to be prevented and occultations and radio interference avoided, has been bounded by the range of 180 to 1800.^{3/} The number of satellites now using geosynchronous orbit is large (approximately 100) and growing. This growth in operating systems and the difficulty anticipated in reserving bandwidth for systems that are not scheduled should combine to expedite both the planning of SPS development and deployment schedules and an early determination of bandwidth requirements. The solar flux in space is not a limited resource but a flow of radiation that is continuous. However, the solar flux that can be intercepted in the geostationary orbit may have a practical limit. Figure 2.2 is a projection of the surface of the earth that shows some of the countries which a piece of the GEO path passing through their "extended air space"; the United States is not one of these countries. Satellites to serve the United States need to be placed over South America (where GEO passes over Ecuador, Peru, Colombia, and Brazil) and to the west as shown.

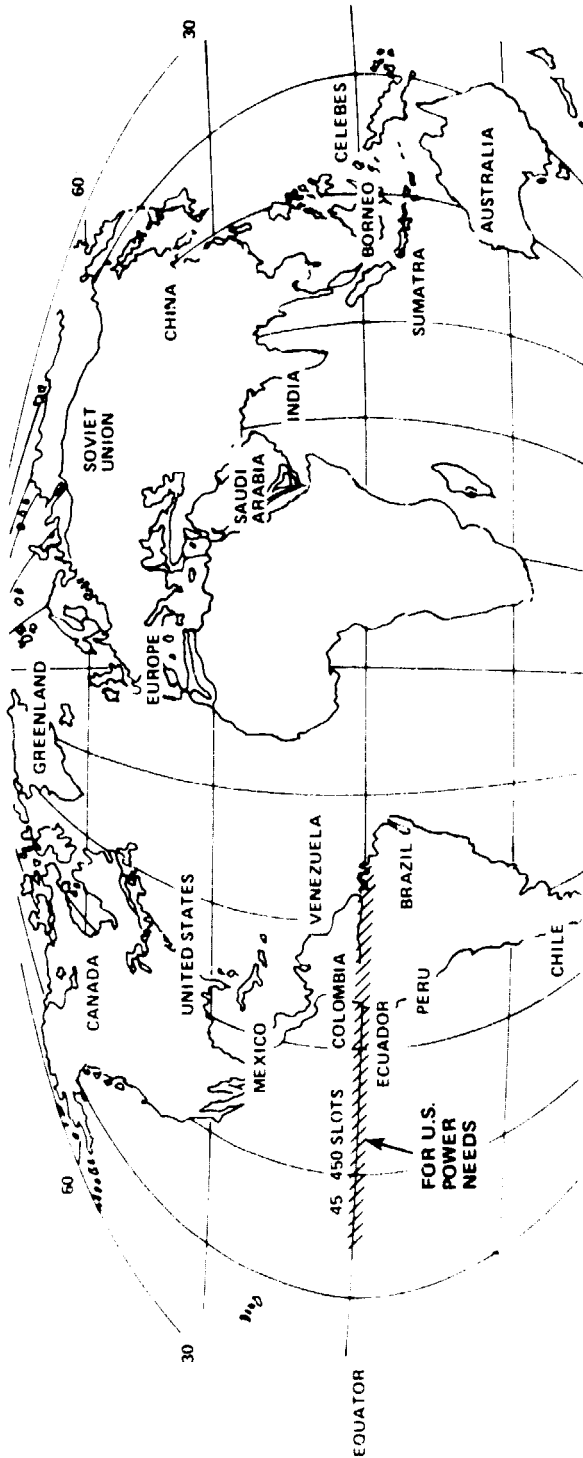


Figure 2.2 Area Over Which Geostationary Orbit Slots Needed To Serve U.S. Power Requirements Are Located

NOTES RELATING TO ORBIT ASSIGNMENT:

- Geostationary orbit is a limited natural resource--360°
- Experts have bracketed number of slots at 180 to 1,800 (problems are mutual interference, collision, eclipse, etc.)
- Part of GEO needed by U.S.* for power; approximately one-fourth of orbit, 45-450 slots available (must be shared with other countries of North, Central, and South America)
- Other slots may be made available to U.S.* for power export
- SPS will share the orbit with communications, navigation, data relay, weather, warning, and conservation satellites
- * May be a consortium of nations including the U.S. or an international business union satisfying U.S. interests.

To obtain the necessary bandwidth and orbit slots needed for U.S. power, it may be necessary to establish an international organization to design, produce, deploy, and operate an SPS that would provide power to all countries of North, Central and South America. The same organization might be able to create and support any military or civilian force needed to provide SPS protection. This organization could also include countries located in other parts of the world, as long as orbit slots and bandwidth are available on a "local" basis and other conditions of any agreements are met.^{e/}

Most of the world's developing countries are located between 30° N. and 30° S. latitude, the region of the globe that is most easily served by an SPS from GEO. Many of these countries are small and have relatively small power demands. Countries in this region currently do not present a threat to the United States; however, within the time required to deploy the SPS, this situation could change-- particularly if one or more of these countries became allied with a larger country (U.S. adversary) and became a staging area(s) for it. It is also possible that SPS power, once available, could reverse the industrial and economic trends of some of these countries, allowing them to become real and significant partners or adversaries.

2.3 RELATIVE VULNERABILITY

The vulnerability of the SPS to disruptive groups or to military forces is believed to be greater than for terrestrial electric power systems. Terrestrial systems are vulnerable to (a) air- and ground-delivered ordinance by military or terrorist groups, (b) military or terrorist groups that could take over operations, and (c) saboteurs within the SPS/utilities and support organizations. The systems are vulnerable at the generating site, in the power distribution system, and in the lines of supply^{3/} for fuel, spare parts, and other operating items. The power distribution and supply systems lend themselves to covert kinds of activity (sometimes part of a larger activity) that can precede open confrontation. The vulnerability of the rectenna site and the distribution system of the SPS is expected to be similar to that of terrestrial systems, except that the supply lines for the SPS do not deliver fuel to the rectenna. "Fuel" is supplied to the rectenna via a beam from the satellite in geosynchronous orbit. Therefore, on the basis of

^{e/} Several questions needing answers are: Should the organization include only friendly nations, or both friendly and not-so-friendly nations? What about the strategic arms limitations treaties? What part can onsite inspections play? What about questions of technology transfer?

a first-order evaluation, the relative vulnerability of the SPS to that of a terrestrial system reduces to a comparison of the vulnerability of the spaceborne parts of the SPS (and launch sites) to the vulnerability of the terrestrial system's fuel supply line(s).

The spaceborne segment of the SPS will be vulnerable to military attack and to the activities of saboteurs. Vulnerability to terrorist attacks is not likely for some time because such attacks would require the use of either a high-technology space transportation system or sophisticated ground-based equipment capable of destroying a target 36,000 km away. Launch sites are vulnerable in much the same way as the terrestrial power plants except that security probably would be better at the launch sites.

There is likely to be at least a nominal effort to harden the satellite components and space transportation units against the hits and explosions of a military attack and the resulting environment. Hardening may be needed against interceptor and satellite killer impacts and explosions, nuclear radiation, high-energy laser and particle weapons, and electronic warfare waged to obstruct the flow of radiation or to compromise and/or gain control of satellite functions. Passive hardening is unlikely to be effective in all these areas; therefore, it is believed that dependable hardening against military attack will necessarily include an active SPS self-defense system unless other assets capable of defending the SPS are available for this function at the time of SPS deployment (see appendix B).

III. ANALYSIS AND EVALUATION

Several major military implications were identified during the survey of relevant literature and related work. Results of an analysis of these implications are discussed in the following paragraphs.

3.1 WEAPON AND MILITARY PREPAREDNESS IMPLICATIONS

The Satellite Power System (SPS) is designed to provide power for peaceful pursuits. As the SPS grows and is relied on by the United States as one of its prime sources of power, it will become a potential military target. Its significance as a potential target will grow in relation to the increasing power demands that it fills. Issues concerning the SPS as a weapon and/or a base for weapons, and as a source for fuel to the military, will need to be considered when scheduling its development and deployment.

3.1.1 Weapon Considerations

As discussed previously, the SPS can be used as an electronic warfare weapon, an energy-beaming weapon, and a powered platform for weapons and weapon system segments.

3.1.1.1 Electronic Warfare Weapon

During normal operation of the Microwave Power Transmission Subsystem (MPTS), noise could be introduced to discriminate against or to render ineffective transmissions in selected bands. During hostile periods, the beam could be defocused to affect a larger area; selected communications or other transmissions over an entire hemisphere could be degraded or blocked. Friendly forces having control of the beam could control noise content, beam spread, and times of noise transmissions. Microwave densities, from the defocused microwave beam, though significant when compared with the sensitivities of many microwave receivers, would be tolerable in terms of the levels (short-term and intermittent) that would be detrimental to health and the public welfare. For example, the microwave power from one 5-GW SPS radiated evenly over the projected area of one earth hemisphere results in a density of approximately $5 \times 10^{-5} \text{ W/m}^2$.

3.1.1.2 Energy-Beaming Weapon

The familiarity of the general public with the concepts of high-energy laser (and particle) beams and their frequently cited ability to distribute deadliness and/or destruction has raised the question of the potential use of SPS power beams as weapons. For example, a target in a circular orbit below and 10,000 km from

the SPS traveling in the same direction of the SPS will have a velocity relative to the beam at the point of crossing of 1.16 km/sec (and 5.85 km/sec for a retrograde orbit). From the position of the SPS, these relative velocities represent angular rates of 0.116 and 0.585 mrad/sec, respectively. To follow a target of the lower angular rate a beam would have to be rotated about its origin at a rate of 360° in 895 minutes (0.4 degrees per minute), and the higher rate 2.0 degrees per minute. In orbits 1000 km below the SPS, these rates would be 0.36 to 20.7 degrees per minute. The angular rates of maneuvering targets or satellites in retrograde orbits at close range generally would be expected to exceed the track capabilities that could be designed into the MPTS. Targets traveling toward the SPS could be followed at much slower slew rates except at close range when a miss or "fly-by" is involved (see figure 3.1). The effectiveness of an energy-beaming weapon depends on the power in the beam, the beam intensity versus time profile, the angular cross-section of the beam, required beam acceleration and slew rates, and the accuracy to which a target can be tracked and the beam pointed. The tracking/pointing error of a system against a moving target (high information rate required) will usually be significantly greater than the error of that same system against a stationary or nearly stationary target (under mechanically damped low information rate conditions).

3.1.1.2.1 Microwave System

The accuracy to which the microwave beam of the reference design can be pointed toward the rectenna site (table 2.1) is considered adequate for a "weapon mode" if this accuracy could be maintained during target track. The antenna, a low-density structure, is large and massive but probably could be used to track nonmaneuvering orbital targets at rates of one or so mrad/sec, provided target detection and/or designation is completed early enough to allow the antenna to be brought on target moving at the appropriate rate without exceeding acceleration limits as established by antenna structural characteristics and figure requirements. Figure tolerances may be as stringent as one tenth the wavelength ($\pm 0.1\lambda = \pm 1.22$ cm) for a frequency of 2.45 GHz. From figure 2.1, it is only after a target has closed to within 12,000 km that irradiance on target is greater than one solar constant. Therefore, use of the microwave system in geostationary orbit (GEO) against earth and near-earth targets does not seem practical. However, at ranges of 4,000 km or less, the rate of temperature rise for highly absorptive targets being irradiated could be significant, causing a damaging heat buildup.

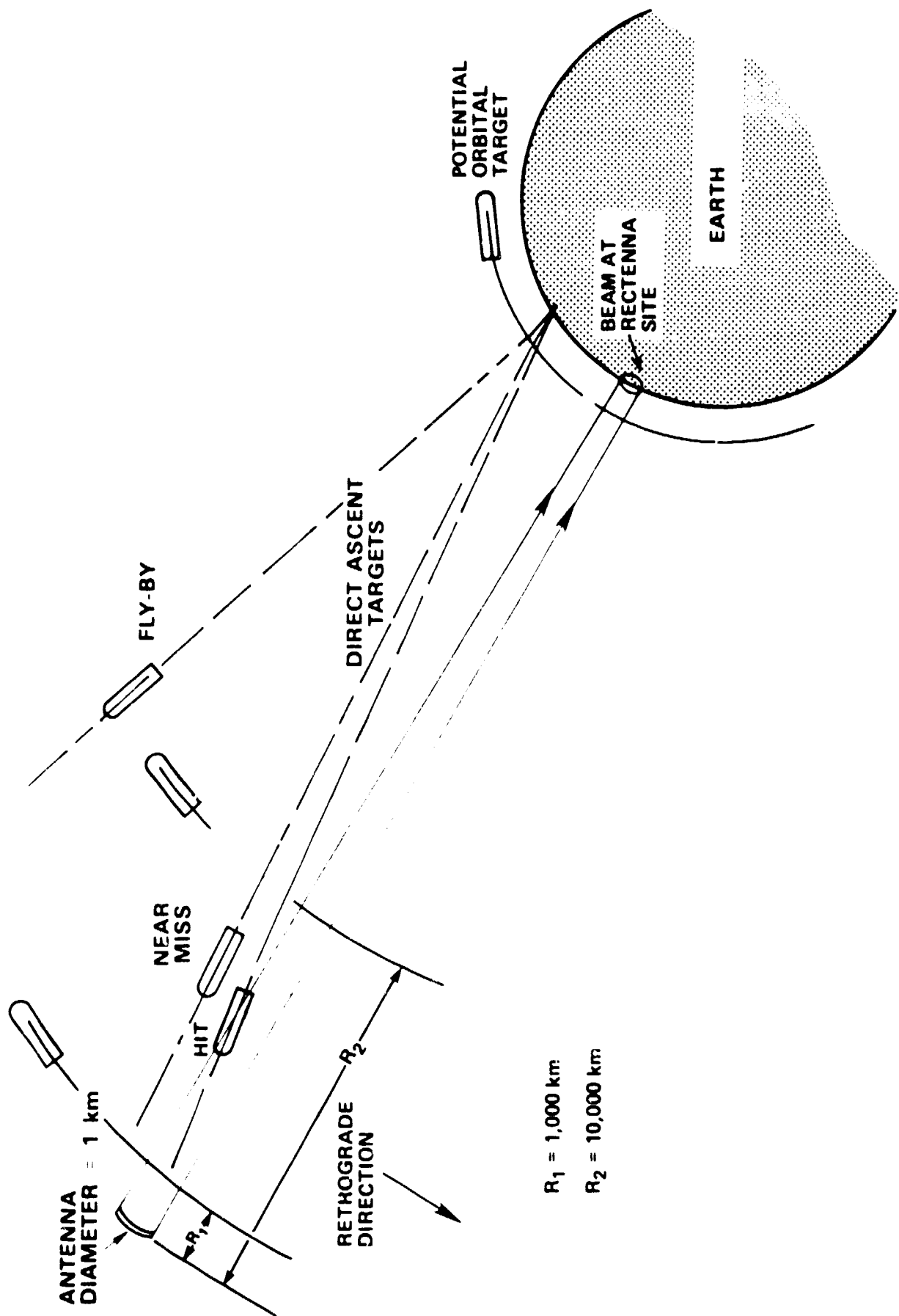


Figure 3.1 Some Examples of Possible Targets That Illustrate the Tracking Problem
(Not to Scale)

It would be possible to increase the energy density on target and thus improve weapon capability by equipping the antenna with higher frequency transmitting units to be used during the weapon mode. Figure 3.2 is a plot of gain (G) in peak power on target versus frequency. (Curve is normalized to 2.45 GHz.) Assuming equal efficiency, power on target (using the 1-km diameter antenna structure) can be increased by a factor of 100, for example, by increasing the transmitting frequency to 24.50 GHz.^{f/} This would reduce beam diameter by a factor of 10, but would decrease figure tolerances, and also decrease the track error allowed by factors of 10.

The smaller, higher frequency transmitting units incorporating electronic scan would handle less power and thus would have to be used in greater numbers than the 2.45-GHz units, and the finer figure tolerances would be expected to require a beefed-up antenna structure. The increased number of transmit modules will result in more complex phasing circuits and the refined tracking accuracy will require more sophisticated track circuits and pointing controls. During operation in the weapon mode, power from the array would be switched from the 2.45-GHz klystrons to the higher frequency transmit units. These additions and modifications to the 2.45-GHz MPTS would increase its weight and cost significantly.

From the foregoing analysis, it appears that the microwave system operating at 2.45 GHz would be relatively ineffective as an energy-beaming weapon, whereas use of shorter wavelength transmitting units and the large 1-km diameter antenna would provide marginally effective results. The cost for either design based on weapon effectiveness probably would be prohibitive, except that with an operating SPS, a large part of the required equipment is already in place. Further study of the weapon potential of the MPTS is needed to identify specifically the feasibility issues and to estimate cost deltas.

3.1.1.2.2 Base for Weapons/Military Operations

The SPS satellite's location at GEO, its size, and the electric power that probably will be available at the site could make it an excellent location for a lookout post and for the deployment of energy-intensive weapons. However, for the lookout function to have greatest value, the satellite must be stationed over the right areas. Stationing such a satellite over the Indian Ocean near the U.S.S.R. or adjacent to other adversary nations without benefit of previous mutual agreements, would likely be provocative. An SPS in GEO used as a base for weapons,

^{f/} Higher frequencies also should be practical.

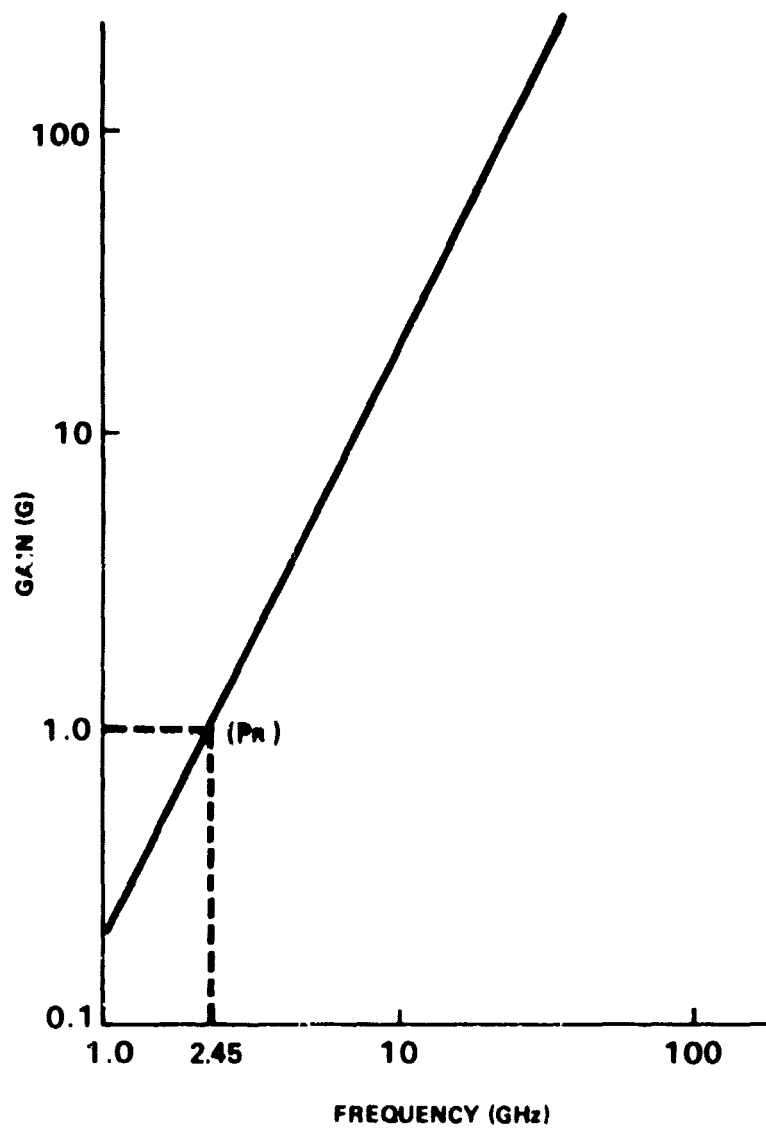


Figure 3.2 Power on Target (Gain, a Ratio, Versus Frequency)

Power density at new frequency (P_F) is given by: $P_F = GP_R$.

(P_R) is 23 mW/cm² at 35,800 km range.

weapon system segments, and their integration into military operational scenarios will be a high-value target and vulnerable to attack, except as this vulnerability is reduced by U.S. strategic deterrence and the SPS self-defense system and/or a space defense system of more generalized capabilities. The deterrent concept is good until it fails, but in any case can provide added time, if needed, for self-defense system development.

The SPS structure may not represent an optimum location for some electronic systems because of the RFI/EMI problems that would result from operation of the SPS Power Transmission Subsystem (PTS) and the electric currents associated with the electrical power transmission system that is part of the solar array. The firing of projectiles or launching of missiles from the array platform depending on launch method could impart a velocity delta. Rotational and/or lateral velocities, contributed in this manner, would have to be compensated for by the SPS orientation and station-keeping system.

These and other questions concerning the SPS self-protection system and use of the SPS as a platform for other weapons and as a support to U.S. military operations should be investigated in detail to determine technology problems, probable costs, schedules, and values and risks of these weapons and activities to the SPS itself and to international stability.

3.1.2 Preparedness

The SPS could be made to contribute to military preparedness by incorporating into its design a weapon mode, by serving as a base for additional weapons and military operations, and by supplying power. The SPS could (1) contribute energy to U.S. activities and industry for a strong and productive economy, (2) provide power to friendly and adversary countries where this promotes U.S. interests and a favorable international stability, (3) supply power to the military, and (4) substitute electricity for portable fuels that then could be released to the U.S. military. The extent to which all these purposes could be served would depend on policy decisions and the SPS's flexibility to service the variety of demands that make up the potential market for SPS power. In discussions with military representatives regarding military preparedness and SPS defense, the following comments/issues were raised:

- The military is concerned about the availability of energy and would use direct SPS power for base operations. The Army may be interested in providing (1) the acreage needed for stable ground power conversion sites and (2) ground security.

- Scheduling early, smaller SPS systems will provide operational experience and allow defense requirements to be worked out incrementally (if defense is possible) before large SPS funding commitments are made.
- The DOD should be brought into system planning and development as early as possible to support the identification of defense/military related issues and be ready to initiate any R&D required to resolve these issues.

3.2 IMPACTS ON INTERNATIONAL RELATIONS

The impacts of the SPS on international relations will be both positive and negative. They will include weapons/military impacts, impacts related to the allotment of the rights to frequency and orbit resources, and impacts that result from large quantities of SPS power being made available for use, export, and control. It is probable that there will be SPS-related disputes to resolve, agreements to forge, and international organizing to do for some time to come.

3.2.1 Weapons Impacts

Both the severity of the weapons impacts on international relations and SPS security will be related to the emphasis that is placed on weapons and military activity at the space site. These impacts will be good or bad, depending on the country in question and its own current self-centered interests. Freedom of space as now recognized, just as freedom of the seas, allows property to be escorted and protected as required. This freedom and the limited restrictions (nuclear weapons and weapons of mass destruction in space) should permit the gradual development and deployment of an effective and accepted SPS self-defense system.

Weapons that provide a military advantage to the nation(s) in control of the SPS without introducing capabilities that tend toward weapon stability may, through the creation of suspicion, fear, and actual vulnerability to those nations not in control, accelerate the arms race.

3.2.2 Power Export/Power Embargoes

The large power production capability of an SPS developed and deployed by the United States will provide a valuable export commodity provided that:

- The necessary agreements can be reached ensuring the United States the required frequency, bandwidth, and orbit slots;
- The SPS is designed with a flexibility that allows it to serve export demands; and
- The necessary agreements can be reached involving assurances relating to payments, reliability of power delivery (embargoes), and SPS system security (transmitting and receiving sites) between export/import countries.

3.2.3 Internationalization

The more logical approach to developing and deploying the SPS from military and security considerations may be to internationalize it from the beginning. Security procedures could then be designed to distribute cost and responsibility among the members of the association of nations formed to exploit the SPS concept. The formation of such an association and the equitable distribution of costs, opportunities, and benefits should facilitate the forging of agreements to obtain needed orbit slots and frequency assignments.

When considering the requirements and opportunities for agreements and/or for internationalization of the SPS, several facts stand out.

- From figure 2.2 it can be seen that the part of the geosynchronous orbit that is of greatest interest to the United States is approximately one-fourth of the orbit that passes over South America and west of it.
- This location is on the other side of the world from the U.S.S.R. and China. Military equipment (and forces) in space protecting SPS and monitoring this region of the world should not cause a maximum level of U.S.S.R./China concern.
- Although South and Central American countries would be easy targets, they are not logical U.S. targets.
- The U.S.S.R. land mass is one of the least favorable locations with respect to a satellite in geosynchronous orbit for receiving power. The long atmospheric transmission paths and the oblique surface of the earth at this location (relative to a line from GEO) may combine to make SPS service to a large part of Russia marginal. A low earth orbit (LEO) relay SPS may be of more interest to Russia.^{9/}

3.3 RELATIVE VULNERABILITY

Communication satellites located in GEO are considered by some to be vulnerable to direct ascent interceptors and to orbiting satellite killers. The COMSAT's prime power, control, and electronic systems are also vulnerable to nuclear radiation and to high-energy laser and particle-beam weapons. The SPS, being much larger, is usually considered to be more vulnerable and, like the communication satellite, can be vulnerable to overt military attack in space and on the ground. Actually its size may permit the use of such techniques as redundancy,

^{9/} The orbits used for this LEO SPS could be selected to satisfy both energy distribution and military objectives.

breakaway structures, placing of decoys of vital aim points at many places on the structure, and other countermeasures to make the SPS less vulnerable than a COMSAT. The large platform of the SPS will also allow the use of larger electronics that are more resistant to radiation such as bipolar devices for some electronics applications instead of the smaller, more vulnerable LSI semiconductor circuits.^{12/} It will also allow some of the more sensitive components to be placed beneath structure to avoid damage due to natural radiation or nuclear radiation from a weapon or test explosion. Hardening against lasers, particle beams, and missiles may be used to control damage and thus require an enemy to come within range of an SPS self-defense system. The SPS transportation system will include the Heavy Lift Launch Vehicle (HLLV), the Personnel Launch Vehicle (PLV) and the Cargo-and Personnel-Orbital-Transfer Vehicles (COTV and POTV). The vulnerability of the personnel vehicles will be a function of vehicle hardening and life-support system design, whereas the vulnerability of cargo vehicles will be a function of the hardening techniques used, escort policy/capability, and vehicle velocity (trip duration). For more information concerning the impact of hostile environments on the SPS, see appendix B.

The rectenna site is vulnerable to ordinary ground attack but probably can be designed so that its performance degrades gracefully. Vulnerability can be reduced by placing much of the power distribution and heavy power-handling equipment underground at the rectenna site and by closely controlling design and site layout data. Care given to the security aspects of the design (controls and data handling/processing equipment) can reduce the risk of SPS equipment takeover by hostile forces.

For the most part terrorist attacks will be limited to ground facilities. Attacks could be launched against the rectenna site, ground-based space transportation facilities, power distribution system, and ground-based supply lines for SPS materials and spares.

Terrorist attacks against SPS space assets are conceivable but probably will not be important considerations until equipment such as high-energy laser and/or particle-beam weapons can be acquired by such groups or until earth-space transportation is commonplace. Sabotage of the system is more likely and can occur on the ground or in space. Losses due to sabotage can be controlled through internal security, employee screening, and the enforcement of harsh penalties for sabotage at SPS, utility, and support organizations.

IV. KEY ISSUES AND GENERAL OBSERVATIONS

During the study several key issues were identified and observations were made concerning the military implications of the SPS. These are noted in the following paragraphs.

4.1 WEAPON AND MILITARY PREPAREDNESS IMPLICATIONS

As a weapon the microwave power transmission subsystem (MPTS) may have some applications as a noise generator in an electronic warfare role. Its applications as an energy-beaming weapon are limited in the current NASA reference system configuration because of the low-power density in the microwave beam and the large massive antenna that would need to be moved to follow the target. A geostationary (GEO) location of the NASA reference system maintains the satellite and any weapons capability stationary over a single spot on earth.

Military preparedness will be supported by the SPS in the following ways:

- Strengthen the civilian/industrial sector allowing more effective technology, production, and capital support to the military;
- Free portable fuels required for military mobility (and stockpiling);
- Provide electricity to military ground installations through the utilities; and
- Supply markets for electricity and thus strengthen mutual security bonds and reduce tensions.

Large, powered, platforms for weapons can be provided by the SPS at several different GEO locations. Weapons or weapon systems segments could include sensors, communications, and laser/particle beam weapons; projectiles/missiles; and electronic warfare and data-handling systems. The platform, reinforced and modified, could be made to provide storage, housing, etc. This additional mass would result in a larger load on the SPS station-keeping system.

Each deployment of modestly sized SPS's would provide operational experience and allow any needed SPS defense system to start small and grow to be compatible with risk. In this manner the ability of the SPS to be defended could be determined before making large resource commitments.

4.2 INTERNATIONAL RELATIONS

International relations could be affected as a result of:

- Disputes between nations with regard to the international agreements that must be made concerning solar flux at GEO, frequency, orbit, power export, security, etc.;

- Possible requirements to place weapons in space to ensure the security of the SPS; and
- Possible need to internationalize the SPS to reduce its vulnerability.

System deployment schedule and flexibility of service may affect the availability of frequency bands and orbit slots needed for the SPS, and flexibility of SPS service available may determine the degree of interest among potential national participants in an internationalized SPS.

4.3 VULNERABILITY

Vulnerability of the SPS relative to terrestrial systems is determined by comparing the vulnerability of the spaceborne segment of the SPS and launch sites with the vulnerability of the terrestrial system's fuel supply line(s).

- The spaceborne segment of the SPS is vulnerable to military adversaries and to saboteurs;
- SPS defensive measures may need to include
 - Hardening against nuclear radiation, laser/particle weapons, and missiles, and
 - A self-defense system;
- Launch sites are expected to be vulnerable in approximately the same manner as terrestrial plant sites, except that launch sites probably will have better security.
- At ground rectenna sites it should be possible to use a redundant design, arranging rectenna modules in parallel so that partial destruction would only degrade rectenna performance. (Much of the cabling and heavy equipment could be placed underground.)

V. RECOMMENDATIONS FOR FURTHER STUDY

5.1 SHORT-TERM TASKS

In conducting this study, four tasks were identified and are recommended for completion in fiscal year 1979.

Task 1 would identify and assess areas of SPS vulnerability to military/quasi-military actions and prepare SPS design guidelines to reduce this vulnerability.

Task 2 would prepare an SPS self-defense system concept and a plan for its evaluation.

Task 3 would investigate the probable effect of the flexibility of the SPS to deliver different sized loads on the ability to get individual nations to support SPS. This support (or lack of it) should be related to the following:

- Prospects for internationalizing the SPS;
- SPS vulnerability to military attack; and
- International acceptance of an SPS self-defense system.

Task 4 would investigate the effect of the SPS deployment schedule on the ability to (a) obtain international support and get needed agreements to allot GEO solar flux, bandwidth, and orbit slots, and (b) plan, develop, and deploy an adequate SPS defense system at a rate to reduce risks of confrontation and "space war."

5.2 LONG-TERM TASK

A fifth task would be longer term designed to identify military implications that result from the specific requirements of potential world customers for SPS power. Information concerning customer requirements relating to participation, timing, product, service and reliability of service would provide important data to be used in designing a secure system. In addition, this task would contribute significantly to the information base needed to promote the international interest and cooperation leading to a militarily secure SPS.

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APPENDIX A MILITARY ACTIVITIES IN OUTER SPACE

by
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Military Uses of Outer Space: The Legal Regime

The legality of military operations in space is set in several important documents. These would include: the 1958 NASA Space Act; the Treaty on Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water (1963); and the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967). Due to the possible impact an SPS beam would have on the Earth's upper atmosphere, the Convention on the Prohibition of Hostile Uses of Environmental Modification Techniques (1977) would also be affected.

Operations in outer space can be manifested in a number of ways. Among these are the peaceful, aggressive, nonaggressive, and military uses of outer space. Disagreement concerning what definitions apply to these words has been the subject of discussion since the earliest days of space exploration.

The meaning "peaceful," according to space law experts, gives rise to two different interpretations. Under one interpretation, primarily used by the United States, "peaceful" connotes "nonaggressive." A second interpretation of the term is "nonmilitary" and is used, although not exclusively, by the Soviet Union. In addition, "peaceful" use has been applied to defense support space missions that are "noninterfering" or "nonaggressive."^(1, 2)

As stated in the Air Force Manual 1-1:⁽³⁾

The underlying goal of the U.S. national space policy is that the medium of space must be preserved for peaceful use of all mankind. Air Force principles relating to space operations are consistent with this national commitment. National policy and international treaties restrict the use of space for employment of weapons of mass destruction. There is, however, a need to insure that no other nation gains a strategic military advantage through the exploitation of the space environment.

The possibility of an SPS linked to high powered laser could lead to a ballistic missile defense capability. In addition, an SPS/laser system could be utilized in a particle beam weapon, with lasers creating highly intense, coherent light

sources to develop a reduced density channel, thereby enhancing particle beam propagation.^(4, 5)

Such possibilities would have significant impact upon existing treaties between the United States and the Soviet Union on the limitation of anti-ballistic missile systems. Signed parties have agreed not to develop, test, or deploy ABM systems or components that are sea-based, air-based, space-based, or mobile land-based. However, suggestions have been made that aspects of the ABM Interim Agreements and Agreed Interpretations, can be interpreted ambiguously, perhaps allowing research, development, and proof testing of space-based ABM systems, short of actual deployment.

Defensive/Offensive Use of Space

Space lawyer Andrew Haley once stated:⁽⁶⁾

...a nation is justified in protecting itself from attack no matter where the staging area of the attack may be, including on the high seas or in outer space, and a nation may carry its defensive forces to such areas. The great unresolved problem, so far as defensive measures in space are concerned, is to translate the general recognition of this right of self-defense into some workable criteria for distinguishing between the defensive and offensive uses of space.

The fear of a technological, space-based "Pearl Harbor" has been reiterated in military literature. According to General Jacob Smart (retired):⁽⁷⁾

Despite wishful thinking to the contrary, man is and promises to remain an aggressive, combative creature. We fear, we hate, we fight one another. Until we remove causes of fear and hatred and correct the conditions which prompt us to arm ourselves, we have no choice but to prepare to defend ourselves against attack in whatever form and through whatever media attacks may come. Today and henceforth, the United States must be prepared to defend itself against aggression in space and from space. We cannot surrender the "high ground" without contest.

Justifications for Military Activity in Space

Recent official speeches⁽⁸⁾ clarify current justification of the U.S. military involvement in the space medium. These are:

- Uniqueness - some functions essentially can only be done from space, such as near real-time warning of a ballistic missile attack
- Economics - some functions are more cheaply done from space, such as long-haul communications
- Function effectiveness - some functions are more effectively done from space, like meteorology
- Force effectiveness enhancement - some space functions can greatly enhance the effectiveness of terrestrial forces.

Denial of Access

With increased use by the military of space-based systems, a dependence has been created. In turn, this dependence has led to fears that an aggressor nation "deny access to such systems." Development of the limited anti-satellite (ASAT) capability by the Soviets has jeopardized "the heretofore accepted sanctuary of space," and now requires the "ability to protect satellites in space" as fundamental "to defending the right of the United States and its allies to use of space to achieve military advantage."⁽⁹⁾

Secretary of Defense Harold Brown⁽¹⁰⁾ also has testified to Congress that:

As the President has clearly stated, it would be preferable for both sides to join in on an effective, and adequately verifiable ban on antisatellite (ASAT) systems; we certainly have no desire to engage in a space weapons race. However, the Soviets with their present capability are leaving us with little choice. Because of our growing dependence on space systems we can hardly permit them to have a dominant position in the ASAT realm.

Soviet ASAT capabilities, although still unable to reach geostationary orbit, have produced studies by the U.S. military to develop special maneuvers for future military satellites once in orbit to avert anti-satellites. These maneuvers would avert satellites that are capable of (a) using pulverized aluminum particles to form a "smokescreen," protecting a satellite from laser beams; (b) increasing U.S. knowledge of the effects of pulsed laser radiation on solar cells and sensors; (c) using alternative power generation for spacecraft instead of vulnerable solar cells and solar cell panels; and (d) renewing emphasis on radiation hardening of delicate electronic payloads to counter possible high-altitude or space-environment nuclear explosions.

The implications of verifying the results of these studies would include adding weight to military payloads, pushing their weight to the upper limit of Space Shuttle carrying capacity. Investigations are now underway to upgrade the Space Shuttle, allowing for heavier-than-expected cargo.

Public Support for the Space Peace/War Potential

A Hudson Institute study has stated that fear of being second in space competition produces a number of social effects. According to the report, war remains of paramount concern to the American public. Support of U.S. space activity has been greatest when there was a linkage between the Cold War and space competition. However, the report cautions that events, such as the launching of the first satellite, the Soviet Sputnik I, resulted in a tendency of the public

...to blame political and governmental officials for allowing the United States to fall behind a competitor. This kind of blame constituted, in effect, strong support for the space program--at least in a period when the public connected space issues to the Cold War.

Becoming second resulted in public questioning of U.S. military competence.

Does military activity in space deter international cooperation? As stated in a U.S. House of Representatives report:⁽¹²⁾

The Defense Department has suggested guidelines for the export of U.S. technology under which maintenance of U.S. technological superiority by absolute control of design and manufacturing know-how is considered by DOD to be essential. All other considerations, including international goodwill, are secondary under these guidelines, according to DOD.

The report raises the following important questions:⁽¹²⁾

Because of the military potential of space technology, should sharing of space technology come under these guidelines? Would maintenance of U.S. technological leadership in space under these guidelines be compatible with U.S. stated policy regarding international cooperation in space? If maintenance of U.S. technological leadership in space can only be achieved at the expense of international cooperation, which goal shall prevail?

Military Use of the Space Shuttle

Lt. General Thomas W. Morgan,⁽¹³⁾ Commander of the Space and Missile Systems Organizations, AFSC, has stated that the Space Shuttle

...will open a new chapter of our national space program. It may well make economically feasible for the first time whole new missions in space - in addition to opening the door to better or cheaper ways of performing traditional missions. I see the 1980's - the time in which the STS (Space Transportation System) becomes a proved quantity - as a time of major reappraisal of the role of space in the Air Force Future.

Military/civilian space dependence on one vehicle, the Shuttle, has developed a number of interesting policy problems. According to the Council of Economic Priorities (CEP),⁽¹⁴⁾

because the DOD will be entirely dependent upon NASA's transportation system for space launches, and because NASA is a small agency in budget and laborpower relative to the DOD, there is danger that in the future, NASA programs will be oriented toward military, rather than civilian and scientific uses.

The CEP feels that NASA could be pressured to restructure the U.S. space program to fit DOD needs.

The possibility exists that, upon operational status, the DOD will increase its manned military activity via the Shuttle. Such a possibility may result in procurement of a special DOD Space Shuttle. According to a report by a panel of the National Academy of Public Administration, shifts in U.S. and Soviet relations could result in increased Defense expenditures. Such expenditures could include establishment of a "...NASA-based civilian (and open) STO (Space Transportation Organization), and a DOD 'classified STO.' "(15)

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Recently President Carter directed under a Presidential Review Memorandum that the National Security Council Policy Review Committee examine existing policy and formulate overall principles which should guide our space activities. Principles were set forth in the Directive.⁽¹⁶⁾ Of interest with regard to SPS are the following:

The U.S. rejects any claims to sovereignty over outer space or over celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right to acquire data from space.

The United States holds that the space systems of any nation are national property and have the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement upon sovereign rights.

The United States will pursue activities in space in support of its rights of self-defense and thereby strengthen national security, the deterrence of attack, and arms control agreements.

The U.S. will encourage domestic commercial exploitation of space capabilities and systems for economic benefit and to promote the technological position of the United States.

The Secretary of Defense will establish a program for identifying and integrating, as appropriate, civil and commercial resources into military operations during national emergencies declared by the President.

While the United States seeks verifiable, comprehensive limits of anti-satellite capabilities and use, in the absence of such an agreement, the U.S. will vigorously pursue development of its own capabilities. The U.S. space defense program shall include an integrated attack warning, notification, verification, and contingency reaction capability which can effectively detect and react to threats to U.S. space systems.

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APPENDIX B

IMPACT OF HOSTILE ENVIRONMENTS ON SPS

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This discussion addresses the influence of natural radiation environment, and of some weapon environments, on the performance of the Satellite Power System. The discussion is generic, rather than system specific, in that it is concerned with classes of effects on equipment of the type that would probably be used to implement the Satellite Power System (SPS) design, rather than with an assessment of the system itself. The weapon environments considered include nuclear radiation from a weapons test, or an attack on another satellite, as well as direct attack by an Anti-Satellite Satellite (ASAT) carrying pellet, nuclear, or laser weapons. Effects are considered from the viewpoint of the payload (solar array) as well as the vehicle-operating systems.

Natural Radiation

The natural radiation environments are the trapped-electron environment, the solar flare proton environment, and the trapped-proton environment, which all contribute to the total dose seen by the system. Current understanding of these environments probably is best exemplified by the NASA AE-7 model for electrons and the AP8MAC and AP8MIC models (also NASA) for protons. Exposure to the total dose environments, for both the payload (solar array) and the vehicle electronics, results in the gradual degradation of performance parameters. For the solar array itself, this degradation would result in a loss of power output of the order of 15 percent over 5 years in orbit. This kind of degradation is generally accounted for by including the end-of-life degradation in the initial design. For the SPS the degradation allowance would be sized to the refurbishment cycle time. Semiconductor devices in the vehicle electronics would be similarly affected, the degradation ranging from insignificant for most diodes and small signal transistors to potential catastrophic failure for some integrated circuit operational amplifiers. Hardening techniques available include mitigation of the dose incident on the parts by the use of added structural, box or piece part shielding, or by determination of the radiation sensitivity of the parts by test in a simulated radiation environment and providing for this radiation sensitivity in the design. This

latter approach requires some degree of ongoing monitoring of production devices, since the total dose sensitivity is very sensitive to manufacturing process changes in some devices. Several device manufacturers are beginning to introduce lines of radiation-hardened devices that should reduce this concern in the future.

Collateral Nuclear Effects

The baseline environment defined for the nuclear radiation levels arising from a nuclear weapons test by another power, or from an attack on another satellite, is the JCS guidelines level defined in SAMSU Exhibit 69-13 (secret). For a synchronous satellite over the continental United States, the probability of seeing these levels resulting from an actual test is very small. Radiation levels resulting from an attack on another satellite will vary depending on the distance from the nuclear event, except for the electron and electromagnetic pulse (EMP) environments which are relatively independent of distance. The following discussion will be based on the distance specified in 69-13, and the levels, and the effects will vary as the distance varies.

The principal impact of nuclear radiation on the Satellite Power System will be in the solar array itself and in the semiconductor devices that implement the vehicle electronics. The potential radiation failure modes are:

- Catastrophic failure, arising from the burnout of semiconductors from X-ray induced photocurrents, or from electrical currents resulting from X-ray illumination of the vehicle cables or structure. X-ray illumination of the solar array itself at 69-13 levels will not result in catastrophic failure of the array, but could result in surges in the primary power lines which could damage equipment connected to those lines. Such surges can be eliminated by a combination of mitigation of the X-ray environment by the use of shielding by material of high atomic number and by limiting the devices response by the addition of limiting impedances in series with the power supply lines to the affected devices. The efficacy of these protective approaches will be valid for increases in the environmental level of 3 to 4 times in most cases. The effects of electrical currents resulting from X-ray illumination of the cables or structure may be eliminated by the use of terminal protection devices (e.g., surge limiters, voltage clamps) at component input/output circuits.
- Degradation, which is the same effect considered in the discussion of the natural radiation environment, except that the environments of concern are the weapon electron and neutron environments. The weapon electron environment will be larger than the natural environment, but otherwise may be treated in the same way. The neutron environment may not be shielded, but at the 69-13 level is too low to be of concern to the large majority of parts. Degradation which does exist must be characterized on the basis of tests on specimen devices in a simulated neutron environment, and then allowed for in the design.

- Transient upset, which is the inadvertent switching or change of state of digital devices when subjected to X-rays or System Generated EMP (SGEMP). It is not a failure mode of concern to the solar array itself, but must be addressed for the vehicle electronics. A typical system response of concern would be the inadvertent firing of station-keeping thrusters which could result in a change of orientation or position of the system. Hardening approaches for such effects include the use of invulnerable devices (e.g., electromagnetic relays) or by the use of devices that will not respond to the short weapon radiation pulse.

ASAT Attack

The options available to conventional satellite systems for withstanding ASAT attack include (1) hardening, in which the weapon impact is conceded, but its ability to kill thwarted, (2) misdirection, in which the attacker's ability to direct the weapon to the target is defeated, either by maneuvering of the target or deceiving the attacker's acquisition and tracking system by decoys or jamming and (3) counterkill in which the ASAT is shot down before it can do any damage. The features of the SPS that dictate a survivability approach are its large size and the large amount of power available to it. Hardening, whether against pellet, laser, or nuclear weapons is not sufficient to ensure survival against an attack, but it can aid the SPS's defensive posture by forcing an attacker to come in closer to fire effectively. Maneuvering and decoys are not feasible for such a large system. Jamming the attacker's acquisition and tracking system would be effective against today's generation of trackers, particularly in view of the SPS power capability. More advanced trackers with home-on-jam capability, or using long-wavelength infrared (LWIR) or optical data may negate this advantage. Counterkill would appear to be a feasible survivability approach, particularly with an on-board laser weapon which could utilize the SPS power capability to fire at long range with sufficient power to destroy an attacker before he got within range with his smaller weapons. Counterkill would require an adequate warning signal from a system such as the Satellite Attack Warning System (SAWS) to be effective, but this should be available in the SPS time frame.