Chapter 8

ENVIRONMENT AND HEALTH

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ENVIRONMENT AND HEALTH

INTRODUCTION

As a large-scale energy system operating in both the space and terrestrial environments, the solar power satellite (SPS) is unique. And because it is a new concept, our understanding and experience of a number of the environmental impacts associated with SPS are limited. The great uncertainties surrounding these effects make comparisons between SPS and other energy technologies especially difficult. While one advantage of SPS is that it would avoid many of the environmental risks typically associated with conventional energy options such as coal and nuclear, it also would generate uncommon environmental effects that presently cannot be quantified or compared to those of other powerplants. The large uncertainties also tend to provoke public debate. In light of past controversies over the siting of powerplants, transmission lines and other facilities, it is clear that environmental issues could play a key role in public consideration of SPS (see ch. 9).

This chapter will outline the environmental and health impacts of SPS that are currently thought to be most important. It will identify research needs and highlight areas of controversy. As with other aspects of SPS, the environmental effects have been evaluated most fully for the reference system. Some of this data is also applicable to the other SPS technical options, differing only in extent or degree, but information on the full range of their environmental effects is limited.

At the current stage of development, SPS environmental studies can play an important role in determining concept feasibility, technical design, and cost. For example, bioeffects research might influence the choice of frequency which, in turn, could determine hardware design and land use. Thus, many of the effects currently identified might be minimized by appropriate choices of design. However, it is also possible that one or more risks might be identified in the development process that could not be reduced to an acceptable level without jeopardizing the economic or technical viability of the SPS concept.

The SPS environmental effects and the cost of reducing them must be viewed in the context of energy technologies, energy needs, other space activities, and the incremental effect on human health and the environment. Preliminary comparative assessments indicate that, in general, those health and environmental impacts of the reference system SPS that can presently be quantified would probably be no more severe than for other large-scale electricity generating technologies although the uncertainties for SPS are high).[1 2 3 4] In fact, when compared to coal, SPS would be an order of magnitude cleaner (see app, D). However, if an SPS program is pursued, further comparative analysis between energy options would be required as more is learned about the unquantifiable impacts that could not be incorporated in the present studies A good portion of this chapter discusses these latter effects for SPS.

The discussion in this chapter relies heavily on the data and analysis generated by the Department of Energy (DOE)[5] and the National Academy of Sciences (NAS).[6 7] The reader is

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[1] L J Habegger, J R Gasper, and C D Brown, *Health and Safety Preliminary Comparative Assessment of the Satellite Power System (SPS) and Other Energy Alternatives,* DOE/NASA report No DOE/ER-0053, April 1980

[2] D E Newsom and T D Wolsko, *Preliminary Comparative Assessment of Land Use for Satellite Power Systems and Alternative Electric Energy Technologies,* DOE/NASA report No DOE/ER-0058, April 1980

[3] D A Kellermeyer, *Climate and Energy: A Comparative Assessment of the SPS and Other Energy Alternatives,* DOE/NASA report No DOE/ER-0500, January 1980

[4] F P Levine, M J Senew, and R R Cirillo, *Comparative Assessment of Environmental Welfare Issues Associated With the Satellite Power System and Alternative Technologies,* DOE/NASA report No DOE/ER-0055, April 1980

[5] *Environmental Assessment for the Satellite Power System Concept Development and Evacuation Program,* DOE/NASA report No DOE/ER-0069, August 1980

[6] Committee on Satellite Power Systems, National Research Council Open Committee Meetings Jan 31-Feb 1, 1980, Apr 9-10, 1980, July 1-2, 1980, Oct 1-2, 1980

[7] C H Dodge (rapporteur), *Workshop on Mechanisms Underly-*

referred to the DOE documents for more detailed discussions. While those studies have not identified any environmental reasons not to continue with SPS development, it is very evident that much more study and research would be required before decisions could be made regarding the environmental viability of SPS. What is not clear is how long it might take before our confidence in the resolution of some environmental impacts such as microwave bioeffects would be high enough to make development or deployment decisions.

As table 28 illustrates, there is a great diversity of environmental and health impacts. Of

(continued from p. 179)

ing Effects of Long-Term, Low-Level, 2,450 MHz Radiation on People, organized by the National Research Council, Committee on Satellite Power Systems, Environmental Studies Board, National Academy of Sciences, July 17-17, 1980

Table 28.—Summary of SPS Environmental Impacts

System component characteristics	Environmental impact	Public health and safety	Occupational health and safety
Power transmission			
Microwave	—[b]**Ionospheric heating could disrupt telecommunications. Maximum tolerable power density is not known Effects in the upper ionosphere are not known** —**Tropospheric heating could** result in minor **weather modification** —[b]**Ecosystem: microwave bioeffects (on plants, animals, and airborne biota) largely unknown; reflected light effects unknown** —[b]**potential interference with satellite communications**, terrestrial communications, radar, radio, and optical astronomy	—[b]Effects of low-level chronic exposure to microwaves are unknown — Psychological effects of microwave beam as weapon —Adverse esthetic effects on appearance of night sky	—Higher risk than for public; protective clothing required for terrestrial worker —Accidental exposure to high-intensity beam in space potentially severe but no data
Lasers	—Tropospheric heating could modify weather and spread the beam —Ecosystem: beam may incinerate birds and vegetation —[b]potential interference with optical astronomy, some interference with radio astronomy	—Ocular hazard? —Psychological effects of laser as weapon are possible —Adverse esthetic effects on appearance of night sky are possible	—Ocular and safety hazard?
Mirrors	—[b]Tropospheric heating could modify weather —Ecosystem: effect of 24-hr light on growing cycles of plants and circadian rhythms of animals —[b]potential interference with optical astronomy	—Ocular hazard? —Psychological effect of 24-hr sunlight —[b]Adverse esthetic effects on appearance of night sky are possible	—Ocular hazard?
Transportation and space operation			
Launch and recovery HLLV PLV COTV	—Ground cloud might pollute air and water and cause possible weather modification; acid rain probably negligible —[b]Water **vapor** and other	—Noise (sonic boom) may exceed EPA guidelines —Ground cloud might affect air quality; acid rain probably negligible — Accidents-catastrophic	—[b]Space worker's **hazards:** ionizing radiation (potentially severe) weightlessness, life support failure, long stay in space,

Table 28.—Summary of SPS Environmental Impacts—Continued

System component characteristics	Environmental impact	Public health and safety	Occupational health and safety
POTV	launch effluents could deplete ionosphere and enhance airglow. Resultant disruption of communications and satellite surveillance potentially important, but uncertain —[b]possible formation of noctilucent clouds in stratosphere and mesosphere; effects on climate are not known —[b]Emission of water vapor could alter natural hydrogen cycle; extent and implications are not well-known —[b]Effect of COTV argon ions on magnetosphere and plasmasphere could be great but unknown —Depletion of ozone layer by effluents expected to be minor but uncertain —Noise	explosion near launch site, vehicle crash, toxic materials	construction accidents psychological stress, acceleration —Terrestrial worker's hazards: noise, transportation accidents
Terrestrial activities			
Mining	—Land disturbance (stripmining, etc.) —Measurable increase of air and water pollution —Solid waste generation —Strain on production capacity of gallium arsenide, sapphire, silicon, graphite fiber, tungsten, and mercury	—Toxic material exposure —Measurable increase of air and water pollution — Land-use disturbance	—Occupational air and water pollution —Toxic materials exposure —Noise
Manufacturing	—Measurable increase of air and water pollution —Solid wastes	—Measurable increase of air and water pollution —Solid wastes — Exposure to toxic materials	—Toxic materials exposure —Noise
Construction	—Measurable land disturbance —Measurable local increase of air and water pollution	—Measurable land disturbance —Measurable local increase of air and water pollution	—Noise —Measurable local increase of air and water pollution —Accidents
Receiving antenna	—[b]Land use and siting—major impact — Waste heat and surface roughness could modify weather	—[b]Land use— reduced property value, esthetics, vulnerability (less land for solid-state, laser options; more for reference and mirrors)	— Waste heat
High-voltage transmission lines (not unique to SPS)	—[b]Land use and siting—major impact —[b]Ecosystem: bioeffects of powerlines uncertain	—[b]Exposure to high light intensity EM fields—effects uncertain	—[b]Exposure to high intensity EM fields—effects uncertain

[a]Impacts based on SPS systems as currently defined and do not account for offshore receivers or possible mitigating system modifications
[b]Research priority.

SOURCE: Office of Technology Assessment

most concern are: 1) the biological effects of electromagnetic radiation produced by the power transmission and distribution systems; 2) the atmospheric effects of electromagnetic radiation and launch effluents and the resulting impacts on telecommunications and air quality; and 3) the land requirements and siting considerations for ground-based receivers. The greatest environmental uncertainties are listed in table 29.

The first part of the chapter will deal with the potential environmental impacts resulting from the construction and operation of SPS systems. These and other effects will then be addressed in the second section as they pertain to human health and ecosystems. Detailed discussion of a number of impacts is found in appendix D.

Table 29.—Major SPS Environmental Uncertainties

Reference and solid-state systems
- Microwave bioeffects
  - —Low-level, chronic exposure
- Launch effluent effects
  - —Ions in the magnetosphere
  - —Natural hydrogen cycle
  - —Ionospheric depletion
  - —Noctilucent clouds
- Microwave heating of the ionosphere Effects on telecommunications
- Land use

Laser **system**
- Laser bioeffects
- Tropospheric heating
- Launch effluents
- Land use

Mirror *system*
- Weather modification
- Land use
- Biological and psychological effects of 24-hr light

Systems comparisons

SOURCE Office of Technology Assessment

ENVIRONMENT

One of the consequences of constructing and operating an energy system in space is that the extent of the environment that is directly affected by the system is much broader than for Earth-based powerplants. For example, both the transmission of SPS power and the injection of launch effluents will directly affect every layer of the atmosphere. The purpose of this section is to discuss the state of knowledge of the predominant environmental impacts of SPS, especially those that are fairly unconventional and to outline areas where further research would be needed. Biological effects, i.e., human health and safety and ecological impacts, are deferred to the second part of the chapter.

The two major environmental concerns at the present time are: 1) the effect on the atmosphere of the transportation and power transmission systems; and 2) electromagnetic interference with communications systems and astronomy.[8] With respect to the former, the effluents emitted from the launch vehicles could deplete portions of the ionosphere, alter the natural hydrogen cycle and magnetosphere dynamics and modify weather and air quality near the launch site. The effects of the power transmission system on the atmosph are a function of the frequency of the For the laser and mirror systems, the mos nificant potential impact is heating of near-Earth atmosphere, which might alter weather. If the microwave beam were to alt the ionosphere, it could disrupt telecom mu n i cat ions.

In order to understand clearly these and the other more conventional environmental impacts described in this chapter, it is worthwhile to review the properties and structure of the atmosphere as illustrated in figure 30 and discussed in box A.

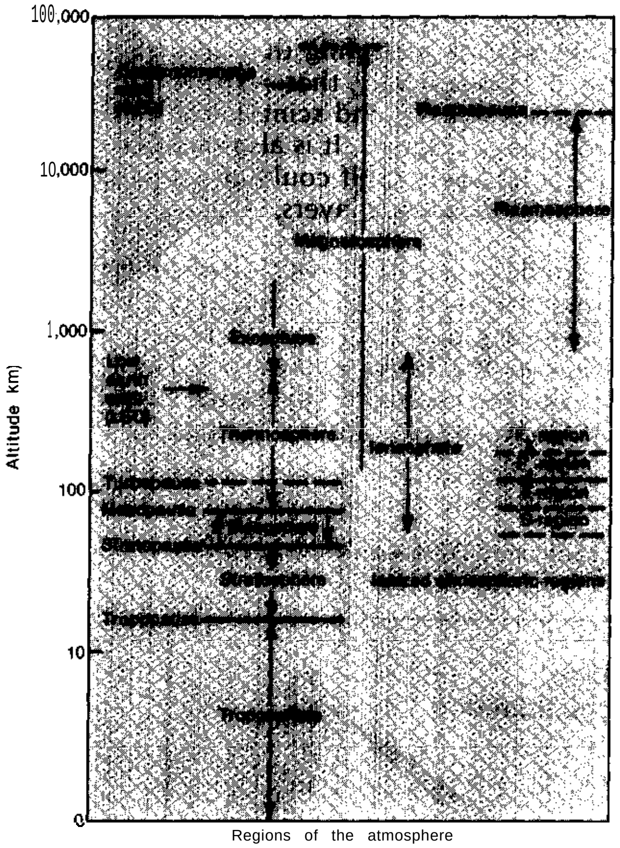
Power Transmission Effects on the Atmosphere and Weather

Current SPS designs transmit energy to Earth using microwaves, lasers or reflected light. Since the atmospheric effects of power transmission are highly frequency dependent, each

[8] *Program Assessment Report, Statement of Findings,* Satellite Power Systems Concept Development and Evaluation Program, DOE/NASA report No DO E/E R-0085, November 1980

Figure 30.— Regions of the Atmosphere

Solar radiation excites, disassociates and ionizes atmospheric constituents. The ionosphere in particular is a region of marked abundance of free electrons and ions. The properties of the ionosphere vary with latitude, time of day, season and solar activity. When electromagnetic waves enter the ionospheric plasma, they will be refracted and slowed down. Depending on the frequency of the incident wave and properties of the ionosphere, the wave can be totally reflected. It is this phenomena that makes many radio frequency communication systems possible.



SOURCE: *Program Assessment Report, Statement of Findings*, Satellite Power Systems Concept Development and Evaluation Program, DOE/NASA Report, DOE/ER-0085, November 1980

[illegible]

of these will be discussed separately. Table 30 summarizes the impacts of most concern.

Microwaves[*]

As the beam from a microwave satellite traveled towards Earth, it would heat the atmosphere. While attenuation of the microwave beam by clouds and rain in the troposphere could cause a slight modification of cloud dynamics and precipitation,[9] absorption

[*] See app D for details

[9] Kellermeyer, op cit

Table 30.—Power Transmission Impacts

Microwaves
- Upper ionosphere telecommunications effects unknown; experiments and improved theory are needed
- Lower ionosphere impacts are thought to be negligible for a number of telecommunications systems; scaling laws must be verified and effects on telecommunication systems operating in the 3 MHz to 20 MHz range must be tested
- The maximum power density for which telecommunications effects are insignificant is not known and must be determined
- Tropospheric heating is not thought to be significant

Lasers
- Thermal blooming in the troposphere may degrade the beam
- Tropospheric heating may cause increased cloud formation, turbulence and weather modification
- Effects on the mesosphere, stratosphere, and thermosphere and continental cloud distribution and albedo are thought to be inconsequential

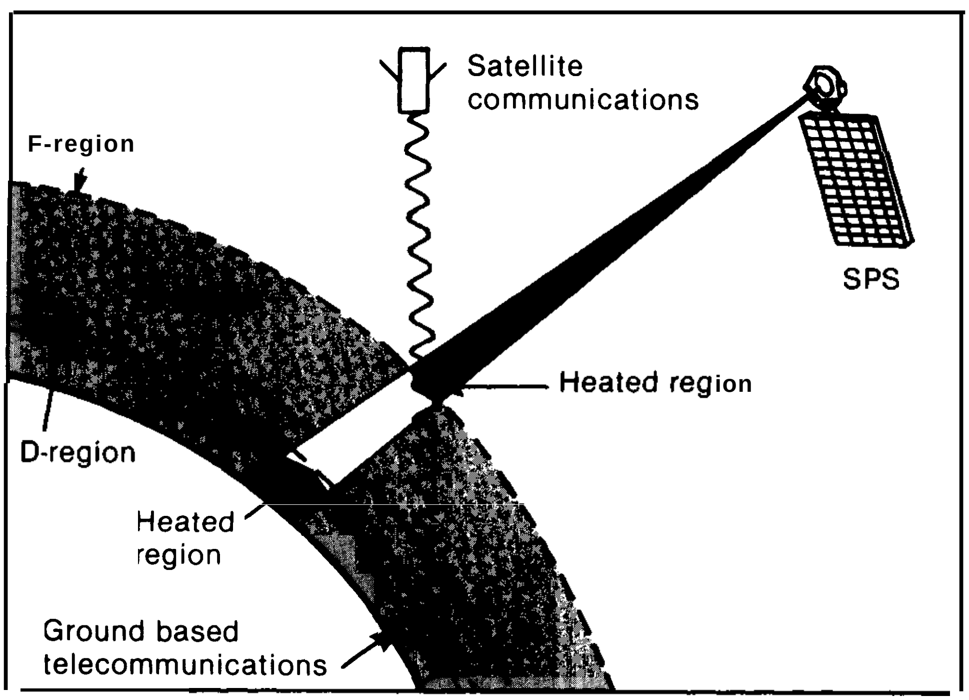
Reflected light
- Weather modification in vicinity of ground sites is possible, but unquantified
- Photochemistry of the ozone layer is not thought to be affected

SOURCE: Office of Technology Assessment.

of microwave energy is most important in the ionosphere. Of particular concern are the effects of ionospheric heating on telecommunication systems that rely on the ionosphere to transmit and reflect radio waves. Changes in the ionospheric properties due to heating can degrade (or in some cases, enhance) the performance of telecommunication systems by absorbing or scattering the radio signals (see fig. 31). Specifically, these effects could result in losses, fading, and scintillation of the electromagnetic signals. It is also possible that the SPS pilot beam itself could be affected by the heated ionospheric layers.

In the course of the DOE assessment several experiments were conducted to test the extent of heating and the effect on telecommunications in the lower ionosphere. These experiments demonstrated that while heating does occur the effects are not serious for the tele-

Figure 31 .—Examples of SPS Microwave Transmission Effects on the Ionosphere and Telecommunication Systems



SOURCE: *Prograrn Assessment Report, Statement of Findngs,* Satellite Power Systems Concept Development and Evaluation Program, DOE/NASA Report, DOE/ER-0085, November 1980 communication systems tested. Some researchers have even suggested that the proposed power density of 23 mW/cm^2 could be doubled without significant impact to telecommunications in the lower ionosphere. However, more research is needed in order to determine the power density threshold in the lower ionosphere, and for this the power density of the existing heating facilities will have to be increased. Additional study is also required to ascertain the effects in the lower ionosphere on telecommunication systems that operate at frequencies greater than 3 MHz (i.e., 3 to 100 MHz) range. In addition the effects of multiple microwave beams need to be determined.

Our knowledge of upper ionosphere (F region) heating is less advanced than in the D & E regions. Few underdense experiments (i. e., the beam travels through the region as opposed to being reflected, which is termed an overdense condition) to simulate SPS heating have been attempted. Recent experiments[12] suggest that ionospheric irregularities can be created when the Platteville heater operates in an underdense mode and that these irregularities induce scintillations in very high frequency satellite-to-aircraft and satellite-to-ground transmission links. Further work would be required, however, to establish whether scintillations would occur if SPS heated the upper ionosphere. Presently, the theoretical scaling models that would extrapolate these results to SPS conditions in the F-region are very uncertain. In order to test these theories, the ground-based heating facilities will have to be upgraded

In sum, it appears that effects on telecommunications in the lower ionosphere would probably be negligible, but more study of the upper ionosphere effects is needed. By making the heating facilities more powerful, the following research can be conducted:

- Lower ionosphere: verify scaling theory; and test additional telecommunication systems (e. g., VHF, UHF, satellite-to-ground)
- Upper ionosphere: refine and verify F-region scaling laws and ionospheric physics and then test effects on representative telecommunications systems for SPS equivalent heating.

Lasers

The most significant potential environmental effects associated with the SPS laser system appear to be local meteorological changes and beam spreading due to tropospheric heating.

Tropospheric heating would result from energy absorption by aerosols and molecules and from the dissipation of receptor waste heat. Attenuation by scattering from molecules and by absorption and scattering from aerosols would be greatest for short wavelengths. Thus scattering would be only significant for visible wavelength lasers, while aerosol effects become important to infrared lasers only under hazy or overcast conditions.

The absorption of laser energy would lead to a process called "thermal blooming, " in which a density gradient acts as a gaseous lens that

[10] *Environmental Assessment for the Satellite Power System – Concept Development and Evaluation Program – Effects of Ionospheric Heating on Telecommunications,* DOE/NASA report No DO E/ ER-10003-T1 , August 1980

[11] W E Gordon and L M Duncan, "Reviews of Space Science — SPS Impacts on the Upper Atmosphere, " *Astronautics and Aeronautics,* vol *18, No 7,8,* July/August 1980, p 46

[12] S Basu, A L. Johnson, J A Klobuchar, and C M Rush, "Preliminary Results of Scintillation Measurements Associated With Ionosphere Heating and Possible Implications for the Solar Power Satellite, " *Geophysical Research Letters,* vol *7, No 8,* August 1980, pp 609-612

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can spread, distort or bend the laser beam.[13] The severity of the thermal blooming would be a function of several parameters, including the frequency and intensity of the laser, the wind velocity, atmospheric density, absorption and altitude. Laser wavelengths that have high atmospheric transmittance would be less likely to suffer from thermal blooming. Thermal blooming could also degrade and spread the beam. It is clear that if spreading did occur it would be less critical for the space-to-Earth SPS beam than for Earth-to-space transmission (i.e., laser pilot beam) that would be deflected earlier in its path.

Tropospheric heating would be likely to induce meteorological alterations. It is unlikely that global climate changes could result since the absorption of laser energy would be less than the typical natural variations of the atmosphere; it would take the deployment of 200,000 to 400,000 laser systems before the global climate might be affected. " The potential local weather effects include changes in wind patterns, evaporation of sections of ground fogs and clouds and elevated temperatures. None of these effects are expected to exceed those associated with conventional nuclear powerplants of comparable power rating. '5 The most significant potential impact would be updrafts above the receptor site, which might induce cloud formations (a problem for the beam) and severe turbulence in the lower troposphere. Increased turbulence is not necessarily an adverse effect; the upward convective air movement would promote vertical mixing and the dispersal of waste heat. [16] However, the turbulence could present a hazard to aircraft that flew in the affected region. For this and other reasons, it has been suggested that aircraft be restricted from flying through transmission areas. [7]

The laser beam would be capable of boring holes through thin clouds and fog by evaporating the water from aerosol droplets. After passing through the beam, the cloud fog would recondense. Portions of noctilucent clouds in the mesosphere might also be vaporized. The possible environmental consequences, such as alteration of the continental cloud distribution or albedo, would be slight but research would still be needed.

Preliminary analysis indicates that the potential impacts in other atmospheric regions would be negligible. [18] In the stratosphere, ozone would not be affected for wavelengths greater than 1 micron. Possible perturbations of the plasma chemistry by the laser beam in the mesosphere and thermosphere are believed to be small and inconsequential, since the interactions would be confined to the laser beam volume; ionospheric heating would also be negligible. " However, research would be needed in order to validate this conclusion.

In the near term, environmental studies could concentrate on the following areas:

- Thermal blooming — increase theoretical understanding and refine models; investigate enhancement of thermal blooming by clouds; study transmission and thermal blooming as a function of laser frequency, time of year, and receptor altitude and location.
- Induced clouds–study the extent and consequences of induced clouding.

Reflected Light

The mirror system would reflect about 0.8 kW/m^2 of light to Earth, somewhat less than the illumination due to the Sun.[20] The primary atmospheric effect of this additional light would be tropospheric heating. Coupled with the sensible heat release at the energy conversion site, the weather might be measurably modified as convection, cloud formation, and

[13] R E Beverly, *Satellite Power Systems (SPS) Laser Studies, Technical Report–Laser Environmental Impact Study,* vol *1,* Rockwell International report No SSD 80-0119-1

"Ibid

[15] Ibid

"[bid

"Ibid.

'"t W Walbridge, *Laser Satellite Power Systems,* Argonne National Laboratory, ANL E S-92, January 1980

'"llt'k erly, op cit

[20] K W' Bi l l man, W P Gilbreath, and S W Bowen, " Solar Energy Economics Orbiting Reflectors tor World Energy, " in *How Big and Still Beautiful Macro-Engineering Revisited,* F P Davidson, et al (eds) (Boulder, Colo American Association for the Advancement of Science, Westview Press, 1980), pp 293-339

rainfall above the site are increased. While no assessment has been made of the magnitude or consequences of this potential impact, the weather effects of other "heat islands" of the same scale, such as New York City that releases about 0.6 kW/m^2 of heat, can be used for comparison. " Weather impacts on a global scale are not anticipated since the mirror system would add less than 0.015 percent to the normal solar heat input. 22 Large-scale computations on weather models applicable to the mirror system size are needed to quantify the effects for different locations. Additionally, the heating effects of the orbiting refiector system could be simulated on the ground, using solar heated ponds or other means without the need for a demonstration satellite and hence at a relatively low cost and at an early time. [23]

Once the potential weather impacts are more clearly understood, the system design and economics could be reevaluated to accommodate possible environmental concerns. For example, one might redesign the system to reflect less light to Earth or use heat dispersion devices on the ground and in space to reject the heat into areas that would have the minimal impact. Dichroic mirrors in space for example, could selectively reflect to Earth only those wavelength bands that would be converted with highest efficiency at the receiving site. It may also be found that the weather modification induced by the mirror system heat is actually beneficial to the receiving region by preventing cloud impingement over site.

In addition to tropospheric heating, other possible environmental impacts have been suggested. The mirror system beam might perturb the photochemistry of the atmosphere, particularly the ozone layer. However, preliminary analysis indicates that the effect would be negligible.[24] Further study is needed to confirm this finding and to investigate the potential photochemistry effects if dichroic mirrors were used in space. [25]

More detailed study is required before reasonable comparisons can be made between the mirror system and the other SPS technical options. Research priorities include:

- weather modeling and large-scale computations applicable to large mirror system size,
- the effects of dichroic mirrors on the system's environmental impacts, and
- possible ground-based experiments to simulate mirror system heating.

Space Vehicle Effects*

There are two major environmental effects associated with the space transportation segment of SPS: the injection of rocket exhaust products into the atmosphere (see fig. 32) and noise generated at the launch site (see Health and Ecology). The severity of these impacts would depend on the size and frequency of launches, as well as the composition of rocket fuels and flight trajectory.

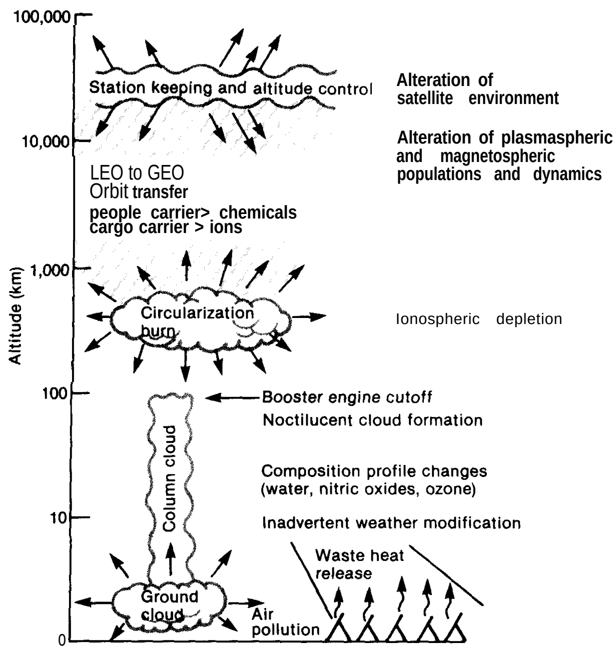
Assessment of the potential SPS effects on the atmosphere is hampered by the unprecedented scale of SPS transportation requirements as well as an incomplete understanding of the atmosphere. The reference design, for example, requires that a heavy lift launch vehicle (HLLV), five times larger than the Saturn V, be flown one to two times per day for 30 years.") The other reference system space vehicles and launch schedules are shown in tables 31 and 32.

The effects of SPS exhaust products on the atmosphere are also uncertain because much of our theory and experience with the effects of launch effluents stem from the space shuttle, which uses solid-fuel boosters. Since the SPS HLLV would be fueled with liquid propellants, the composition and distribution of the

[21] Kenneth Billman, EPRI, Private Communication
[22] K Billman, W P Gilbreath, S W Bowen, "Solar Energy Revisited With Orbiting Reflectors," NASA, Ames
[23] Billman, private communication
[24] Billman, Gilbreath, and Bowen, Solar Energy Economics, op cit

[25] Billman, private communication
* See app. D for details
[26] Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program, DOE ER-0069, August 1980

Figure 32.—Summary of SPS Atmospheric Effects



SOURCE: *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program, DOEI/R-0069,* August 1980.

reference system launch effluents would differ from that of the shuttle.

The major space vehicle impacts of the reference system are identified in table 33. Presently, the greatest uncertainties are associated with four potential effects[27] (treated in more detail in app. D):

- In the magnetosphere, the emission of ions from COTVS and POTVS would substantially increase the ambient concentrations of these particles. Because of our poor understanding of the complex dynamics and composition of this region, potential impacts can be identified, but the likelihood and severity of these effects are highly uncertain. Possible effects include enhancement of Van Allen belt radiation and changes in magnetospheric and plasm aspheric dynamics that could perturb ionospheric electricity, tropospheric weather, and satellite communicat ions.

[27] *Program Assessment Report, Statement of Findings,* op cit

Table 31 .—SPS Space Transportation Vehicles

Name	Function	Propellants	Launches[b] per year	Operating altitude (km)	Main exhaust products[c]
Heavy-lift launch vehicle (HLLV)	Transport material between Earth and LEO	CH_4/O_2 (stage 1) H_2/O_2 (stage 2) H_2/O_2 (circularization/deorbit)	375 375 375	0-57 57-120 450-500	CO_2, H_2O H_2O, H_2 H_2O, H_2
Personnel launch vehicle (PLV)	Transport personnel between Earth and LEO	Details not available (probably same as HLLV)	30	0-500	C_2, H_2O, H_2
Cargo orbit-transfer vehicle (COTV)	Transport materials between LEO and GEO	Argon H_2/O_2	30	500-35,800	Ar+ plasma H_2O, H_2
Personnel orbit-transfer vehicle (POTV)	Transport personnel between LEO and GEO	H_2/O_2	12	500-35,800	H_2O, H_2

[a] CH_4/O_2: liquid methane/liquid oxygen H_2/O_2: liquid hydrogen/liquid oxygen.
[b] Assuming construction of two (silicon option) 5-GW satellites/year.
[c] CO_2: carbon dioxide H_2O: water H_2: hydrogen Ar + : argon ion.

SOURCE: *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program, DOE/ER-0069,* August 1980,

Table 32.—Exhaust Products of SPS Space Transportation Vehicles[a]

Atmospheric region	Altitude range (km)	Source[b]	Total mass (t)[c]	Mass of specific emission products (t)				
				CO_2	CO	H_2O	H_2	Ar +
Troposphere	0-0.5	HLLV, PLV	650-	260	117	260	13	—
	0.5-13	HLLV, PLV	2850	1140	513	1140	57	—
Stratosphere	13-50	HLLV, PLV	3027	1210	546	1210	61	—
Mesosphere	50-80	HLLV, PLV	758	199	90	450	19	—
Thermosphere	80-125	HLLV, PLV	2031	—	—	1960	71	—
	LEO[d]	HLLV, PLV	33	—	.	443	1	—
	LEO	POTV	460	—	—	443	11	—
Exosphere	GEO[d]	POTV	153	—	—	147	6	—
	477-GE0	COTV[e]	985	—	—	0	0	985[f]

[a] Mass emissions per flight.
[b] PLV emissions would be chemically similar to those of the HLLV, but are not Otherwise determined at this time. The numbers shown are emissions Of the HLLV only
[c] t = metric ton = 1000 kg.
[d] Low earth orbit (LEO) is at 477 km; geosynchronous earth orbit (GEO) is at 35,800 km.
[e] In additio_n t. mass emissions, th_e argon plasma engines of the COTV would inject a significant amount of energy into this altitude range. Also argon plasma engines would be used for satellite attitude control and stationkeeping control at GEO; these em issions are unknown at present and have not been included.
[f] Ar + mass for the silicon photovoltaic cell option. For the gallium aluminum arsenide option, the Ar + mass would be 212 t.

SOURCE: *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program*, DOE/ER-0069, August 1980.

Table 33.—Space Vehicle Impacts

Troposphere
- Ground cloud nuclei and heat could have a measurable effect on weather
- NO_x emissions are small compared to typical powerplant, but in conjunction with ambient concentration could exceed projected EPA standards

Stratosphere and Mesosphere
- [a]Emission of water vapor may cause noctilucent clouds in the mesosphere; climatic effects would probably be small, but uncertain
- [a]Water and NO_x are not expected to significantly alter ozone, but uncertainties remain

Ionosphere
- [a]Formation of large ionospheric hole in F-region from water and other effluents should not adversely affect HF telecommunication signals over distances significantly larger than the ionospheric depletion, impacts on other telecommunications systems are not known; more studies are needed; long-term depletion around launch trajectory possible
- [a]D&E region effects are poorly understood; impacts on telecommunications from depletion of the ionosphere are possible
- Possibility of enhanced airglow and Perturbation of Van Allen belts, but likelihood is-unknown'

Thermosphere and Exosphere
- [a]Large increase **in water content might alter the natural hydrogen cycle and affect the dynamics of the region**

Plasmasphere and Magnetosphere
- [a]Argon ions and hydrogen atoms might enhance Van Allen belt radiation, generate ionospheric electric currents that would interfere with public utilities, modify auroral response to solar activity and affect weather and satellite communications, but probability and severity are unknown
- The effects of the satellite structures are thought to be negligible or easily remedied

[a]**Research priorities.**
SOURCE: Office of Technology Assessment

- **The injection of water vapor in the upper atmosphere would significantly increase the water content relative to natural levels. One possible consequence is an increase in the upward flux of hydrogen atoms through the thermosphere. If an accumulation of hydrogen results, the dynamics of the thermosphere and exosphere could be affected. Satellite drag could also be increased. Models of the natural hydrogen cycle are needed to quantify and simulate the effects of SPS on global scale.**
- **The injection of rocket exhaust, particularly water vapor, into the ionosphere could lead to the depletion of large areas of the ionosphere. These "ionospheric holes" could degrade telecommunication systems. While the uncertainties are greatest for the lower ionosphere, experiments are needed to test more adequately telecommunications impacts and to improve the theoretical understanding of chemical-electrical interact ions throughout the ionosphere.**
- **Another consequence of increasing the concentration of water in the upper atmosphere might be the formation of noctilucent clouds in the mesosphere. While global climatic effects of these clouds are thought unlikely, uncertainties remain, especially with respect to the persistence**

of the clouds as a function of temperature.

The transportation system for other SPS options could be substantially different from that for the reference system. For example, the mirror system and the bulk of the laser system satellites operate in low-Earth orbit (LEO). The magnetospheric effects associated with transporting materials to geostationary orbit (CEO) would therefore not be a problem for these systems. Environmental impacts are also determined by the frequency of launches, which depends on the size of the vehicle, and the total mass in orbit. For the same size launch vehicle and total system power, it appears that the mirror system, which is the least massive per kilowatt of the four alternatives, would require the least number of flights, whereas the laser system would require the most.

Other transportation scenarios have been proposed (see ch. 5). With respect to the reference system, some of the environmental effects could be mitigated by changing the flight trajectory of the HLLV, the rocket fuel of the COTV or other transportation characteristics that present a problem. Laser propulsion, for example, has been suggested as an option. The tradeoffs associated with these design changes would need to be studied as the SPS concept evolved.

As an alternative to the HLLV, it has been argued that economies of scale result from increasing the number and frequency of launches of a vehicle much smaller than the proposed HLLV.[28] However, it is not clear how the effects of more launches of a smaller rocket compare to the impacts of fewer flights of a larger one.

A very different approach in the construction of SPS would be the utilization of nonterrestrial materials. This could significantly reduce the amount of terrestrial materials that need to be transported to space, and hence reduce the environmental impacts associated with the frequent launch of transport vehicles.[29] While the economics and technical feasibility of this concept have been evaluated, the possible environmental impacts have not been studied and require consideration

Electromagnetic Interference

Each SPS transmission option, whether microwave, laser, or mirror, has the potential for affecting other users of the electromagnetic spectrum. In general, where such effects occur they will be detrimental to one user or another, since most systems now depend on the relative purity of the wavelength band they use.

Sharing the same air or ground space is possible by operating at different frequencies and at specified power levels. This is most obvious for radio frequencies, where the frequency band width and power levels at which systems can operate are assigned by national agencies working in accord with national and international standards. Where potential for interference occurs in the radio frequency spectrum, the power level and antenna characteristics of such interference are strictly regulated in order to keep it below the available technology's ability to filter out undesirable effects. The principle is to assure that electronic systems are compatible with one another, i.e., that interference from one system does not degrade the overall performance of a second.

Because of the large amounts of power that the microwave, laser, or mirror SPS systems transmit through the atmosphere, and the extensive area covered by a full satellite deployment, potential interference effects would be much greater than any other system which now use the electromagnetic spectrum. They would also be commensurately more difficult to ameliorate. Affected parties would include users of space and terrestrial communications and sensor systems, radar systems, various terrestrial control devices, computers, radar and radio telescopes, optical telescopes, and

[28] D L Akins, "Optimization of Space Manufacturing Systems," in *Space Manufacturing From Non- Terrestrial Materials*, J Grey and C Krop (eds) (New York AIAA, November 1979)

[29] J Grey, *Satellite Power System Technical Options and Economics*, contractor report prepared for OTA, Nov 14, 1979

microprocessors. SPS systems using microwaves for power transmission would generate the greatest potential interference because communications systems and passive receivers of all sorts share this portion of the spectrum, as well as other electronic equipment (e. g., computers, control devices, sensors) that are susceptible to microwave energy. The reference system is designed to transmit at 2.45 GHz, the center of the Industrial, Scientific, and Medical band (ISM).

This analysis focuses on the affected users on an area-by-area basis. It is based on the presumed characteristics of the three transmission options of table 34. However, it should be emphasized, that the precise characteristics of the transmission beams are as uncertain as other details of the proposed alternative systems. Not only are the characteristics of the systems and their components poorly known, the theory is inadequate to extend known data to other frequencies, angles, or distances. Nevertheless, it is possible in most cases to indicate broadly the sources of potential interference and their effects on other users of the spectrum.

Potential Affected Users of the Electromagnetic Spectrum

SPACE COMMUNICATIONS

All artificial Earth satellites use some portion of the electromagnetic spectrum, either for communication, remote-sensing or telemetering data. All would be affected in some way by the SPS.

- *Geostationary satellites.* These would be most strongly affected by the microwave systems. They would experience microwave interference from the fundamental SPS frequency (e.g., 2.45 GHz for the reference design) and noise side bands, spurious emissions in nearby bands, harmonics of the fundamental SPS frequency, and from so-called intermodulation products. All radio frequency transmitters generate harmonics and minor spurious components in addition to the desired signals. The unintentional outputs are filtered to satisfy national and international regulations about compatibility with other spectrum users. Receivers also generally include sufficient filtering to prevent degradation by the residual undesired signals. However, the magnitude of the power level at the central frequency and in harmonic frequencies for a microwave SPS would be so great that the possibility of degrading the performance of CEO and LEO satellite receivers is significant. Examples of serious interference include the 2.50 to 2.69 GHz direct broadcast satellite band, the 7.3 to 7.45 GHz space-Earth government frequency slot,[10] and the S-band National Aeronautics and Space Administration (NASA) space communications channel.

In addition to the direct effects from microwave power transmissions, geostationary communications satellites may experience "multipath interference" from geostationary power satellites due to the latter's sheer size. In some cases, microwave signals traveling in a straight line between two communications satellites would experience interference from the same signal reflected from the surface of the power satellite lying between them. Communications satellite uplink channels would be degraded by multi path interference from the SPS vehicle during orbit periods when the SPS is at a lower altitude than the adjacent communications satellites.

These adverse effects would necessitate a limit on the spacing that a geostationary satellite must have from a power satellite in order to operate effectively. The minimum necessary spacing would depend directly on the physical design of the satellite, the wavelength at which it operates, the type of transmission device used (i.e., klystron, magnetron, solid-state device), and the satellite antenna sidelobe magnitudes, transmitted power, orbit perturbations, and intermodulation product frequency distribution and amplitudes.

Because a microwave SPS as currently configured must share the geostationary orbit with other satellites, the value of the minimum

[10] John R Juroshek, "The SPS Interference Problem – Electronic System Effects and Mitigation Techniques, " *The Final Proceedings of the Solar Power Satellite Program Review,* Conf 800491 (DOE), pp 411-438

Table 34.—Summary of Electromagnetic Effects

System	Spectral region	Affected systems	Mechanism/effect
Microwave			
	Microwave		
	• Power radiation at central frequency (2.45 GHz or some other choice)	Terrestrial	Scatter in atmosphere, from rectenna
		LEO satellites	Pass through SPS beams
		Radio astonomy receivers	Scatter from rectennas, atmosphere
		Deep space communications	Direct interference
	• Harmonics of central frequency	GEO satellites	Direct interference
		Radio astonomy receivers	Direct interference
	• Spurious noise near central	GEO satellites	Direct interference
		Radio astronomy receivers	Scatter from rectennas
	• M u l i path interference	GEO satellites	Two-beam interference
	Infrared		
	• Thermal radiation from all satellite components	Radio astronomy receivers	Direct interference (raised background). Satellite appears as spurious source
		Infrared astronomy receivers	Satellite appears as spurious source
	All wavelengths (reflected sunlight)		
	• Diffuse reflections		
	• Specular reflections	Optical telescopes	Sky background increased.
	Ž Glints		Portions of sky obscured.
Laser			
	Microwave		
	• **No** discernible effect	None	
	Infrared		
	• Central beam radiation	Infrared receivers near terrestrial receiver	
	. Thermal radiation from all components	Radio astonomy receivers	Direct interference (raised background). Satellite appears as spurious source
	All wavelengths (reflected sun/ight)		
	• Diffuse reflections	Optical telescopes	
	• Glints	Probably no effect	
Mirrors			
	Microwave		
	• No discernible effect	None	
	Infrared		
	• Thermal radiation from all components	Radio astonomy receivers	Direct interference (raised background). Satellite as spurious source
	All wavelengths (reflected radiation)		
	• Specular reflection to terrestrial station	Optical telescopes near terrestrial station	General sky brightening
	• Diffuse reflection	Optical astronomy	Sky background obscured around satellite
	• Glints from structural components	Effect probably small	

SOURCE: Office of Technology Assessment

necessary spacing has emerged as one of the most critical issues facing a geostationary SPS. However, in the absence of a specific design, it is impossible to characterize the exact form and nature of the potential interference parameters that are needed in order to calculate the minimum required spacing. In addition, even if the design parameters were known accurately, the theory of phased arrays is insufficiently developed at present to predict the minimum spacing with any accuracy. Estimates range from ½° to 1°.[31] The lower limit would probably be acceptable. However, a minimum spacing much greater than 10 would, result in too few available geostationary slots to allow both types of users to share the orbit over the continental United States.

In 1980, some 80 civilian satellites shared the geostationary orbit worldwide, and by 1990 that number is expected to increase substantially. Even though improvements in technology will lead to a reduction in the total number of satellites necessary to carry the same volume of telecommunications services, total service demand is expected to rise dramatically. At present the minimum spacing for domestic geostationary satellites is 40 in the 6/4 GHz communication band and 30 in the 14/12 GHz band. At these spacings, a total of 90 6/4 GHz band satellites and 120 14/12 GHz band satellites could theoretically coexist at geostationary altitudes, in the absence of SPS. Additional satellites could use other frequency bands without interfering with the above satellites, though this would ultimately be limited by the station-keeping capability of the various satellites. Multiple use platforms represent one possible option to reduce contention over orbital spaces.

The laser and mirror systems in LEO would not interfere substantially with geostationary satellites. Even in the unlikely event that such a satellite were to pass precisely between a geostationary satellite and its ground station, the time of passage as well as the apparent size of the occluding power satellite would be so small as to cause only a slight diminution of the signal.

- *Other satellites.* In addition to geostationary satellites that would operate at the same altitude as the GEO SPS, there are numerous remote sensing, communications, and navigation satellites in various LEOs that may pass through an SPS microwave beam. Proposed high-Earth orbit (HEO) satellites would also be affected because of shadowing in the path from orbit to terrestrial station by the large SPS vehicles, and receiver interference thresholds that could be exceeded by the unintentional emissions from the SPS platforms. They use a range of optical and microwave sensors, particle detectors, computers, and communication devices. Although the optical sensors are not damaged by a microwave beam, increased device noise can result in microwave interference in related parts of the satellite. " A number of shielding and filtering techniques are available to ameliorate potential interference. These would need to be tested for specific satellite and deployment scenarios. Such satellites could protect their uplink communications receivers from adverse interference by shutting down for that short period (a few seconds) during SPS power beam traversal, or it might be feasible for the SPS to shut down for the satellite passage. " For short-term SPS shutdown, high-capacity battery storage would have to be Included in the ground segment (see ch. 9, sec B). This shutdown presents a severe control problem (reduce power, start up again), as well as serious network load transfer complexities. It may also be possible for some satellites to fly orbits that would not intersect the SPS beam. For example, satellites traveling in an equatorial orbit at altitudes lower than 1,000 km would not intersect SPS beams directed to rectennas at 350 latitude or greater. Computer and processing/control circuit functions can be protected by improved module shielding and interconnection noise filtering.

The laser and mirror systems might interfere with nongeostationary satellites by causing reflected sunlight to blind their optical sensors or by occluding communications beams. Of the two systems, the mirror system would be

[31] E Morrison, et al , *SPS Effects on LEO and GEO Satellites,* NTIA publication (in press)

[32] W B Grant, E L Morrison, J r , and K C Davis, "The EMC Impact of SPS Operations on Low Earth Orbit Satellites, " *The Final Proceedings of the Solar Power Satellite Program Review,* Conf-800491(DOE), pp 411-434

[33] P K Chapman, "Encounters Between SPS Power Beams and Satellites in Lower Orbits, " *The Final Proceedings of the Solar Power Satellite Program Review,* Conf -&100491 (DC) E), pp 428-430

most problematic because of the large size of the mirrors and their orbital speed. To date, no one has calculated the possible adverse effects due to this cause.

- Deep space communications. Because deep space probes generally travel in the plane of the solar system (known as the ecliptic), they would be especially affected by a geostationary microwave SPS. As seen from the Earth, the ecliptic crosses the Equator in two places. A microwave SPS would effectively prevent ground communication with the probe when the latter happens to lie near the part of the ecliptic that crosses the Equator. This interference is especially serious for deep space vehicles because it is essential to be able to communicate with them at any time for the purposes of orbit control and for timely retrieval of stored data. The susceptibility problem is more serious than normal satellite communications links because of receiver sensitivities and the low signal-noise ratios imposed by the long distances from Earth station to probe.

It would be possible to avoid such interference by establishing a communications base for deep space probes in orbit. As we penetrate deeper into space, this may be advisable for other reasons. Such a communications station would effectively add to the cost of the SPS.

TERRESTRIAL TELECOMMUNICATIONS AND ELECTRONICS

Both civilian and military terrestrial telecommunications and electronic equipment would suffer from a number of possible effects of a microwave beam. Direct interference can occur from the central frequency and harmonic emissions. In addition, scattered and reflected radiation from the rectenna and structure intermodulation products could cause additional interference problems for terrestrial receivers. At the very least, rectennas would have to be located far enough from critical sites such as airports, nuclear powerplants, and military bases to render potential interference as small as possible. In addition, most equipment would have to be modified to permit far better rejection of unwanted signals than is now necessary. This appears to be technically feasible; primary concerns would be modifications to the shielding of sensitive circuitry. The initial estimate of the cost of modifying terrestrial electronic equipment is in the range of 0.1 to 5 percent of the unit cost (approximately $130 million for the 1980 estimate of the inventory of susceptible equipment).

The EMC evaluation program determined that most terrestrial electronic equipment would be unacceptably degraded by SPS interference for power levels possible within a 50- to 75-km distance of a rectenna site. The most sensitive equipment, such as high capacity satellite terminals and radio astronomy receivers would be adversely affected at distances of 100 to 200 km.

Mitigation techniques have been evaluated for radars, computers and processors, sensors, and multichannel terrestrial microwave communications. With the exception of the most sensitive receivers, modifying shielding and grounding procedures and using rejection filters in radar and communications receivers would allow most systems to operate with the SPS interference levels expected at the rectenna site boundary. Special mitigation techniques for more sensitive systems involving interference cancellation methods have been considered, but they must be tested to determine the range of protection possible.

EFFECT ON TERRESTRIAL ASTRONOMY AND AERONOMY

None of the proposed SPS systems could benefit astronomical research except insofar as they would indirectly provide a transportation system for placing large astronomical facilities in space. Their detrimental effects would vary depending on the system chosen. The impacts of a microwave system would likely be severe for both optical and

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[34] E Morrison, "SPS Susceptible Systems Cost Factors – Invest-111 ent Summary and Mitigation Cost Increment Estimates," in press

[35] P A t kstron and G M Stokes, "Workshop on Satellite Power Systems (SPS) Effects on Optical and Radio Astronomy," (ont 7')05141 (DOE)

radio astronomy. An infrared laser system[36] would have fewer detrimental effects on both forms of astronomy than the reference system. The mirror system would have its most serious effect on optical astronomy.

- *Optical astronorny.* For the reference system, diffuse reflections from the satellite structures would cause the greatest degradation for terrestrial telescopes. Because they appear to remain stationary along the celestial Equator, reflected light from a system of 15 to 60 satellites would meld together to block observation of faint objects over a large portion of the sky near the Equator for telescopes located between the longitude limits of the satellites. Some major foreign, as well as most domestic observatories would be affected. Observations of bright objects would be possible, but degraded in quality. In addition, reflected light from the LEO construction base could be expected to interfere with observations of faint sources in its vicinity. Telescopes in orbit, such as the U.S. Space Telescope, to be launched in 1984, will travel in nonequatorial orbits and therefore would not be affected significantly by a reference system SPS. The danger of pointing directly at a geostationary satellite will increase the complexity of the telescope-pointing mechanism. Astronomical photometry and spectrometry instrumentation, and high resolution telescope tracking systems would be degraded if located within 50 to 60 km of a rectenna site. The EMC evaluation program indicated the necessity of improving sensor and sensitive circuit shielding, and maintaining a minimum separation distance of 50 to 60 km between rectenna sites and telescopes using sensitive electronics to remove SPS induced degradation.

  The effect of diffuse reflections from a laser SPS in LEO could be expected to cause fewer problems for observations of diffuse objects near the Equator because the laser collection and transmission satellite would be constantly in motion. Thus, no part of the sky would be permanently blocked from view. The relay satellites located in CEO would not be likely to interfere with optical observations. However, large moving satellites would present optical astronomy with another observational obstacle. Scattered light from them would vary in intensity as the satellite passes near a celestial object of interest, making calibration of the nearby background radiation very difficult if not impossible. Photographic exposures of faint celestial objects may last from 1 to 3 hours and individual photographs cannot be added effectively. The laser satellite would interfere with infrared astronomy studies involving wavelengths adjacent to the transmission wavelength of the beam.

  The mirror system, which would involve a number of large, highly reflective moving mirrors in LEO, would have very serious effects on optical astronomy. While the precise effect has not been calculated, it would render a large area around the ground stations totally unacceptable for telescopic viewing. Because of diffuse reflections from the atmospheric dust and aerosols above the ground station, the individual mirrors would create moving patches of diffuse light that would preclude studies of faint objects that lie in the direction of the satellite paths.

- *Radio astronomy.* Radio astronomy would suffer two major adverse affects from microwave systems: 1) electromagnetic interference from the main PS beam, from harmonics, from scattered or reflected SPS signals, and from reradiated energy from rectennas; and 2) increasing the effective temperature of sky noise background, which has the effect of lowering the signal-to-noise ratio of the radio receivers. Studies of faint radio objects near the Equator would be rendered impossible. In addition, rectennas would have to be located more than 200 km from radio observatories and in terrain that would shield the observatories from reradiated microwave energy. Also of concern to radio astronomers is the possibility that expected failures of the klystron or other microwave emitting devices would result in spurious noise signals that would further disrupt radio astronomy reception.

[36] C Bain, *Potential of Laser for SPS Power Transmission,* SPS CDEP, October 1978

Neither the laser nor the mirror systems would contribute to the first effect. However, they would raise the effective temperature of the sky background. Low-level measurements such as scientists now routinely conduct, for example, to measure the amount of background radiation from the primordial explosion of the universe would thus be extremely difficult if not impossible from terrestrial stations. Many other types of sensitive radio astronomy observations would be seriously degraded.

The susceptibility of radio astronomy receivers results from their high sensitivity, and the wide range of observing frequencies in the microwave spectral region. Mitigation techniques effective for other electronic equipment are only marginally useful because of the sensitivity factor and associated dynamic range. A preliminary review of interference canceling techniques indicates that this method has a high probability of providing rejection of SPS signals to a level that would allow rectenna sites to be located within a 100- to 150-km range from radio astronomy facilities. Detailed design and testing at a radio astronomy receiver is necessary because of the unique aspects of integrating a canceler function into such complicated and sensitive receivers.

Space basing of radio telescopes, especially on the far side of the Moon, would eliminate the impact of SPS and other terrestrial sources of electromagnetic interference. However, such proposals, though attractive from the standpoint of potential interference, are unlikely to be attractive to astronomers for many decades because of their high cost and relative inaccessibility.

- Optical aeronomy. Much of our knowledge of the upper atmosphere is gained by nighttime observations of faint, diffuse light. Some of the observations that are made today must be carried out in the dark of the Moon. The presence of satellites whose integrated brightness is equal to a quarter Moon would effectively end some studies of the faint airglow and aurora. Other observations would be severely limited in scope.

Terrestrial Activities

The terrestrial environment would be affected by SPS in a number of ways. The construction and operation of receivers could alter local weather, land use, and air and water quality. The mining, manufacturing, and transportation associated with SPS could also adversely affect the environment.[37]

Land Use and Receiver Siting

Land use and receiver siting are important issues for SPS, especially from a political perspective (see ch. 9, Issues Arising in the Public Arena).* This is due in part to the microwave and mirror system land requirements for large contiguous areas for receiving stations and transmission lines. In siting receivers, tradeoffs would have to be made between a number of parameters such as the topography and meteorology of the candidate locations, local population density, land and transmission line costs, electromagnetic interference, and electricity demand, as well as environmental impacts. The construction and operation of SPS receivers would have measurable effects on the ecology, soil, air and water quality, and weather of the receiver area.[38] Since many of these impacts are site-specific, an extensive program would have to be carried out in order to locate and assess each proposed site.

The severity and extent of the environmental impacts of SPS ground receivers and transmission lines would also depend on which SPS system is deployed. For example, as shown in table 7, the baseline mirror system (1) would deliver power to a few, extremely large sites, whereas the laser system might be designed to

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[37] *Satellite Power System, Concept Development and Evaluation Program,* reference system report, DOE/E R-0023, October 1978

*The majority of remarks made in this section pertain to land-based receiver sites as specified by the technical systems addressed in this report It is Important to note, however that off-shore receptor siting that may alleviate some of the problems associated with land-based s ites is a l so possible

[38] *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program,* DOE/E R-0069, August 1980

generate the same amount of power at a great number of sites, each of which is two to three orders of magnitude smaller than the mirror sites. Smaller mirror system (1 1) sites are also possible.

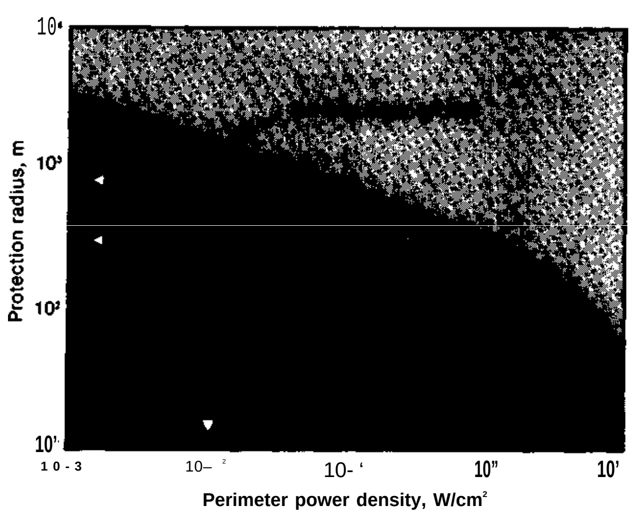
For safety purposes, buffer zones would be established around each site. For the laser design, the infrared power density at the edge of this zone would be 10 mW/cm² (see fig. 33). As shown in figure 34, the microwave power density at the edge of the reference system exclusion boundary would be 0.1 mW/cm². If microwave standards become considerably more stringent, SPS land requirements could increase. For example, if the power density at the edge could not exceed 0.01 mW/cm² (the Soviet standard), then each site would require almost 1,700 km² of land.[39]

In addition to land for receivers, about 20 to 850 km² would be needed for launch facilities.[40] This could be made available through expansion of the Kennedy Space Flight Center in Florida, although environmental considerations might preclude this option. Transmission line, mining, and transportation land uses are not considered in table 35. More analysis is needed to determine these impacts and to explore tradeoffs between centralized and dispersed electricity systems with respect to transmission line siting. In table 36, the SPS reference system is compared to other electricity powerplants.

[39] J B Blackburn, *Satellite Power System (SPS) Mapping of Exclusion Areas for Rectenna Sites*, DOE/NASA Report HCP/R-4024-10, October 1978

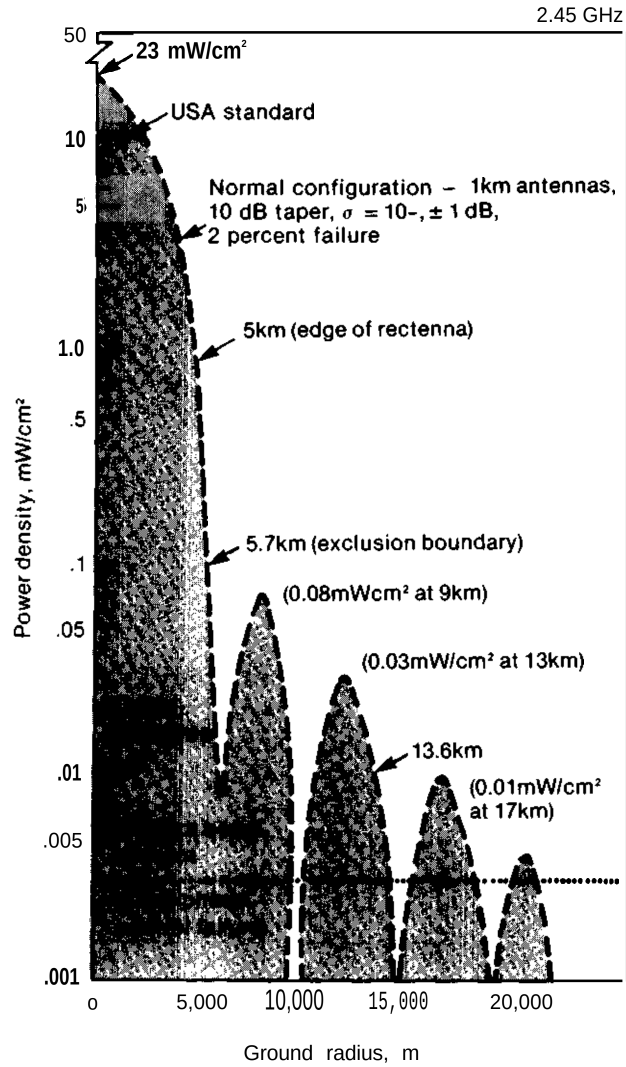
[40] Ibid

Figure 33.— Receptor Site Protection Radius as a Function of the Perimeter Laser Power-Density Level



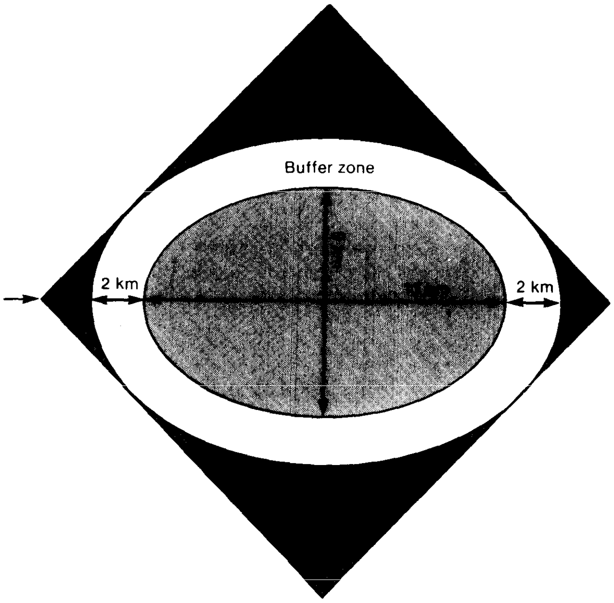
SOURCE: R. E. Beverly, *Satellite Power Systems (SPS) Laser Studies, Technical Report—Laser Environmental Impact Study*, vol. 1, Rockwell International report, SSD 80-0119-1.

Figure 34.—Microwave Power Density at Rectenna as a Function of Distance From Boresight



SOURCE Satellite *Power System, Concept Development and Evaluation Program*, reference system report, DOE/ER-0023, October 1978.

Figure 35.—Rectenna/Washington, D.C. Overlay



Washington , D C

SOURCE: Office of Technology Assessment.

Some of the environmental, societal and institutional problems associated with land-use and receiver siting might be remedied by siting receivers in shallow offshore waters. For some land-scarce areas such as New England and Europe, this concept is particularly desirable. The taper of the solid-state power-transmission system makes offshore siting particularly attractive. A few preliminary technical studies have been conducted," including an offshore rectenna siting study,[42] (see fig. 36). However, little attention has been paid to the environmental ramifications of offshore siting. Areas of special concern include the effects on weather and ecosystems from thermal release and the effects of microwaves on aquatic life and birds that might be attracted to the receiver

Land-use problems might also be alleviated by innovative receiver designs that would permit multiple land use under the receivers, such as crop agriculture, biomass production and aquaculture.43 Again, however, until the biological effects of microwaves and reflected sun light are better understood, the environmental impacts and hence viability of these ideas are largely unknown.

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[4] J Freeman, et al , *Solar Power Satellite Of fshore Rectenna Study*, contract report No **NAS 8-33023,** prepared for Marshall SpaceFlight (-enter, May 1980

[4] *Satellite Power System (SPS) Rectenna Siting A vailability and Distribution of Nor-n inally Eligible Sites,* DC) E/E R-10041-TI O, November 1980

[4] Grey, op cit

Table 35.—SPS Systems Land Use

SPS system	km^2/site	km^2/1,000MW	Number of sites for 300,000 MW	Total land area (km^2) for 300,000 MW	m^2/MW-yr[a]
Reference	174.0	35.0	60	10,400.0	1,280
Solid state[c]	50.0	33.0	180	9,000.0	1,230
Laser I[d].	0.6	1.2	600	360.0	44-35[e]
Laser II[f].	40.0	80.0	600	24,000.0	2,960-3,550[e]
Mirror If	1,000.0	7.4	- '29	2,200.0	274-329[e]
For **comparison**					
Washington.	174.0				
New York City.	950.0				
Chicago.	518.0				

a These units are presented for comparison with table 36. The values for the reference and solid-state designs assume a 30-year lifetime and a capacity factor Of 0.9.
b Rectenna at 34O latitude covers a 9km x 13km (117km²) elliptical area, Microwave power density of edge of rectenna is 1.0 mW/cm². If an exclusion boundary is set at 0.1 mW/cm², then the total land per site is approximately 174 km² (2 km extra on each side for buffer zone). J. B. Blackburn, *Sate//ire Power System (SPS) Mapping of Exclusion Areas for Rectenna Sites,* DOE/NASA report No. HCP/R-4024-10, October 1978, Does not include land for mining or fuel transport.
C The solid-state sandwich design is described in J. Grey, *Satellite Power System Technical Options and Economics,* contractor report prepared fOr OTA, Nov. 14, 1979.
d Laser I and Laser II are two laser systems considered by DOE. Both deliver the same amount of power but the beam of Laser I is more narrow (and hence more intenSe) than that of Laser II. See C. Bain, *Potential of Laser for SPS Power Transmission,* SPS CDEP, October 1978.
e The values for the laser and mirror systems assume a 30-year lifetime and Capacity factors of 0.75-09
f Mirror system parameters are defined by SOLARES System as described in K. Billman. W P Gilbreath, S. W. Bowen, "Solar Energy Revisited With Orbiting Reflectors," NASA, Ames,
g The SO LARES system is designed to deliver 810 GW to 6 sites; 2 SOLARES sites actually provide 270 GW.

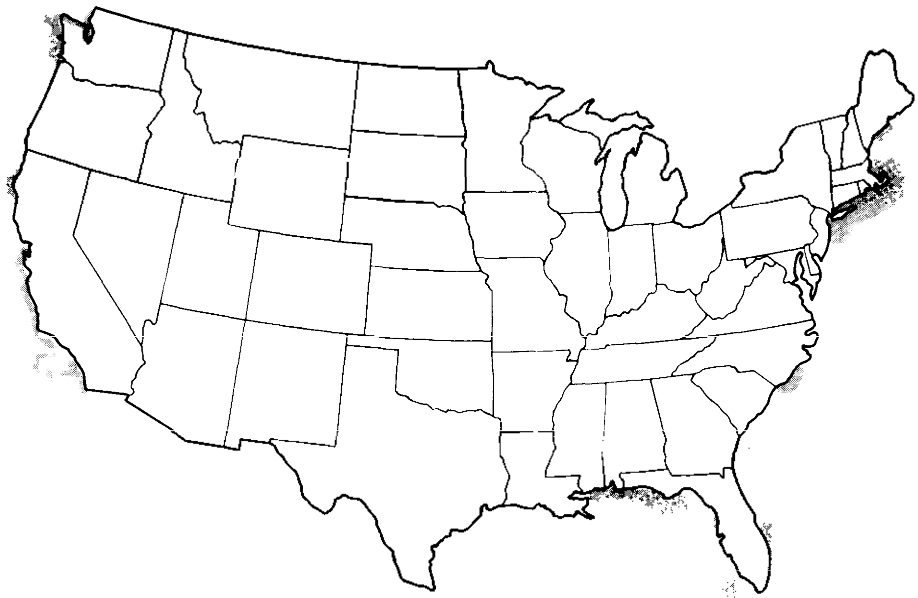
Table 36.—Summary of Land Requirements

Purpose	Construction	Plant	Fuel	Disposal	Transmission
CG/CC					
Quantity	—a	7.2-150 m^2/MW-yr	1,800-4,520 m^2/MW-yr	5 m^2/MW-yr	**300** m^2/MW-yr (480 km)[b]
Duration	—c	30 yr	30 yr	—c	30 yr
Location	—c	—c	—c	—c	—c
FBC					
Quantity	—a	5.2-16.8 m^2/MW-yr	—c	1.4 m^2/MW-yr	**300** m^2/MW-yr (assume same as combined cycle)
Duration	—c	30 yr	—c	—c	30 yr
Location	—c	—c	—c	—c	—c
LWR					
Quantity	—a	57-174 m^2/MW-yr	31 m^2/MW-yr	4 m^2/MW-yr	225-1000 m^2/MW-yr (480-1600 km)[b]
Duration	—c	**30-40** yrs (20 m^2/MW-yr "permanent")	30 yr	10^6 years	30-40 yrs
Location	—c	—c	—c	—c	—c
LMFBR					
Quantity	—a	76-133 m^2/MW-yr	**5** m^2/MW-yr (plant life-time) and .25 m^2/MW-yr (permanent)	—c	200 m^2/MW-yr (80 km)[b]
Duration	—c	30 yr	—c	—c	30 yr
Location	—c	—c	—c	—c	—c
TPV					
Quantity	—a	600-3,800 m^2/MW-yr (depending on cell efficiency and capacity factor)	negl[d]	negl[d]	300-3,000 m^2/MW-yr (480-4,800 km)[b]
Duration	—c	30 yr	NA[e]	NA[e]	30 yr
Location	—c	Southwest	NA	NA	—c
STE					
Quantity	—a	2,260-6,650 m^2/MW-yr	negl[d]	negl[d]	300-3,000 m^2/MW-yr 480-4,800 km)[b]
Duration	—c	30 yr	NA	NA	30 yr
Location	—c	Southwest	NA	NA	—c
OTEC					
Quantity	—a	negl	negl[d]	negl[d]	**300** m^2/MW-yr (480 km)[b]
Duration	—c	NA[e]	NA[e]	NA[e]	30 yr
Location	—c	NA[e]	NA	NA	—c
SPS					
Quantity	20-850 km^2 (launch)	1,480 m^2/MW-yr[g] (rectenna)[f]	negl[d]	negl[d]	300-1,000 m^2/MW-yr (480-1,600 km)[b]
Duration	30 yr	30 yr	NA[e]	**NA[e]**	30 yr
Location	Florida?	—c	NA	NA	—c

aApproximately the sum of plant and transmission requirements.
bDistance to load center.
cData lacking; some categories are discussed in text
dNegligible.
eNA-Not applicable
fIncludes buffer zone, rectenna proper occupies about 50% of total.
gAssumes 200 km^2 per rectenna site.

SOURCE: D. E. Newsom and T. D. Wolsko, *Preliminary Comparative Assessment of Land Use for Satellite Power Systems and Alternative Electric Energy Technologies*, DOE/NASA report No. DOE/ER-0058, April 1980.

Figure 36.—Offshore Summary Map



Offshore siting study - dark areas are *not* eligible for rectenna siting

SOURCE: *Satellite Power System (SPS) Rectenna Siting Availability and Distribution of Nominally Eligible Sites*, DOE/ER-10O41-TIO, November 1980.

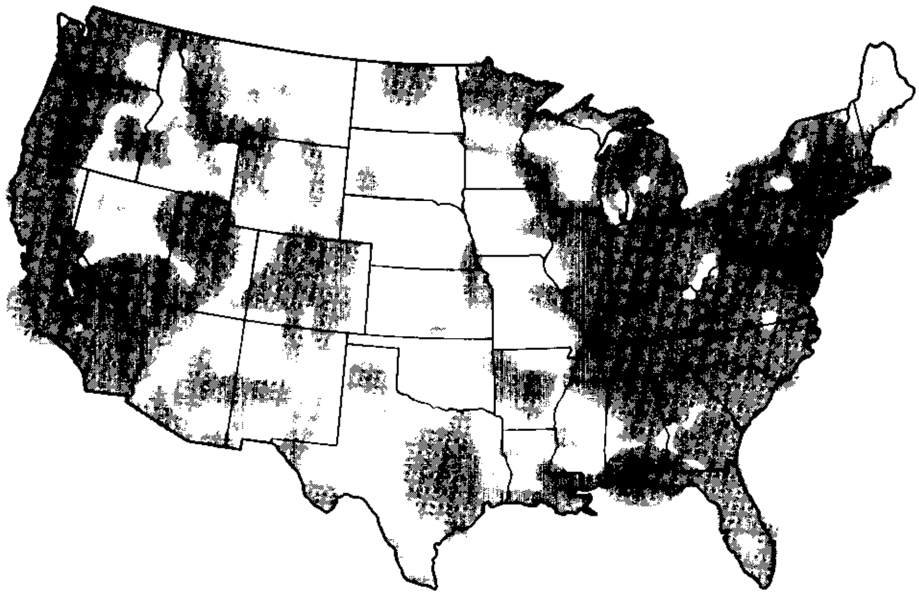
If SPS is to be deployed on a multinational scale, the siting constraints may be different from those in the United States. This is especially true with respect to microwave exposure standards, which in some countries are more stringent than in the United States (see Health and Ecology, Microwaves). The environmental standards of other nations and their effects on SPS siting requirements need to be explored in more detail.

A siting study for the continental United States has been conducted for the reference system to determine if 60 candidate sites can be found. " The United States was divided into grids, each approximately the size of a rectenna. Grid squares were eliminated from consideration if they violated a set of "absolute" exclusion variables that included inland waters, high population density areas, marshlands, military reservations, habitats of endangered species, National recreation areas, Atomic Energy Commission lands, and unacceptable topography. Sites were also excluded if they were found within a specified distance from military installations, nuclear powerplants and other facilities that might suffer from electromagnetic interference with the SPS microwave field.

In figure 37, ineligible grids were marked with an "x." In this first exercise 40 percent of the United States remained eligible. After the application of additional "potential" exclusion variables that were categorized as having an unknown or adverse, but potentially correctable impact (e. g., agricultural lands and flyways of migratory waterfowl), 17 percent of the United States remained eligible. In general, the greatest number of eligible sites was found in the West, Southwest, and in the northern regions of the Midwest; the least number of eligible sites occurred in the Mid-Atlantic States, where 3 to 10 percent of the land was eligible (31 to 83 grids, depending on the criteria for eligibility). The exclusion variables that had the greatest incremental effect in rendering land ineligible included topography, popula-

[44] J. B. Blackburn and B A Ballinger, "Satellite Power System Rectenna Siting Study, " in *The Final Proceedings of the Solar Power Satellite Program Review*, Apr 22-25, 1980, DOE/NASA report No Conf -800491, July 1980

Figure 37.—Satellite Power System—Societal Assessment



SOURCE: *Satellite Power Svstem (SPS) Rectenna Sitinq: Availability and Distribution of Nominally Eligible Sites,* DOE/ER-1OO41-TIO, November 1980.

tion and electromagnetic compatibility' (absolute variables) as well as private agricultural lands, flyways, and Federal dedicated and protected lands (potential variables).

The siting study also revealed an important point about the siting of smaller rectennas. Smaller site sizes could increase the likelihood that sites identified as eligible (in the first application of absolute exclusion variables) would remain so upon closer examination in a "validation" process. However, they would be unlikely to make previously excluded grid squares eligible. Therefore, it was concluded that smaller rectenna size (i. e., one-fourth or one-half the rectenna area) would not make a substantial difference in the siting process. 45

The effects of eliminating isolated sites were also considered on the assumption that local variations and the problems associated with public or private land acquisition would make siting more difficult in areas that did not contain a large number of adjacent eligible grid squares. By imposing the constraint that eligible sites had to fall within a 3 x 3 grid pattern, the amount of eligible sites dropped dramatically, especially in the Mid-Atlantic region and the Southeast. A less restrictive requirements of 2 x 2 grid patterns produces a considerably less drastic result.

The siting results (from the application of "absolute variables") were then correlated with the distribution of projected electrical demand.[46] Based on one projection of future electricity demand, it was concluded that the only potential site scarcity would occur in the Mid-Atlantic region (see fig. 38). In most other regions there would be about 100 times more eligible grids than "required" sites. Scarcity of large load centers relative to allocated rectennas could be a problem in sections of the Midwest and West.

A prototype environmental assessment was conducted for a rectenna site in the California desert (Rose Valley, 250-km north of Los

*This was also an important constraint for the siting of offshore rectennas

"Ibid

" A Kotin, "Relationship of Eligible Areas to Projected Electricity Demand, " in *The Final Proceedings of the Solar Power Satellite Program Review,* Apr 22-25, 1980, DOE/NASA report No Conf -800491", July 1980

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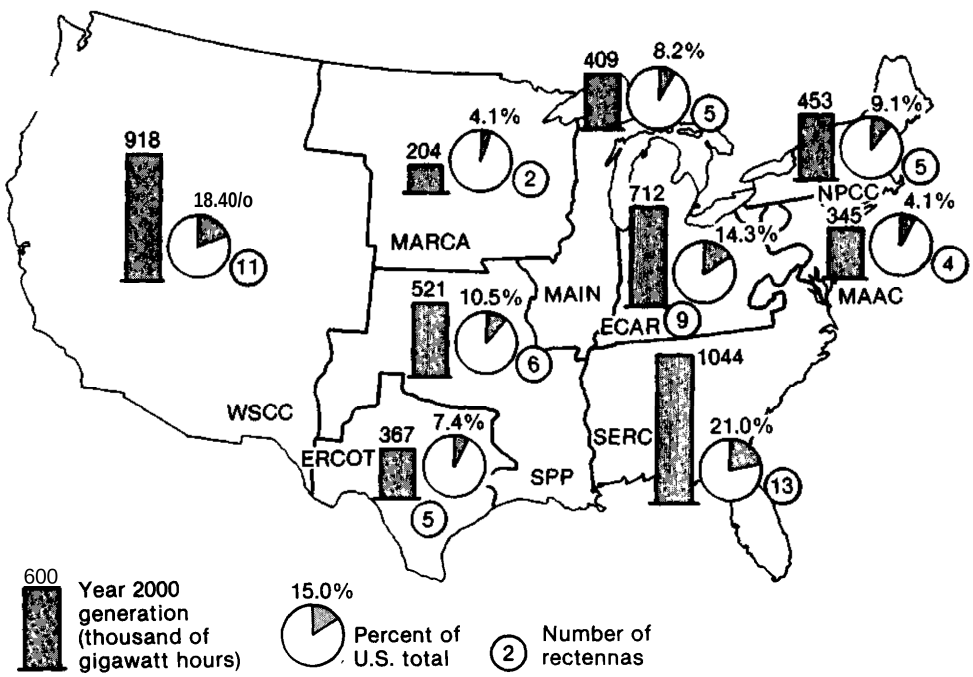
Figure 38.—Regional Generation (2000) and Rectenna Allocations



Note: This figure is based on the EIA Leap Series C (1978) protection of electricity in the year 2000 which assumes a 4 10/. electricity growth rate per year from 1977-1995. See chapter VI or discussion on alternative electricity growth rates

SOURCE. A. Kotin, "Relationship of Eligible Areas to Projected Elect ricity Demand," in *The Final Proceed/rigs of the Solar Power Satellite Program Review*. Apr 22-25, 1980, DOE/NASA report No conf -800491, July 1980

Angeles)." The major environmental impacts (excluding microwave effects) and possible solutions are summarized in table 37.

The assessment emphasized that large amounts of contiguous land area must be completely committed to the project, totally displacing existing land use and completely altering the existing natural environment. investigators also noted that after the site boundaries are selected, there is no flexibility in the siting of individual rectenna structures, so that areas particularly sensitive to SPS impacts could not be avoided. To alleviate adverse effects, they recommend that land areas much larger than the minimum requirements be located in the site selection process. In addition, the study recommends that: 1) rectenna panels be light and open to allow passage of sunlight and rain; 2) natural characteristics of the site be considered in the panel and diode/dipole design, e.g., taking account of possible attraction birds and rodents might have to the panels for resting or nesting; and 3) the design minimize the use of materials.

Finally, investigators note that the siting of receivers in the Southwestern United States will be especially hampered by land-use conflicts with other energy sources, archaeological sites and military programs. In particular it is pointed out that 15 percent of the California Conservation Area is reserved for defense purposes.

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[7] *Protot ype Environmental Assessment of the Impacts of Siting and Constructing a Satellite Power System (SPS) Ground Receiving Station (GRS)*, DOE/NASA report No DOE/E R-O072, August 1980

Table 37.—Summary of Environmental Impacts of Rectenna Construction and Operation at a Specific Study Site

Technical area	Rectenna construction	Rectenna operation	Mitigation
Air quality and climatology	. Probable standards violation for nitrogen oxides, particulate, and hydrocarbons. • No climatic impacts.	. No significant air quality impacts. • Unknown, but possibly significant microclimateic effects at or near ground surface	• Adequate dust suppression program during construction would mitigate particulate impacts. . Extending construction schedule would reduce emission peaks for hydrocarbons and nitrogen oxides. • Pending further research, project modifications might be needed for ground surface microclimate impact
Noise	• Substantially elevated noise levels, but in areas with low population density, • Possible impacts on noise-sensitive species.	. No significant impact.	• Improved noise control technology by construction time frame for vehicles, equipment, and processes would mitigate impacts. • During construction, noise-sensitive habitats should be avoided to maximum extent possible during breeding and nesting seasons.
Geology and soils	• Geologic impacts less important than geologic constraints. • Study area very active • seismically, but within normal range for southern California. • Soils impacts significant: large disturbed area, compaction, wind/water erosion. • Soils constraints: diversity of soils types implies variability in engineering properties (e.g., shrink/swell potential, corrosivity to metals/concrete).	• Seismicity has potential for facility destruction or loss of efficiency (alinement v. satellite). • Soil productivity impacted for project life: depends on extent and degree of construction—phase and ongoing operations disturbance.	. Thorough seismic and soils studies required as part of site-specific engineering. • Careful soil-stabilization/age/erosion-control programs required.
Hydrology and water quality	• Project requirements: 2-14 x $10^6 m^3$ (depends on dust suppression methods used). • Meeting project needs from groundwater would lower water table 0.2-1.5 m/yr; would reduce underflow to adjoining valley, could lower water level in nearby lake; might contaminate usable water through hydraulic connection with unusable ground water.	. Project requirements minor unless major revegetation program undertaken. Revegetation could require 27 x $10^6 m^3$/yr for 3 yr, that could cause water table drawdown.	• Careful soil stabilization/drainage/erosion-control program required. • Ground water withdrawal impacts could be alleviated by importing water from outside study area. • Proper sewage control program necessary during construct ion to prevent water quality degradation).

Table 37.—Summary of Environmental Impacts of Rectenna Construction and Operation at a Specific Study Site-Continued

Technical area	Rectenna construction	Rectenna operation	Mitigation
Flora	• Land disturbance would completely modify site's floral communities. • Possible indirect impacts on flora from hydrologic changes, air and water pollutants, and personnel activities • No endangered species present at Rose Valley/ Coso; one rare species present.	• Impacts similar to construction phase. • Microclimate changes at ground surface a key issue for severity and potential for mitigation of floral impacts.	• Reestablishment of preexisting flora problematic; major and difficult revegetation program required. • Careful placement of ancillary facilities necessary to minimize impacts on sensitive habitats. • Careful planning, design and construction/ operations practices necessary to minimize indirect impacts (e.g., water quality degradation).
Fauna	• Land disturbance would completely modify site faunal communities. • Possible indirect impacts on fauna from hydrologic changes, air and pollutants, personnel activities, and loss of feeding areas for nearby fauna. • Surface water sources for migratory water and land birds would be lost (Playas) and jeopardized (Little Lake). • One protected species (Mohave ground squirrel) found in Rose Valley.	• Impacts similar to construction phase. • Impacts closely related to flora impacts. • Microclimate changes at ground surface a key issue for severity and potential for mitigation of fauna impacts.	• Reestablishment of preexisting fauna problematic; closely linked to strategy and success of floral mitigation. • Careful placement of ancillary facilities needed to minimize impacts on sensitive habitats. • Careful planning, design, construction, O&M practices, and construction scheduling needed to avoid indirect impacts and to avoid sensitive habitats during breeding and nesting seasons.
Land use	• Total displacement of existing site uses (e. g., farming grazing, recreation). • Minor loss of mineral resources (cinder, pumice). • Minor indirect (growth-related impacts. • Potential land acquisitior/use conflicts with Navy (China Lake NWC), energy (geothermal), wilderness, archaeological resources, native American use and access to cultural and religious sites.	Same as construction phase	• Major impacts could not be mitigated. It might be possible to achieve joint use of rectenna sites but this remains speculative.

SOURCE: *Prototype Environmental Assessment of the Impacts of Siting and Constructing a Satellite Power System (SPS) Ground Receiving Station (GRS),* DOE/NASA report No. DOE/ER-0072, August 1980.

Receiver Structure: Weather Modification

Other DOE studies have investigated the potential of the rectenna for modifying local weather. They indicate that the surface roughness and albedo of the rectenna structure and the waste heat generated by rectenna operation (750 MW per site) would have a small, but detectable impact on regional weather and climate.[48,49] In particular, rectennas would perturb the average surface heat exchange by about 10 percent. SPS land-use changes could alter temperature (on the order of 10 C), cloud density and rainfall. However, it is important to note that these effects would be no greater than those attributable to other nonindustrial urban activities. For example, the waste heat generated by typical coal and nuclear plants range from 750 to 6,000 MW. The waste heat rejected at laser receptor sites, would also produce weather effects that would be less significant than those associated with nuclear plants of comparable power. 50

Resources

The construction and operation of SPS could strain supplies of some critical materials, as shown in table 38. The most serious problems arise for the solar cell materials (e. g., gallium, gallium arsenide, sapphire, and solar grade silicon) and the graphite fiber used for the satellite structure and space construction facilities of the reference system.[51] It appears that the silicon SPS systems pose less serious problems than the gallium arsenide option, but this may be due to the immature state of gallium arsenide technology. The most serious resource strain for the gallium arsenide system is gallium; for the silicon option, large amounts of electricity might be needed to produce the cells.

[48] *Environmental* Assessment for *the Satellite* Power *System* Concept Development and Evaluation Program, op cit.

"Proceedings of the Workshop on Meteorological Effects *of* Satellite Power System *Rectenna* Operation and Related Microwave Transmission *Problems,* Aug 23-25, 1978, DOE/NASA report No Conf -7808114, December 1979

[50] Basu, Johnson, Klobuchar, and Rush, op cit

[51] R R Teeter and W M Jamieson, *Preliminary Materials Assessment for the Satellite Power System (SPS),* DOE/NASA report No DOE/E R-0038, January 1980

Table 38.—Summary of Materials Assessment Results

Parameter	Percent supplied as byproduct	World production growth rate	SPS percent of demand	Net percent imported	Percent world resource consumption	cost $lkw
Threshold value[a]	50%	10%	100/0	50%	200%	$50/kw
Gallium	A	A	A	—	—	—
Graphite fiber	—	A	A	—	—	A
Sapphire	—	A	A	—	—	A
Silicon SEG	–	A	A	—	—	A
Gallium arsenide	—	A	A	—	—	A
Electricity	—	—	—	—	A	—
Arsenic/arsenic trioxide	B	—	—	B	—	—
Kapton	—	B	B	—	—	—
Oxygen (liq)	–	B	B	—	—	—
Silica fiber	—	B	B	—	—	—
Silver	B	—	—	B	—	—
Silver ore	—	—	—	B	B	—
Glass, borosilicate	—	—	B	—	—	—
Hydrogen (liq)	—	B	—	—	—	—
Mercury	—	—	—	B	—	—
Mercury ore	—	—	—	B	—	—
Methane	—	B	—	—	—	—
Petroleum	—	—	—	—	—	B
Steel	—	—	—	—	—	B
Tungsten	—	—	—	B	—	—

Note: "A" signifies problem of serious concern "B" signifies problem of possible concern.
[a] Parameter value above which a potential problem exists. Materials in this table exceeded these values where an "A" or "B" is recorded.

SOURCE: R. R. Teeter and W. M. Jamieson, *Preliminary Materials Assessment for the Satellite Power System (SPS),* DOE/NASA report No. DOE/ER-0038, January 1980.

Most of the resource constraints identified stem from limitations in production capacity rather than exhaustion of reserves. SPS could compete for graphite composite with the automobile industry and, depending on its time of introduction, with terrestrial photovoltaic technologies and the electronics industry for semiconductor materials. The demand by SPS for a few materials such as gallium, tungsten, and mercury could also increase U.S. dependence on foreign sources. Further analysis would be required to determine the severity of the resource limitations identified for the reference system and possible measures that would circumvent them.

While no assessment has been made of the material requirements for any of the other SPS technical options, a few observations can be made. The solar cell, graphite, and transportation materials that are problematic for the reference design might also be used in the three other options. The solid-state design calls for silicon or gallium arsenide devices in the transmitting antenna as well as in the solar collector. While the solid-state satellites would be smaller than the reference design, the solid-state material needs per unit energy would be greater. Therefore, if the reference design were to strain supplies of semiconductor materials, the solid-state variant most certainly would tax them as well (assuming that both systems deliver the same total amount of power and use the same materials). The laser and mirror systems would require slightly less photovoltaic material per kilowatt of delivered electricity than the reference system. The quality of the photovoltaics material used in the mirror design might be different than the reference materials however, since in the mirror system they would be placed on the ground. All of the systems would require graphite for structures, and fuels for space transportation. Further analysis is required in order to compare the material requirements of the alternative designs to the reference system. Moreover, the effect on SPS material requirements of using nonterrestrial materials (lunar soil contains aluminum, titanium, iron, silicon, and oxygen) and developing space processing and industrial capacity needs to be investigated.

Mining, Manufacturing, and Transportation

The minerals extraction, materials processing, manufacturing, and transport activities associated with SPS could result in a measurable increase in air and water pollution and sol id wastes.[52] For example, the potential environmental impacts of mining include water pollution from leaching and drainage modifications, air pollution from fugitive dust and land disturbance from strip mining, subsidence and spoil piles. Manufacturing would produce stack emissions, process effluents and solid wastes. In table 39, order-of-magnitude estimates have been made of some of the environmental impacts resulting from these reference system activities. The incremental domestic processing of materials required for SPS can also serve as a rough guide to increased pollution levels.

While these exercises help identify the potential scope and extent of environmental impacts, a thorough and quantitative assessment is presently lacking. However, it is anticipated that most impacts would be conventional in nature and could probably be minimized by methods currently used in industry[53] There is no information on similar effects

[52] *Prototype Environmental Assessment of the Impacts of Siting and Constructing a Satellite Power System (SPS) Ground Receiving Station (GRS)*, DOE NASA repot-t No DOE ER-0072, August 1980

[53] Ibid

Table 39.—Annual Environmental Effects of SPS[a] (mining, processing, manufacture, and ground-based construction)

Air pollutants	Percent U.S. total[c]
Particulate	**0.8%**
Sulfur dioxide	0.04
Carbon monoxide	0.05
Hydrocarbons	0.05
Nitrogen dioxide	0.005
Nonrecoverable water[d]	0.24
Solid waste[e]	**0.70**
Land requirements[f]	0.12

[a] Based on an earlier SPS design assumes two satellites and rectennas are built per year.
[b] From mining. processing and fabrication
[c] U. S totals in 1973
[d] For propellant manufacture, launch pad coating, construction.
[e] From dun-tin urn and steel processes.
[f] For rectenna Sites as fraction of total US. land area.

SOURCE Adapted from *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program*, DOE/ER-0069 August 1980 due to the other SPS technical systems. Studies should be conducted as the design parameters become more clear. Analysis would also be needed to determine the incremental effect of SPS on the environment relative to other electricity generating facilities.

HEALTH AND ECOLOGY

Human health and safety could be affected by launch and space activities, mining, manufacturing, and transport, and the construction and operation of SPS receiving antennas and powerlines. These effects and the public concern about them are likely to be most pronounced closest to launch and receiver facilities. Long-term exposure to low-level electromagnetic radiation from SPS power transmission and distribution is a critical issue, involving potential health effects about which very little is known. For SPS space workers, exposure to ionizing radiation is of the utmost concern. Other important terrestrial impacts are shown in table 40. While the effects of some SPS activities such as mining and manufacturing are fairly conventional and could be routinely assessed, the uncertainties of other health and ecological impacts, such as exposure to microwaves, are great. When experimental data does exist it is rarely directly applicable to SPS. Furthermore, extrapolation from experimental animal to human health and safety standards is tenuous and uncertain without a good theory on which to base the extrapolation. For other impacts, such as exposure to ionizing radiation, it is not clear if existing standards should apply to SPS. More stringent standards can strongly influence SPS design, cost, and social acceptability. Ecological effects of SPS are also extremely uncertain as little attention has been paid to this complex area.

This second part of the chapter will identify the health and ecosystem impacts that presently appear most significant. The first section will address the bioeffects of terrestrial activities on the public, SPS workers and ecosystems. In the second section, the implications for the health and safety of SPS space workers will be discussed. With the exception of power-transmission effects, most of the health and safety risks described here pertain to the reference system only. There is not enough information on the personnel requirements, industrial activities and environmental impacts to treat adequately the other technical options. It is assumed that many of the effects would be similar to those of the reference system, varying only in intensity and degree. It is important to note that some of the impacts identified for the reference system could be minimized or avoided by worker training, protection devices, or changes in the system design, but the effect of these measures on concept feasibility and cost need to be examined in more detail.

Terrestrial Effects

The primary sources of potential health and ecological effects are electromagnetic radiation from the power transmission and distribution systems and noise and pollution from launches, mining, manufacturing, and construction (see table 40). The risks to the terrestrial worker are usually greater than to the general public because of the increased frequency, duration, and intensity of occupational exposure to certain hazards (although occupational exposure could be more easily controlled by protective devices). Estimates of SPS hazards have in many cases been extrapolated from other technologies, such as the space shuttle. Risk analysis would improve as the system design becomes more clear. However, the major uncertainties associated with some effects (e. g., electromagnetic radiation) rest in the state of biophysical knowledge and not SPS specifications.

Table 40.—Terrestrial Health and Ecological Impacts

Microwaves
- Effects of public and ecosystem exposure to low levels uncertain
- Occupational exposure higher; may require protective clothing

Laser **Light**
- Hazard to people and other living organisms directly exposed to beam
- Hazard to slow airplanes, birds, and insects flying through the beams

Reflected light (mirror system)
- Ocular effects not expected to be significant; potential hazard with binoculars not known
- Psychological impacts on public, effects on the photoperiod of plants and circadian rhythms, and navigation of wildlife are unknown

Reflected light (from reference system)
- Plants and animals would probably not be unduely affected, but many effects are uncertain. The human eye could be damaged if SPS reflected light were viewed for too long or with magnifying devices.

High-voltage transmission lines
- Effects of public and ecosystem exposure to electromagnetic fields not well demonstrated but still uncertain (not unique to SPS)

Noise
- Without preventative measures, construction noise from certain machinery could exceed occupational standards; no significant public or ecosystem effect is anticipated
- Launch noise and sonic booms could present problems for public and ecosystems. Workers would wear heavy protective devices

Air Pollution
- Without preventative measures, construction of rectennas could violate standards for certain emissions such as hydrocarbons and particulate
- Mining, manufacturing, and transport emissions are expected to be comparable to industrial and energy producing processes (except coal)
- Launch effluents are not thought to exceed emissions standards unless ambient levels are high but studies must be refined
- Effects on ecosystems are unclear

Water Pollution
- Construction and revegetation could deplete or contaminate local water, depending on site
- Onsite facilities would be needed to treat polluted water at launch site

Safety
- Risks to public, workers, and ecosystems from the handling and transport of toxic and explosive materials such as rocket propellants
- Occupational risk of catastrophic explosion or launch accident higher than that for public and ecosystems

SOURCE: Office of Technology Assessment.

Electromagnetic Radiation

Over the last few decades, the development and proliferation of technologies that utilize electromagnetic radiation has been astoundingly rapid and widespread. However, there is a growing concern about the biological consequences of exposure to the radiant energy these devices employ. Terrestrial life as we know it has evolved in response to a very specific spectral distribution, diurnal and seasonal cycle, and intensity of solar and terrestrial radiation. It is possible that the alteration and enhancement of the ambient electromagnetic environment brought about by modern technologies could have a profound impact on biological entities and human health.

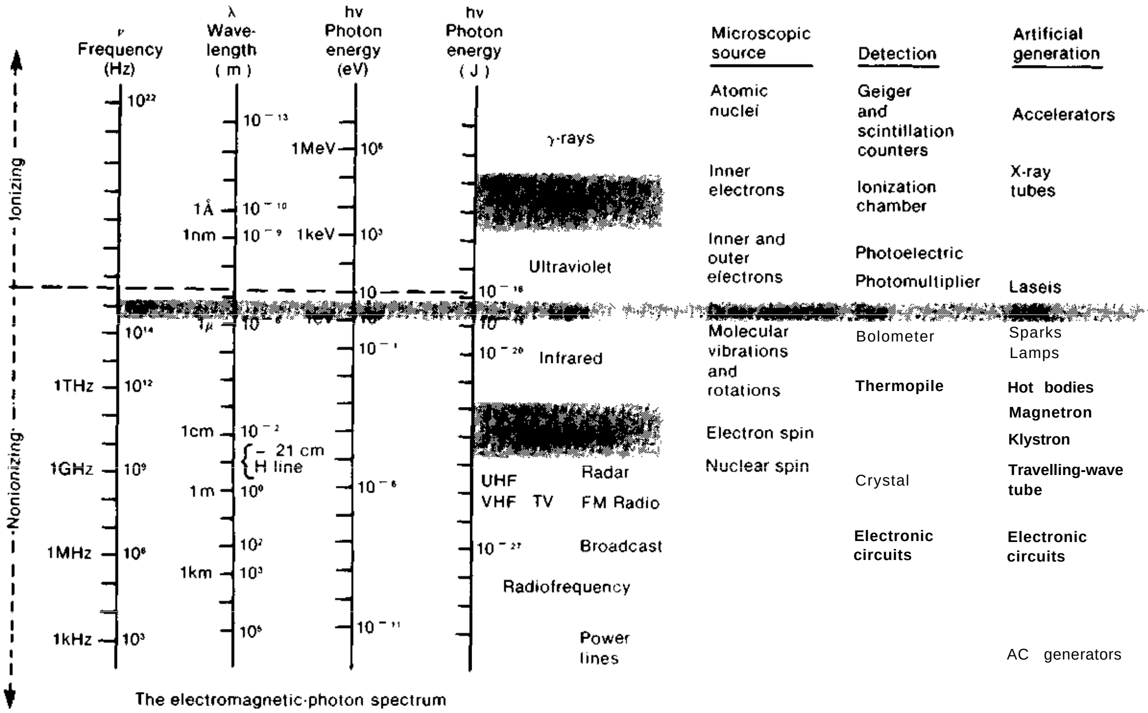
SPS would increase the local levels of nonionizing radiation (see fig. 39) in a few areas of the spectrum, e.g., microwaves, infrared laser light, or reflected sunlight from the power-transmission system.[54] The distribution of power from the receiving site via transmission lines would also increase exposure to very low frequency or static field radiation at some locations. Light reflected from the surfaces of space structures and vehicles would be visible from Earth. Space workers involved in the construction and operation of SPS could also be exposed to high levels of nonionizing and ionizing radiation in space.

MICROWAVES

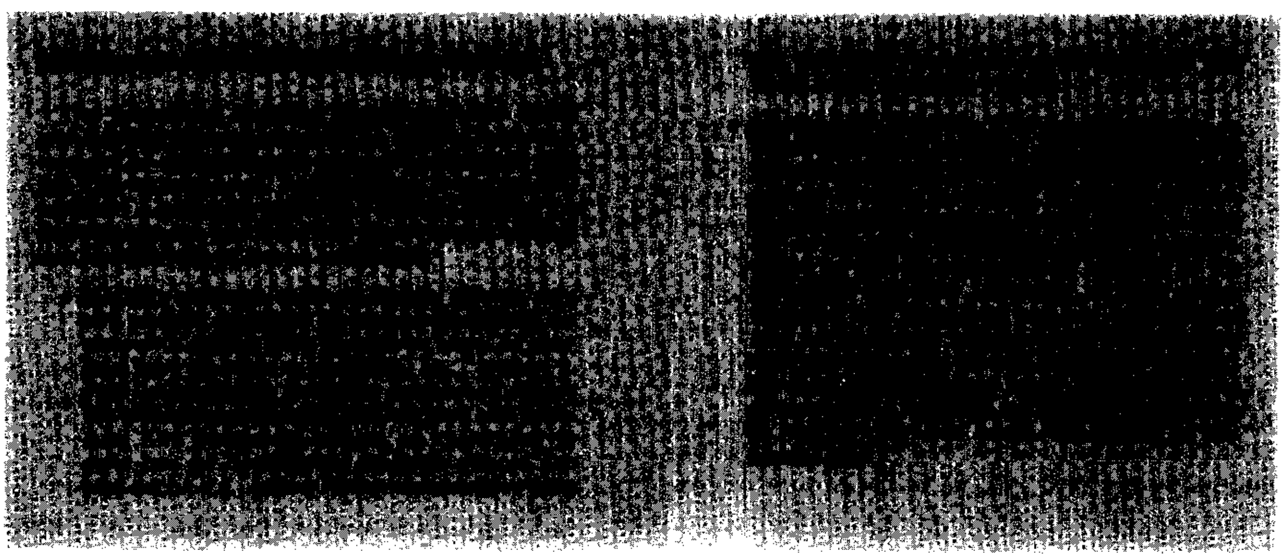
There is not enough relevant data currently available to assess reliably the biological risks to humans, plants, and animals exposed to SPS microwaves. The data base that does exist is incomplete, often contradictory and usually not directly applicable to SPS.[55] In particular,

[54] P Lorrain and D R Corson, *Electromagnetic Fields and Waves* (San Francisco W.H Freeman, 1970)
[55] *Preliminary Environmental Assessment for the Satellite power System (SPS) Revision 1,* DOE/NASA report No DOE/E R-0036, January 1980

Figure 39.—The Electromagnetic-Photon Spectrum



SOURCE: P. Lorrain and D. R. Corson, *Electromagnetic Fields and Waves*, W. H. Freeman. San Francisco, 1970



there is a lack of information on the bioeffects of chronic exposure to microwaves at low-power densities. Data is presently lacking on empirical dose-response relationships at these low levels as well as on the theoretical mechanisms of interaction between living organisms and microwaves. Improved theory would facilitate extrapolations (which are currently tenuous and oversimplified) from experimental animal data to the prediction of human bioeffects.

This knowledge is also required for the quantification of SPS microwave risks, without which no useful assessment of the SPS microwave concepts can be made, If an SPS program is pursued, the study of microwave bioeffects should receive top priority. Microwave research and future microwave standards could play a large role in determining the design and feasibility of SPS systems.

- SPS microwave risks. The SPS reference system microwave environment is illustrated 'in figure 40. Table 41 presents the public, occupational, and ecosystem exposure levels. Since the power densities emitted by the solid-state system are lower as a function of distance from the rectenna center than the reference system, they will not be specifically addressed here.

No quantitative risk assessment for SPS workers has been performed or is currently possible. Occupational exposures would need to be controlled by adequate protective clothing and shielding, dosimeters (all of which are not presently available), and possibly changes in system design.[56] The extent of the necessary protection has yet to be determined. For occupational exposure engendering the greatest risks, (e. g., space workers and terrestrial personnel working above the rectenna) it might be necessary to shut off or defocus the microwave beam if other protective measures prove insufficient. Additional research would be required to clarify the risks and protective criteria for short-term exposure. Possible synergisms between the space environment (e. g., ionizing radiation, weightlessness) and microwaves must be explored as well as the plausibility of simultaneously shielding microwaves and ionizing radiation (see Space Environment). It is also imperative that understanding of the long-term effects improve substantially (see below) before a reliable occupational safety threshold can be determined. In addition, possible disparities between SPS microwave levels and occupational standards in this and other countries (see table 42) should be addressed, especially if SPS were to be a multinational system. The effects on system cost and feasibility of implementing protective measures, complying with safety standards, and reducing the risks of long-term effects will need to be analyzed.

Public and ecosystem exposure to SPS microwaves is presently of greatest concern. It has been estimated that the 60 satellite reference system would raise the ambient microwave level in the continental United States to a minimum of 10^{-4} mW/cm^{2}.[57] Although not directly comparable, this level is two orders of magnitude greater than the median population exposure to FM radiowaves.[58] (Ambient microwave and radio frequency levels are inturn 10^{6} times greater than natural levels of solar and terrestrial radiation.) It therefore appears that the general population and ecosystems would be exposed to levels significantly higher than current background microwave radiation.

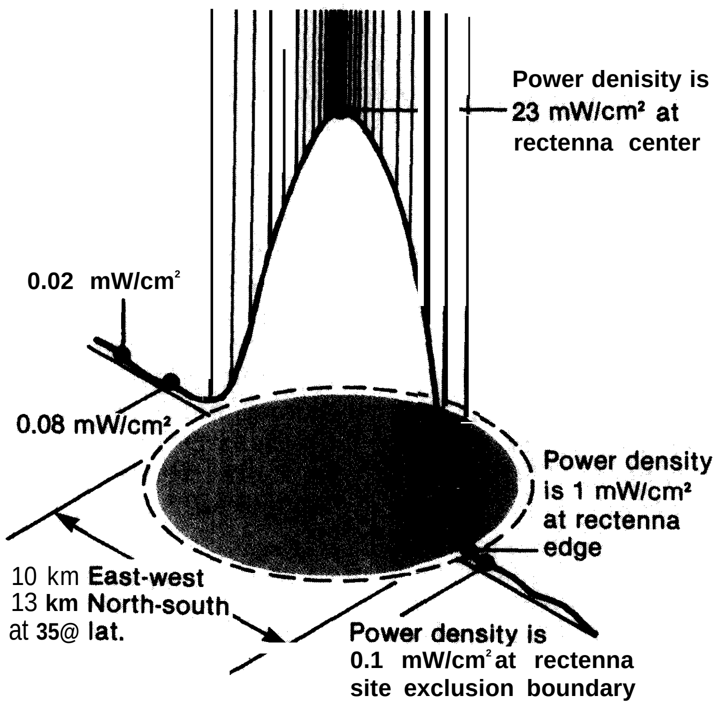
The health risks of chronic exposure to microwaves, especially at these low levels (i. e.,

[56] *Program Assessment* Report, *Statement of Findings,* op c it

[57] Ibid

[58] R A Tell and E D Mantiply, "Population Exposure to VHF and U H F Broadcast Radiation in the United States, " *Proc. IEEE,* 68(1) 6-12, 1980

Figure 40.—SPS Microwave Power-Density Characteristics at a Rectenna Site



SOURCE: *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program,* DOE/ER-0069, **August 1980**

Table 41 .—Characterization of Exposure to Reference System Microwaves

Public		Outside buffer zone	Between 10^{-4} mW/cm² and 0.1 mw/cm²
		Airplane flying through beam	Less than 23 mW/cm² (shielding)
Terrestrial workers		Rectenna field	Up to 23 mW/cm² (may be higher if reflections occur)
Space workers		Transmitting antenna	Up to 2.2 W/cm²
Ecosystems (plants, wildlife, airborne biota)	Under rectenna	Rectenna field: Outside buffer	Less than 0.1 mW/cm²
		Inside buffer	Between 0.1 mW/cm² and 1.0 mW/cm²
		Rectenna field: above rectenna	Up to 23 mW/cm²

SOURCE: *Environment/ Assessment for the Satellite Power System Concept Development and Evaluation Program,* DOE/ER-0069, **August 1980.**

Table 42.—Microwave Exposure Limits

	Frequency (G Hz)	Occupational (mW/cm²)	Occupational duration	Public (mW/cm²)
United States[a]	0.01-100	10.0	No limit	None
U. S.S.R.[b]	0.3-300	0.01	Workshift	0.001
Canada[c]	1-300	5.0	8 hours	1.0
Czechoslovakia	0.3-300	0.01	8 hours	0.0001
Poland	0.3-300	0.2	10 hours	0.01
Sweden[d]	0.3-300	1.0	8 hours	1.0

aThis is a guideline only and is not enforceable; the standards in the United Kingdom, German Federal Republic, Netherlands and France are similar to that Of the U.S. guideline; ANSI will probably recommend 5 mW/cm² as a new occupational exposure limit. ANSI and EPA are presently considering a new population limit.
b0.1 mW/cm² for rotating antennas.
cCanada is proposing a 1 mW/cm² limit at 10 MHz to 1 GHz frequency.
d5 mW/cm² at 0.01 to 0.3 GHz for 8 hours.

SOURCE: Adapted from L. David, *A Study of Federal Microwave Standards,* DOE/NASA report No. DOEIER-1OO41-O2, August 1980.

less than 1.0 mW/cm²) cannot be analyzed with the current data base. While appreciation for the complexities of the interaction between microwaves and biological systems (see app. D) has grown in recent years, the state of knowledge, particularly with respect to low-power microwaves, is immature and incomplete; hence, no assessment for SPS can be conducted at this time. However, a DOE review of the existing scientific literature identified the biological systems that might be most susceptible to microwaves. 59 For the public and ecosystems outside of the rectenna, DOE tentatively concluded that effects on the reproductive systems would be small; risks to special populations (e. g., people taking medication, children, older and pregnant people, etc.) and effects on behavior would be uncertain and effects on the immune and blood systems appear unlikely. No cancer, development or growth effects would be expected. Again, however, the data base on low level chronic exposure that supports these conclusions is incomplete and more research would be required to satisfactorily assess potential effects.

For ecosystems (and SPS workers) at the rectenna site, effects on physiology, behavior, development, reproduction and the thermoregulatory, immune and blood systems might be possible.[60] Of particular concern are the effects on insects and birds that might fly through the beam. Birds in flight are often near their thermal limit and exposure to microwaves might result in thermal overloading. " DOE has initiated three laboratory studies to test the effects on bees, birds, and small animals at SPS frequency and power densities. (See app. D.) While no significant effects have been observed to date, the research is far from completed.

- Research needs. A workshop organized by the National Research Council (NRC) recently identified the principal research priorities for the bioeffects of exposure to low-level SPS microwaves.[63] These are listed in table 43. Basically, three kinds of laboratory studies are needed:

  1. animal laboratory experiments to establish effects empirically as well as dose-response relationships;
  2. studies of mechanisms of interaction at different levels of biological organization (e.g., atoms, molecules, cells, organs); and
  3. improvement of dosimetry, instrumentation and models.

While limited resources might dictate that these studies be carried out only at the SPS reference system frequency and power densities, it is clear that research at many frequencies and power densities would help to elucidate the fundamental mechanisms of interaction that allow extrapolations to be made between frequencies, irradiance and

59A. R. Valentine, "Environmental Assessment Overview," In *The Final Proceedings of the Solar Power Satellite Program Review,* Apr 22-25, 1980, DOE/NASA report No Conf -800491, July 1980.
"'I bid

[61]*Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program,* op cit
[62]Ibid
"Dodge, op cit

Table 43.—Research Needs To Help Reduce Uncertainties Concerning Public Health Effects Associated With Exposure to SPS Microwave Power Densities and Frequency

Local or general thermal effects
- Long-term experiments at power densities< 0.1 mW/cm² at whole body, organ, and organelle levels, testing for biological endpoints such as alteration of enzyme reaction rates and cell membrane confirmational changes.
- Studies of basic physical interactions of electromagnetic fields with molecular components of living tissue, to develop models of biological effects or phenomena. (For example, biophysical experiments are required to determine the role of microwaves at SPS frequencies and intensities at the molecular level and their action on ionic conductivity. Any responses, biological, biochemical, or physical, should be investigated from the point of view of alteration of enzyme reaction rates, and cell membrane phase transitions and confirmational changes.)
- Better dosimetry techniques for calculating and measuring (such as a probe that could be used within an organism to measure in a nonperturbing way) internal field patterns.

Interactions with drugs or other chemicals
- Repeat selected experiments showing effects (including the potential of microwaves as a cocarcinogen), using carefully controlled dosimetry and statistical analysis.
- Develop and test hypotheses to explain effects.
- Long-term dose-response experiments at power densities around 0.1 mW/cm² and with a larger number of drugs at whole body, organ, and organelle levels.

Immunological effects
- Repeat selected Russian research at 1 to 500 mW/cm² levels; repeat selected U.S. work to validate it.
- Mechanistic and molecular biological experimentation.
- Long-term studies, particularly autoimmune response.

Effects on calcium ion efflum in brain tissue
- Studies to determine bioeffects using 2450 MHz as the carrier frequency or studies to determine whether the power density "windows" are carrier-frequency dependent.
- Studies to establish the interaction mechanism (the interaction site) of the modulated fields and ELF fields on calcium ion efflux.
- Studies to determine whether the phenomenon will occur under the modulation and power characteristics expected of the SPS microwave beam.
- Studies to determine whether the calcium ion efflux phenomenon correlates with Russian and East European findings of neurological/behavioral decrements in people and animals exposed to low levels of microwaves.
- Experiments to determine whether other ions—sodium, potassium, magnesium–are similarly affected.

Effects on organized structures
- Studies of changes in behavioral responses under simulated SPS conditions, using behavioral tests (such as time-based schedules of reinforcement) that are both sensitive and reliable measures of such effects.
- Studies of long-term effects.
- Neurological and blood-brain barrier experiments at low levels.
- Determine the neurological and physiological significance of behavioral responses.
- Molecular level studies on biological relaxation times.
- Consideration of long-term animal experiments at 2,450 MHz to evaluate, if possible, whether there is any trend toward life shortening in animals.

SOURCE: C H. Dodge, (rapporteur), *Workshop on Mechanisms Underlying Effects of Long-Term Low-Level, 2.450 MHZ Radiation on Peep/e,* organized by the National Research Council, Committee on Satellite Power Systems, Environmental Studies Board. National Academy of Sciences, July 15.17, 1980

species. It may also be possible that frequencies other than 2.45 GHz would be used for SPS. If a much different frequency were used, however, low-level microwave research would have to be done at that frequency as well, because different frequencies cause different responses,

In addition to laboratory experiments, epidemiological studies are also needed.[64] It has been argued that such studies are currently of limited usefulness; they are very expensive, difficult to accurately document (i.e., it is difficult to determine the dose to which individuals are exposed) and may overlook important biological endpoints.[65] In addition they have limited usefulness for exposure to low levels of microwaves because the variability of the response is small and might be masked by other effects. It is also not clear how many people would need to be observed. Nonetheless a coordinated program of prospective epidemiology (as opposed to retrospective studies that rely on medical records many years after exposures) and laboratory research is essential to bridging the gap between biological effects observed in a laboratory animal and human health standards.

Special attention must also be paid to effects on ecosystems. To date, nearly all studies have been conducted in a controlled laboratory environment on a relatively few species. Virtually nothing is known about the effects of microwaves on a complete ecosystem and no studies have been performed that even ap-

[64] Office of Science and Technology Policy, A *Technical Review of the Biological Effects of Non-Ionizing Radiation,* Washington, D C , May 15, 1978

[65] Paul Tyler, Armed Forces Radiological Research Institute, private communication, July 30, 1979

preach the projected time scale of SPS operation (i.e., 30 to 100 years). With respect to SPS, it must be determined if animals and airborne biota would be attracted to the beam or would avoid it. What impact would microwaves have on the navigational systems of birds and insects (as well as aquatic life for offshore rectennas)? What effect would exposure to microwaves have on the productivity of plants and their susceptibility to drought? How would SPS affect the local food chain? The effects on micro-organisms, such as bacteria, fungi, and algae should be invest igated.[66]

- **Microwave standards.** The biological consequences of exposure to low-level microwaves are poorly understood because of inadequate and sporadic support of microwave bioeffects research in general and because the bulk of research performed in this country has focused on the bioeffects at levels of 10 mW/cm² or greater.[67] This emphasis stemmed from a belief that the only biologically significant damage from exposure to microwaves is due to heating. In fact, occupational guidelines developed in the 1950's through the Department of Defense and its contractors in response to concerns about exposure of radar personnel were based on biological injuries (e. g., cataracts, burns) from acute exposure to microwaves on the order of 100 mW/cm². It was concluded that humans could well tolerate exposures to power densities 10 times smaller[68] (i. e., 10 mW/cm²) without suffering serious or permanent damage.[69] This reasoning was accepted by the American Standards Association (now the American National Standards Institute (ANSI) which in 1966 recommended a maximum permissible exposure of 10 mW/cm², averaged over any 6-minute period (1 O to 100 GHz).[70] This rationale also forms the basis of the current U.S. occupational guideline (which in 1975 was ruled advisory rather than a mandatory standard") as promulgated by the Occupational Safety and Health Administration (OSHA) which adopted the ANSI recommendation in 1971. Presently, there is no official recommendation for general population exposures in this country.

The reasoning underlying the U.S. guideline is currently in dispute and OSHA and ANSI are considering new recommendations.[72 73] The conflict centers around the assumption that only thermal effects result from exposure to microwaves. While it is generally acknowledged that exposure to microwaves of 10 mW/cm² or greater will result in heating, the effects and consequences of exposure to lower power densities are controversial. Experiments documenting behavioral and neural changes and the enhancement of calcium efflux from brain cells[74] in particular have suggested the existance of other effects at power densities below 1.0 mW/cm². These phenomena are thought by some to result from direct interactions with the electromagnetic field rather than as an indirect consequence of heating. Some of the mechanisms that have been postulated for non ionizing radiation include:

1. distortion of the shapes of individual molecules or rearrangement of a group of molecules that might transiently or per-

[66] O P Gandhi, "Biohazards of Microwave Beams From Proposed Satellite Power Stations", in *Health Implications of New Energy Technologies*, W N Rom and V E Archer (eds) (Ann Arbor, Mich Ann Arbor Science Publishers Inc , 1980)

[67] P Tyler, "Overview of Radiation Research Past, Present and Future," in *Biological Effects of Nonionizing Radiation*, P Tyler (ed) (New York Academy of Sciences, annals, vol 247, 1975)

[68] R Bowers, et al , (*ommunications for a Mobile Society (Beverly Hills, Calif Sage Publications, 1978)* (Bell Laboratories and General Electric recommended 0 1 mW/cm² and 1 () mW/cm² respectively as maximum permissible exposure limits)

[69] N H Steneck, H J Cook, A J Vander, and G 1 Kane, "The Origins of U S Safety Standards for Microwave Radiation," *Science*, vol 208, pp 1230-1237, June 13, 1980

[70] L David, *A Study of Federal Microwave Standards*, DOE/NASA report No DO E/E R-10041-02, August 1980

[71] General Accounting Office, *Efforts by the Environmental Protection Agency to Protect the Public From Environmental Non-Ionizing Radiation Exposures*, Washington, D C , Mar 29, 1978

[72] A W Guy, "Non-Ionizing Radiation. Dosimetry and Interaction," in *Non-Ionizing Radiation*, proceedings of a Topical Symposium, Nov 26-28, 1979, The American Conference of Governmental Industrial Hygienists, Inc , 1980

[73] Z R Glaser, "Basis for the NIOSH Radiofrequency and Microwave Radiation Criteria Document," in *Non-Ionizing Radiation*, proceedings of a Topical Symposium, Nov 26-28, 1979, The American Conference of Governmental Industrial Hygienists, Inc , 1980

[74] Dodge, op cit

manently alter the function and replication process of a biological unit;[75]

2. reorientation of dipole molecules in the microwave field and polarization of molecules that control membrane permeability;[76]
3. biological electromagnetic interference in which the microwave field disrupts or enhances the transfer of biological information in the form of electromagnetic energy between molecules and cells;[77] and
4. field receptor interactions where neural tissue acts as a receptor of weak fields.[78]

The discussion of low-level effects is hampered by the experimental difficulties of isolating the various possible mechanisms. Most U.S. microwave experts acknowledge the need for research on low-level effects, but remain skeptical about their biological significance, especially at the proposed SPS single frequency of continuous radiation.

The controversy over low-level effects has been fueled by the disparity between U.S. and U.S.S.R. research and exposure standards (see table 14)—the Soviet standard is three orders of magnitude lower than the U.S. guideline. Some U.S. authors have attributed the different standards to dissimilar research philosophies.[79] For example, microwave studies thought most valid by U.S. scientists are those performed in a controlled laboratory environment, whereas Soviet researchers rely on clinical and "subjective" data as well.[80] In fact, based on the complaints of radar personnel, "microwave sickness" has been isolated as a distinct occupational disease in the U. S. S. R." It has also been argued that the Soviet exposure levels are based on the occurrence of a biological effect whereas the U.S. guideline reflects levels of known biological damage (with a safety margin). " Moreover, it has been claimed that the Soviet standard has been set without regard to the practical feasibility of meeting such low levels. It is further argued that in any case the standards are not enforced, especially in the military sector, although this would be difficult to substantiate.

For many years the flow of information between East European and Western researchers was restricted. Translation problems sometimes also contributed to misunderstandings.[83] This situation has improved considerably, and attempts are being made in the United States to replicate many of the low-level experiments performed in other countries (although the United States still has not sponsored any clinical studies). Western literature is also beginning to acknowledge the possibility of behavioral response and selective sensitivity of organs to low levels .84 Partly for these reasons, it is anticipated that new ANSI guidelines will be established that are more stringent than the present exposure levels (see fig. 41). At the SPS frequency of 2.45 GHz, the maximum occupational exposure that is now being considered is 5 mW/cm². * EPA is also considering

"K D Straub, "Molecular Absorption of Non-Ionizing Radiation in Biological Systems" in *The Ph ysical Basis of Electromagnetic Interactions With Biological Systems: Proceedings of a Workshop, University of Maryland, June 15-17, 1977,* L Taylor and A Cheung (eds), US DHEW, 1978, report No [FDA) 78-8055, Washington, D C , April 1978

"A S Pressman, *Electromagnetic Fields and Life (New* York Plenum Press, 1970)

[77]Ibid

[78]D R Justesen, et al , "Workshop on Radiation: Scientific, Technological, and Sociological Implications of Research and on Biological Effects of Radio-Frequency E lectromagnetic Radiations," in *Proceedings of the 1978 Conference on U.S. Technical Policy (New* York. IEEE, 1979)

"W C Milroy and S M Michelson, "The Microwave Controversy, " *International Journal of Environmental Studies,* VOI *4,* p 123, 1973

[80]D R Justesen, Veterans' Administration, private communication, J u ly 16, 1979

[81]C H Dodge and Z R Glaser, "Biomedical Aspects of Radio Frequency and Microwave Radiation A Review of Selected Soviet, East F u ropean, and Western References" in *Biological Effects of Electromagnetic Waves: Selected Papers of the USNC/URSI Annual/ Meeting,* L L Johnson and M Shore (eds), Boulder, Colo , October 1975, USDHEW, (report No (FDA) 77-8010/8011), Washington, D C 1976

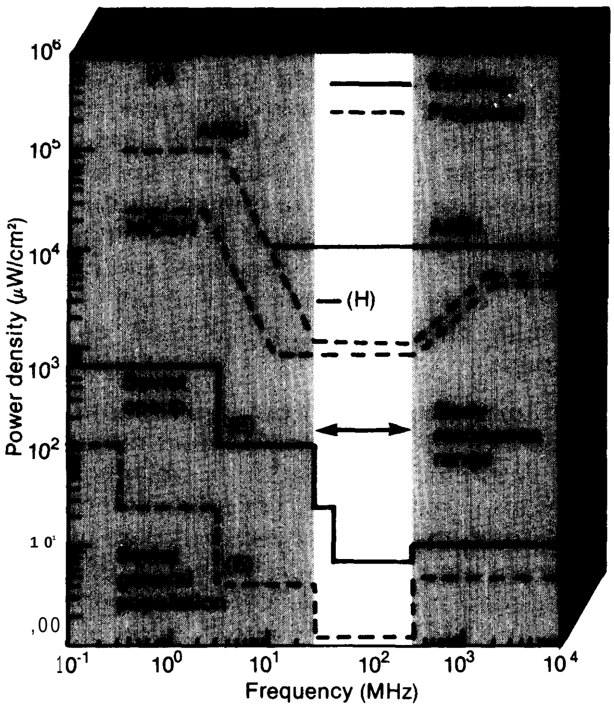
[82]D Michaelson, in *Symposium on the Biological Effects and Health Implications of Microwave Radiation, S* Cleary (ed), Richmond, 1969, USDHEW, report No BRH/DBE 70-2, 1970, pp 76-81

"'F'rzemyslaw Czerski, Department of Genetics, National Research Institute of Mother and C h ild (Poland), private commu n ication Sept 5, 1979

[84]C H Dodge and Z R Glaser, "Trends in Non-ionizing Electromagnetic Radiation Bioeffects Research and Related Occupational Health Aspects," *Journal* of Microwave *Power,* vol *12,* No 4 1977, pp 319-334

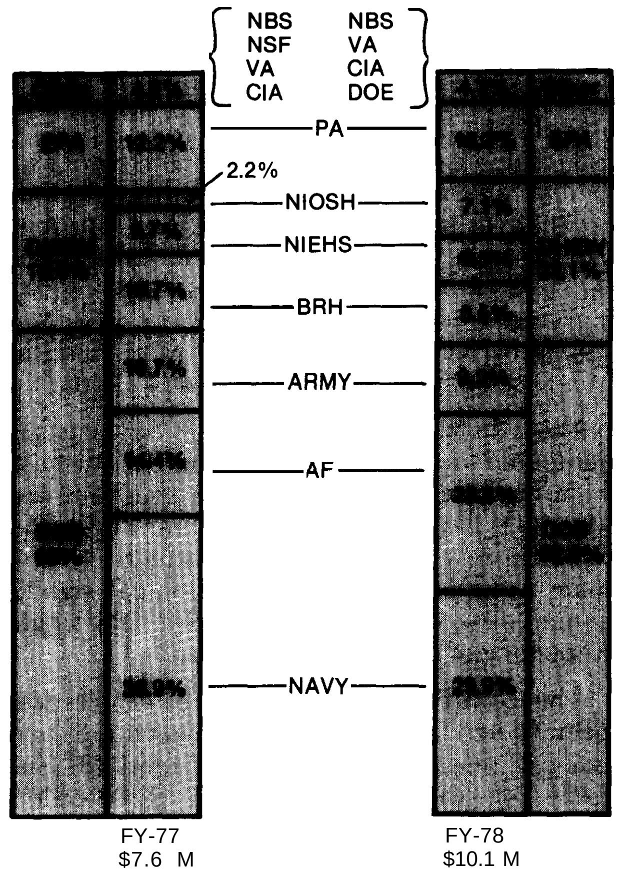
*This level has been criticized by the National Resources Defense Council as being arbitrary and not found with any recognition of possible nonthermal effects, see ch. 9, *Public Issues*

Figure 41.—Comparison of Exposure Standards



SOURCE: A. W. Guy, "Nonionizing Radiation: Dosimetry and Interaction," in *Nonionizing Radiation,* Proceedings of a Topical Symposium, Nov. 26-28, 1979, The American Conference of Governmental Industrial Hygienists, Inc., 1980.

Figure 42.— Program Funding



SOURCE: *Fifth Report on "Program for Control of Electromagnetic Pollution of the Environment: The Assessment of Biological Hazards of Nonionizing Electromagnetic Radiation,"* NTIA report No. 79-19, U.S. Department of Commerce, March 1979.

the development of exposure guidelines for the general population, although it does not have the jurisdictional authority to enforce standards. It is conceivable that future public standards could be established at 1.0 mW/cm^2 or below.[85] The impact of more stringent standards on SPS design and concept viability should be addressed.

Agencies. At present, the study of the bioeffects of nonionizing radiation falls under the jurisdiction of 13 Federal agencies.[86] The allocation of funds (currently about $15 million per year) is shown in figure 42. The agencies primarily responsible for regulation and the establishment of microwave guidelines[87] include the Department of Health and Human Services (the Bureau of Radiological Health/Food and Drug Administration, for example, sets emission standards for electronic products such as microwave ovens); the Department of Labor (which sets occupational guidelines); and EPA (which sets environment guidelines for other Federal agencies).

The Federal effort has been coordinated at various times by other Federal agencies, but a clear, dedicated, well managed and adequately funded national program in microwave bioeffects research is currently lacking. To some extent, the ineffectiveness of the agencies responsible for the management of the Federal program is due to lack of control

[85] David, op. cit.
[86] *Fifth Report on "Program for Control of Electromagnetic Pollution of the Environment: The Assessment of Biological Hazards of Nonionizing Electromagnetic Radiation,"* NTIA report No 79-19, U.S. Department of Commerce, March 1979.
[87] David, op cit

over the allocation of research funds.[88] It is also often the case that within each of the research and regulatory agencies, microwave research receives low priority on the agency's agenda. jurisdictional ambiguities have caused some agencies to take a limited approach to research and protection. Multiagency effort has also made public participation and education difficult.

Often, the most cohesive and vigorous research and evaluation of microwave bioeffects take place in conjunction with one particular technology such as a radar facility. This is not always the best arrangement since in the past, user agencies with vested interests have often been responsible for the assessment of health and environmental impacts. Moreover, fundamental research is needed in order to elucidate the mechanisms of interaction; technoiogy-specific research is helpful but usually does not contribute significantly to basic understanding. In addition, long-term continuous studies are needed and project-specific research is sporadic and unpredictable.

[88] Tyler, op cit

Nonetheless, unless the Federal research effort is consolidated into fewer agencies and given greater support, it is likely that an SPS program would be required to sponsor microwave bioeffects studies as it did in the DOE assessment. If the current climate continues, this research would not only gather information specifically relevant to SPS, but would probably be quite fundamental in nature. If a microwave SPS program is pursued, the development of SPS would entail the involvement of the Federal agencies shown in table 44. State agencies might also be affected.

Conclusion. DOE-sponsored microwave studies stimulated thinking about the design of microwave bioeffects experiments, tended to clarify research needs and obstacles and con-

Table 44.—SPS Development

SPS development phase	Microwave aspect	Agency involvement
Basic research	Environmental and public health effects evaluation MPTS technology	DOE, EPA, HEW/FDA, NASA
Applied research	Conduct experiments and further define health and safety risks of MPTS to public, the environment and SPS workers	DOE, NASA, HEW/FDA, Department of Labor/OSHA EPA
Exploratory development	Preliminary standards development radiation exposure standards occupational health and safety standards development	HEW/FDA, DO E/EV, EPA, HEW/FDA, Bureau of Radiological Health, Department of Labor/OSHA
Technology development	Final standards for MPTS chosen occupational health and safety standards finalization	HEW/FDA, DOE/EV, EPA, DOL/OSHA
Engineering development	Preparation of environmental impact	Council on Environmental Quality
Demonstration	Guidelines for health and safety (worker) enforcement	Department of Labor/OSHA
	Guidelines for public health and safety environmental impact statements	HEW/FDA-Bureau of Radiological Health, EPA, Council on Environmental Quality
Commercialization	Review guidelines for worker health and safety	Department of Labor/OSHA
	Review guidelines for public health and safety	HEW/FDA, EPA
Production	Enforcement of guidelines for worker health and safety	Department of Labor/OSHA
	Enforcement of regulations for public health and safety	EPA
Operations	Enforcement of guidelines for worker health and safety	Department of Labor/OSHA
	Enforcement of guidelines for public health and safety	EPA

SOURCE: L. David, *A Study of Federal Microwave Standards,* DOE/NASA report No DOE/ER-10041-02, August 1980.

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tributed to an increased study capability. While the results of these studies are useful, the time and resource constraints of the SPS assessment program precluded a thorough research agenda; in particular, no studies on long-term exposure to low levels of microwaves could be initiated and little more could be done to improve our theoretical understanding. In spite of the general acknowledgment by the microwave community of the need for studies of chronic, low-level exposure, practically no such studies are underway or planned. Clearly, if many of the fundamental questions about the bioeffects of microwaves are to be resolved within the next one or two decades, a more comprehensive, dedicated national research program will be needed.

LASER LIGHT

The biological risks associated with the laser system have been assessed only to a very limited degree. The power density of the focused laser system beam would be sufficiently great to incinerate biological matter."' Safety measures (such as a perimeter fence and pilot beam system) would have to be devised in order to avoid beam wandering and the direct exposure of the nearby public and ecosystems. Less easy to protect would be birds and insects flying through the beam; without some sort of warning device they would be incinerated.[90] It is not known if air-borne biota would be aware of the beam, and if so whether they would be attracted to or avoid it. Siting studies should consider migratory flyways and local bird populations.

It has been suggested that aircraft be restricted from the power beam area.[91] While it is not expected that jets and their passengers would suffer any damage in traversing the beam due to their high speed and infrared reflectivity, slower flying, less reflective aircraft could be affected. More important, laser light specularly reflected from an airplane would present an ocular hazard to the public.[92] A radar warning system might be devised to defocus the laser beam if a plane did happen to fly through it.

The primary risk to the public and nearby ecosystems outside of the direct beam would be due to laser light scattered from clouds, dust and the receptor site. This "spill over" of laser power (less than 1 percent) would necessitate establishing a buffer zone surrounded by an opaque, tall fence.[93] As shown in figure 33, it has been estimated that a protection radius of 300 to 800 m would be required in order to limit public exposure at the perimeter to 10 m W/cm a recommended maximum whole-body irradiance limit.[94] More research would be needed to verify this exposure guideline and to investigate the effects of chronic exposure to low level laser radiation. For visible laser beams, the risk of ocular damage could be increased at the receiving site if magnifying devices were used. Prolonged occupational exposure at infrared power densities greater than 10 mW/cm^2 would be of particular concern, especially for the cornea. Workers at receiving sites would probably be required to wear protective clothing and eye goggles.

Hazards outside of the site have not been assessed. It is unlikely that wildlife or vegetation at the receptor site would survive.[95] The etfects of the low level laser light on ecosystems outside of the receptor area are not known It is possible that certain infrared sensitive Insects would be attracted to the laser beam, but this requires further study .9'

The bulk of research on the biological effects of lasers is not directly applicable to the infrared lasers that have been suggested for SPS Most studies have concentrated on the effects on the eyes and skin of visible and near infrared lasers in a pulsed mode. The standards that have been promulgated pertain predominantly to short-term occupational exposure to

"'Beverly, op cit
[90]Walbridge, op cit
[91] Beverly, op cit
[92] Walbridge, op cit

' 'Beverly, op cit
[94]D H Sliney, K W Vorpahl, and D C Winburn, "Environmenta I H ea lth Hazards From H igh-Powered I nfra red Laser Devices" Arch Environmental Health, VOI 30, April 1975, pp 174170
"'W~lhrldge, op cit
[96]Ibid

lasers operating in a controlled indoor environment such as a laboratory or medical facility. Few studies have examined the effects of chronic exposure at SPS-like power densities and under SPS environmental conditions. A summary of known effects on the skin and eyes is presented in appendix D.

REFLECTED LIGHT FROM THE MIRROR SYSTEM

The light reflected by the mirror system to Earth would be visible at night as a general glow at up to 150 km from the receiving site. " The potential health impact of most concern is ocular damage from either the scattered light or from direct exposure to reflected light as the mirror image sweeps across the Earth during orientation maneuvers. Since the Collective intensity of all the mirrors at one site would be equal to that present in the desert at noon, it appears that the intensity of light would be too low to be of danger to the observer. One investigation revealed that under the worst conditions (i.e., staring, no blinking) it would be safe to view the mirrors directly for at least 2.4 minutes. " No information is available regarding the ocular effect produced when an individual views the mirrors with a binocular or telescope. The psychological effects of a "24-hour day" or alterations of the sky near the sites also needs to be studied.

The ecological impacts have not been assessed. It is known that the polarization, frequency and intensity of light as well as the percentage of daylight hours influence the behavior, navigation, and lifecycle of many species of wildlife and vegetation; many species have inherent biological clocks or circadian rhythms that are triggered by the diurnal and seasonal variations of sunlight.[99] However, ecosystems in the area surrounding the receiver site would be exposed to low levels of incremental sunlight and so it does not appear likely that significant biological effects would occur. Nonetheless, research should be conducted in this area. The effects of changing the night sky also need to be studied for ecosystems both near and distant from the site. Ecosystems could also be indirectly affected by weather modification induced by the mirror system.

LIGHT REFLECTED FROM REFERENCE SYSTEM

The transportation vehicles, construction and staging bases, and the satellite structure of the orbiting satellite systems will reflect sunlight, discernible on Earth. Some specular reflections from reference system components may be exceptionally bright due to their large size, low altitude, and reflectivity.[100] Most specular reflection would be restricted to small, fast moving spots or "glints" as the structures and vehicles change orientation. The worst cases, which may exceed acceptable limits, occur for reflections from the solar panels of the OTVS while in LEO, and the back of the solar panels in CEO. Diffuse reflections, brighter than most stellar sources would make the LEO OTV staging base visible during the day It may be possible to reduce most of these reflections by controlling the orientation, surface curvatures, solar panel alignment and surface quality of the vehicles and structures. Reflection of visible light from the components of other SPS technical options may be similar to the reference system depending on the orbit and size of transportation vehicles and space structures.

The effects on the public and ecosystems have yet to be evaluated in depth. One study found that the reflections from the reference system would be bright but not dangerous to the human eye[101] unless viewed for too long or with a magnifying device. Studies would be further needed to evaluate the ground illumination in terms of human exposure limits and to explore any possible psychological effects While DOE has tentatively concluded that plants and animals would not be unduly

[97] Billman, private communication, op cit

'*M T Hyson, "Sunlight Reflections From a Solar Power Satellite or SOLARES Mirrors Should Not Harm the Eyes, " in *The Final Proceeding of the Solar Power Satellite Program Review*, Apr 22-25, 1980, DOE/NASA report No Conf -800491, July 1980

"*McGraw-Hi/l Encyclopedia of Science and Technology*, VOI 10 (New York McGraw-Hill Book Co , 1977)

[100] D L Liemohn, D H Tingey, and B R Sperber, "Characterization of Reflected L ight From the Space Power System, " in *The Final Proceedings of the Solar Power Satellite Program Review*, Apr 22 25, 1980, DO E/NASA report No Conf -800491, July 1980

[101] Hyson, op cit

affected by the reflected light, ecosystem effects are largely uncertain. More research would be needed to investigate how alterations of the day and night sky could influence behavior, navigation, and lifecycles of wildlife and vegetation.

Noise

Noise is generated during rocket launches and the construction of receiving stations. With respect to the latter, the highest noise levels would result from heavy equipment used to prepare the site and build the support structure. The DOE prototype siting study concluded that it would be unlikely that significant noise-related impacts on the public and most animals located 2 km or more from the prototype construction site would occur.[102] For some machinery, occupational noise standards would be exceeded. Mitigation measures include ear protection devices, mufflers for machinery, and special insulation in factories.

Very high noise levels would be associated with launch vehicles during ascent and reentry. Table 45 presents the estimated noise produced by the HLLV. Table 46 is exhibited for comparison. A preliminary assessment indicates that the OHSA standard of 115 db(A) would be exceeded within 1,500 m of the launch pad, and the EPA guideline violated within 3,000 m.[103] Using the Kennedy Space Center as a prototype launch site, the study concluded that launch noise would not interfere significantly with speech (interruption for 2 minutes at 30 km twice a day), but that interference with sleep could occur 30 km from the site Table 47 presents an estimate of the number of people annoyed by the noise as a function of distance. Sonic booms would also be generated; pressure levels are shown for HLLVs and PLVs in table 48. The HLLV sonic booms would not cause injury but would invoke gross body movements and might interfere with sleep. It has been suggested that the trajectories of launch vehicles should avoid population areas.

The effects of noise on wildlife include startle responses and disruption of diurnal and reproductive cycles that could be particularly significant in endangered species habitats. It has been suggested that wildlife would adapt to the noise, but this is not clear.[104] While the noise generated by the space shuttle is not expected to be serious, the effects of HLLVs would be greater because of the increased fre-

[102] *Prototype Environmental Assessment of the Impacts of Siting and Constructing a Satellite Power System (SPS) Ground Receiving Station (GRS)*, op cit

[103] *Environmental Assessment* for the *Satellite* Power *System* Concept Development and *Evaluation Program*, op cit

[104] Ibid

Table 46.—Representative Noise Levels Due to Various Sources

Source or description of noise	Noise level (db)
Threshold of-pain	120
Riveter	95
Elevated train	90
Busy street traffic	70
Ordinary conversation	65
Quiet automobile	50
Quiet radio in home	40
Average whisper	20
Rustle of leaves	10
Threshold of hearing	0

SOURCE *Environmental Assessment for tire Satellite Power System Concept Development and Evaluation Program*, DOE/ER-0069, August 1980

Table 45.— Estimated Sound Levels of HLLV Launch Noise

Sound level and duration	Distance from launch pad 300 m	1,500 m	3,000 m	9,000 m	30,000 m
OASPL[a] (dB)	149	136	130	120	109
A-level[b] [db(A)]	130	114	105	89	72
Duration(s)	12	42	54	77	77

[a] OASPL: overall sound pressure level expressed in decibels (db) above the level corresponding to a reference pressure of 20 pa (pa= pascal=1 N/m²)
[b] A-level: Weighted average sound level over the frequency spectrum in accordance with the Performance of the human ear

SOURCE: *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program*, DOE/ER-0069, August 1980

Table 47.–Community Reaction to HLLV Launch Noise

Distance from launch point (m)	Percent of people highly annoyed[a]
300	90
1,500	45
3,000	24
9,000	5
30,000	1

[a]Based on a 24-hr average of the noise

SOURCE *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program* DOE/ER-0069, August 1980

Table 48.—Sonic Boom Summary (Pa)

Vehicle	Launch	Reentry
HLLV booster	1,200	190
HLLV orbiter	—	140
PLV booster	770	140
PLV orbiter	—	70

SOURCE *Environmental Assessment–for the Satellite Power System Concept Development and Evaluation Program* DOE/ER-0069, August 1980

quency and level of noise, due especially to sonic booms.

Terrestrial workers would be exposed to noise levels higher than the general public and would require hearing protection.[105] Possible hearing damage and pyschological effects should be studied in light of the unprecedented frequency and size of launches.

Other Risks

Quantitative studies are needed to determine SPS impacts on air and water quality and the generation of solid wastes. It is currently assumed that these impacts would be comparable to typical industries and powerplants (except coal) and that unusually high risks would not be encountered by the public and terrestrial workers that could not be minimized or corrected.[106] The effects on ecosystems are less certain.

DOE has concluded that acid rain from the SPS launch ground cloud would be localized, temporary and minimal. Because of the consequences of ozone depletion, i.e., a l-percent decrease in ozone corresponds to a 2-percent increase in biological harmful ultraviolet radiation that reaches the Earth,[107] the effects of SPS on the ozone layer has been studied. preliminary analysis concludes that the change in ozone brought about by SPS launch effluents would be negligible, but further study is requ i red.[108]

The deployment of SPS would also require the mining, production, and transport of certain toxic materials. Some toxic materials such as hydrocarbons could also be released from fuel burning in the launch and recovery of space vehicles. Rocket propellants such as liqu id hydrogen are of special concern because they are toxic, flammable, and explosive.[109] A spill of liquid oxygen would adversely affect local ecosystems. However, no information is available to quantify the exposure or risk to the public, workers or ecosystems. An incremental increase in the risk of catastrophic explosions or fire is thought possible, especially because of the large amount of fuels involved; the occupational risk, of course, being considerably higher than that for the public. Launch and recovery accidents are not likely to have any more impact on the public than conventional aircraft accidents, although it has been suggested that flight trajectories avoid populated areas. The noise and shock waves from a catastrophic explosion of an HLLV could possibly blow out windows and doors in buildings up to 15 km from the launch pad[111]

Space Environment

Many space workers would be needed to construct and maintain an SPS system. The reference design, for example, requires 18,000 person-years in space;[112] workers would serve ten 90-day tours over 5 years. Other SPS designs may have different personnel requirements, but they will not be specifically ad-

[105]Ibid

[106]Ibid

[107]S Hamer, "Ozone Controversy, " *Editorial Research Reports*, vol 1, No 11, 1976

[108]Ibid

[109]Ibid

[110]Ibid

[111]Ibid

[112]*Program Assessment Report, Statement of Findings*, op cit

dressed here. The health effects of the space environment are potentially serious, but highly uncertain; experience with people in space is limited to a few highly trained astronauts who lived mostly in LEO for a maximum of a few months.[113] NASA's current ground-based program as well as future activities with the space shuttle and space operations center will yield information relevant to SPS space worker health and safety. DOE does not consider the potential health effects an obstacle to continued planning and development of SPS,[114] but if this and other space projects are to be considered, the health and safety of space personnel should be a high-priority research task,

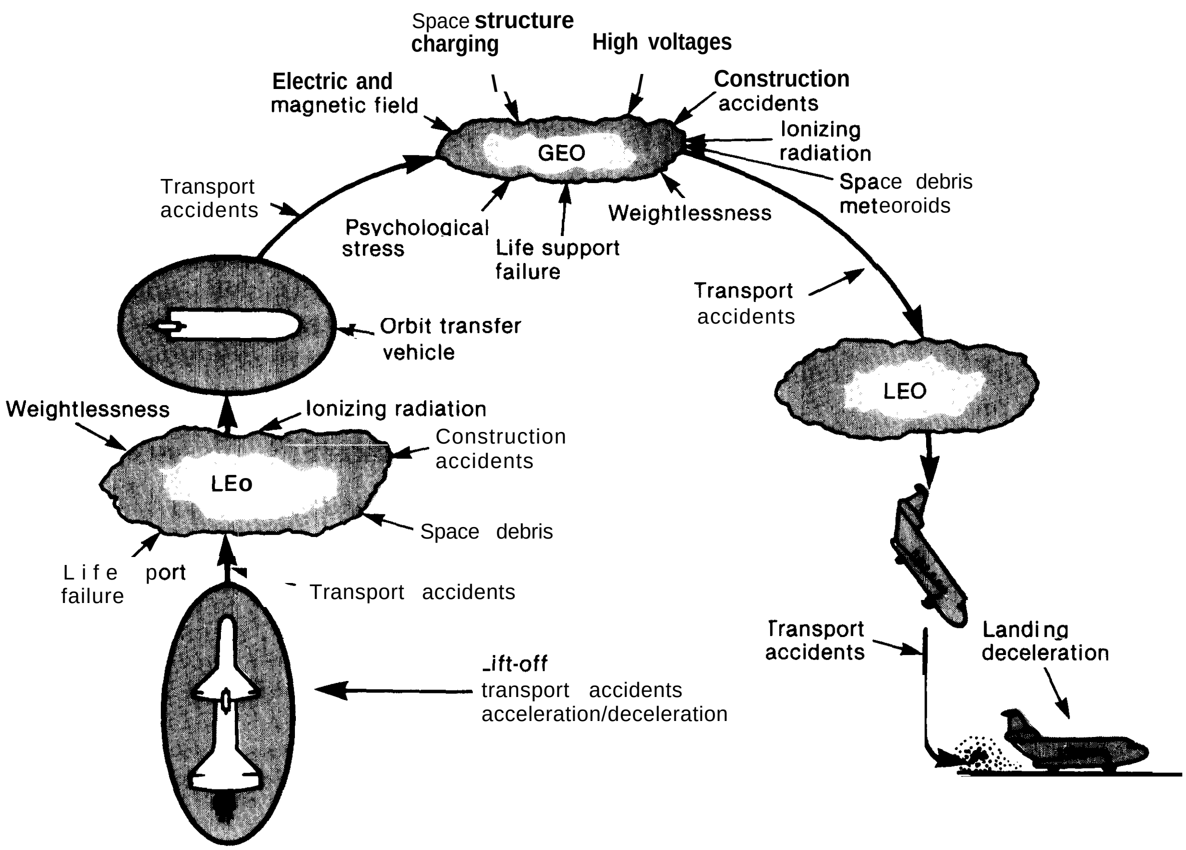
The principal health and safety risks of the space segment of SPS are illustrated in figure 43. Effects on the general health and safety of space workers such as acceleration and weightlessness are discussed in appendix D.

The most serious potential health risk of the space environment is exposure to ionizing radiation. The types of radiation found in the different SPS orbits are listed in table 49. Exposure to radiation in CEO and in transit between LEO and CEO are of most concern because, under the reference system scenario, workers spend approximately 91 percent of

[113] Ibid.

[114] *Environmental Assessment for the Satellite Power System Concept Development and Evaluation Program*, op. cit.

Figure 43.— Factors Pertinent to Space Worker Health and Safety



SOURCE Program Assessment *Report Statement of Findings* Satellite Power Systems Concept Development and Evaluation Program, DOE/NASA report No *DOE/E R-0085* November 1980

Table 49.—Types of Radiation Found in the Different SPS Orbits

GEO
- Radiation belts
  —Electrons—dominant when shielding is less than 3gm/cm² aluminum
  —Bremsstrahlung —produced by electron interactions with shielding—dominant when shielding is greater than 3 gm/cm² aluminum
  —Protons—low energy—stopped by minimal shielding
- Galactic cosmic rays
  —Protons
  —Helium ions
  —High-energy, heavy ions
- Solar particle events— i.e., particles accelerated to high energies during a solar f l are
  —Protons
  —Heavy nuclei

Travel **Between Orbits**
- Radiation belts
  —Bremsstrahlung radiation produced by electrons
  —Protons

LEO
- South Atlantic Anomaly
  —Protons
  —Electrons—low energy—stopped by minimal shielding

SOURCE: Margaret R. White, Lawrence Berkeley Laboratory, private communication, Feb. 12, 1981

their time in the higher orbit where the radiation environment is the most severe.[115] In GEO, except under the unusual circumstance of a large solar flare, the major part of the radiation dose in the reference system would be due to bremsstrahlung produced by the interaction of high-energy electrons with the shielding material. The biological effects of this kind of radiation are reasonably well understood, and innovative shielding might reduce this dose. However, radiation from the high-energy, heavy ions (HZE) in galactic cosmic rays cannot be stopped by conventional shielding and their biological effects are currently very poorly understood. From theoretical considerations and preliminary experiments it appears that they may be much more effective in causing biological damage than other types of ionizing particles. Thus, though they contribute a small fraction of the total radiation dose in the reference system, they are of major concern with regard to the health of space workers.[116]

Estimates of the radiation dose for exposed SPS space workers are uncertain. Few measurements have been made of the radiation flux in GEO.[117] It is also difficult to quantify the radiation levels at any one time because solar storms that significantly increase the levels are currently impossible to predict. Moreover, there is considerable controversy over the models that are used to estimate the amount of energy absorbed in the human body as well as the biological consequences of the absorbed radiation.[118] The most significant long-term effect of ionizing radiation is cancer. Cancer risk depends on a number of factors including the total l-fetime dose-equivalent; dose rate; duration of exposure; and the age, sex, and susceptibility of the exposed person.[9]

DOE has estimated that space workers for the SPS reference design (which includes modest shielding— 3 g/cm² aluminum for habitat and work stations and 20 to 30 g/cm² for the storm cellar, used during solar particle events) would receive 40 reins per 90-day tour or 400 reins for the planned 10 tours.[120] This estimate could be inaccurate (probably too high) by a factor of 5 or 10.2' However, the biological impacts could actually be higher than this dose would indicate if HZE bioeffects are taken into account and/or a solar particle event occurs. In spite of the large uncertainties, it is almost certain that reference system exposure would exceed current limits for radiation workers as recommended by the National Council on Radiation Protection and the International Commission on Radiological Protection.[122] For comparison, the general population receives about 0.1 rem/year on the average;[123] occupa-

[1] "ionizing Radiation Risks to Satellite Power Systems (SPS) Workers, LBL-9866, November 1980, advance copy

[116] M R White, *Environmental Assessment for the Satellite Power System, Non-Microwave Health and Ecological Effects,* DOE, in press (1981)

' 'Margaret R White, Lawrence Berkeley Laboratory, private communication, Feb 12, 1981

" "Program *Assessment Report, Statement of Findings,* op. cit

' 'JT Lyman, "Hazards to Workers From Ionizing Radiation in the SPS Environment," in The *Final Proceeding of the Solar Power Satellite Program Review,* Apr 22-25, 1980, DOE/NASA report No Conf -800491, July 1980

[120] *Ionizing Radiation Risks to Satellite Power Systems (SPS) Workers,* op cit

'" Program Assessment Report, Statement of Findings, op cit

"Zlbld

" 'Committee on the Biological Effects of Ionizing Radiation, The E f fects on Populations of *Exposure to Low Levels of Ionizing Radiation (BE/R III),* National Academy of Sciences, 1980, typescript edition tional exposure limits (for blood terming organs) are 3 reins for 90 days and 5 reins over 1 year;[124] and the NAS maximum recommended exposure limit (for bone marrow) for astronauts is 35 reins for 90 days, 75 reins over l-year period and 400 reins for life.[125] If space worker careers were 5 years, with 90 days in space alternated with 90 days on Earth, it would be expected that for each 10,000 workers in space, between 320 to 2,000 additional cancer deaths in excess of normal cancer mortality would occur.[126] An issue critical to SPS design and economics is whether the radiation standards developed for astronauts should be applied to SPS workers.[127]

Risks could be reduced in a number of ways. For example, the time per tour and the number of tours per worker could be decreased. Robots and teleoperation could be used to reduce the number of people required in space. It is also essential that accurate, quick and rugged dosimeters be developed that monitor the real-time radiation flux and energy levels to which each individual is exposed.[128] instruments would also have to be developed to warn personnel in GEO of solar storms or other unforeseen high radiation events so that they can move to shelters. Considerable improvements in dosimeter technology are needed since present devices are not very accurate and take a long time to display radiation levels. Shielding is also crucial Some of the risks associated with the reference system could be reduced with additional or innovative shielding. Analysis is needed to determine if better shielding techniques can be devised that would not incur a greater weight or cost penalty. Studies are also needed to examine to what extent additional shielding mass will incrementally reduce risks of exposure to most radiation (because secondary radiation can be produced as the thickness is increased),[129] or if shielding materials can be developed to stop HZE particles.

DOE has concluded that as presently designed, the reference system construction scenario is unacceptable.[130] Risks could be reduced if personnel spent more time in LEO. More study is required to improve the current assessment and to explore the impacts on the system Cost and feasibility of modifications of the reference system in order to minimize ionizing radiation hazards.

In sum, research priorities include:

- measurements of radiation flux in CEO. This can be done with CEO satellites; the space shuttle and space operations center will provide data on LEO;
- study of the bioeffects of HZE particles;
- continued study of radiation bioeffects and refinement of models;
- improvement in dosimetry techniques and shielding technology; and
- for SPS, improved analysis of exposure risk, and shielding techniques, consideration of exposure limits, and assessment of the viability of workers in space: tradeoffs between human health, system feasibility, and economics.

[124] W Schimmerling and S Curtis (eds), Workshop *on the Radiation Environment of the Satellite Power System (SPS)*, Sept 15, *1978,* DOE, Conf -7809164, December 1979
1251b;d

[125] Whke, *Environment/ Assessment for the Satellite power System, Non-Microwave Health and Ecological Effects,* op cit

[126] *Program Assessment Report, Statement of Findings,* op cit

[127] *Environmental Assessment for the Satellite Power System Concept Development and Evacuation Program,* op cit

[129] *Program Assessment Report, Statement of Findings,* op cit

[130] Ibid