Glaser

APPENDIX D

ENVIRONMENT AND HEALTH

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APPENDIX D: ENVIRONMENT AND HEALTH

I. Microwaves - Ionosphere Interaction

While only a small fraction of the incident microwave energy is absorbed by the ionosphere, the resultant heating at microwave frequencies is comparable to that of the sun and could significantly alter the thermal budget of the ionosphere. In the lower ionosphere (D & E regions) a phenomenon called "enhanced electron heating" can occur if the microwave heating overwhelms the natural cooling mechanisms of the ionosphere. The resultant heating can then affect electron-ion recombination rates, changing ionospheric densities or drive additional interactions. Furthermore, in the E region it is possible that the microwave heating could enhance natural density irregularities called "sporadic E" which can cause scintillations or scattering of radio frequency signals particularly in the Very High Frequency (VHF) band, e.g. citizen-band and some television bands.[1]

New experiments and theories were needed to understand the effects of an SPS microwave beam travelling <u>through</u> the ionosphere (an example of what is called "underdense" heating) because almost all of the data generated in the past has focused on the "overdense" case, i.e. where the ionospheric density is great enough to <u>reflect</u> the incident heating frequency.

Two High Frequency (HF) ground based heating facilities have been used to simulate SPS heating in the lower ionosphere. At Arecibo, Puerto Rico, ionospheric physics and heating mechanisms have been studied. The Platteville facility in Colorado has tested the effects on specific radio frequency navigation and broadcasting systems, namely VLF (3 kHz - 30 kHz, e.g. OMEGA), LF (30 kHz - 300 kHz, LORAN-C), and MF (300 Hz - 3 MHz, AM).[2]

However, neither Arecibo or Platteville are equipped to generate a beam of SPS frequency and power density. Instead the experiments were performed at lower frequencies and power densities and the results extrapolated to SPS conditions using the scaling law:

$$\frac{P_{SPS}}{f^2_{SPS}} = \frac{P_{HF}}{f^2_{HF}}$$

where P_{SPS} and P_{HF} are the power of the SPS beam (i.e., 23 mW/cm^2) and heating facility beam respectively, and f is the frequency of the beam (i.e., f_{SPS} = 2.45 GHz).[3] This extrapolation is thought to be valid only if the primary heating mechanisms is ohmic (i.e., heating by collisions between ions). This assumption has been verified over a limited range of frequencies. By upgrading the Platteville power densities and frequencies, confidence in the scaling theory could be improved. Experiments are also needed to test the effects on telecommunication systems operating in the 3 MHz - 20 MHz range.

In the upper ionosphere (F region), effects on telecommunications and on the SPS pilot beam stem primarily from a phenomenon called "thermal self focusing" which results when an electromagnetic wave propagating through the ionosphere is focused and defocused as a result of normal variations in the index of refraction. As the incident wave refracts into regions of lesser density, the electric field intensity increases. Thermal pressure generated by ohmic heating drives the plasma from the focused areas, thereby amplifying the initial perturbation. Although the heated volume in the D and E regions is confined essentially to that of the beam, the heated particles in the F region will traverse magnetic field lines so that large-scale field-aligned striations or density irregularities form. These striations reflect VHF and UHF radiowaves specularly, causing interference and the long-range propagation of the signals.

Less is known about the F region than the D and E layers. The power scaling law in the upper ionosphere may differ from that in the lower regions (i.e., thermal self-focusing instability may be defined by $1/f^3$ rather than $1/f^2$). Experimental data is needed to improve theory and test the effects on telecommunications.

NOTES

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2. Environmental Assessment for the Satellite Power System - Concept Development and Evaluation Program - Effects of Ionospheric Heating on Telecommunications, DOE/NASA Report, DOE/ER 10003-T1, August 1980.

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II. The Effects of Space Vehicle Effluents on the Atmosphere

SPS reference system rocket exhaust products would affect every region of the atmosphere. In Table D-1, the atmospheric effects of most concern are listed. As part of its assessment, DOE has also identified possible means of resolving these uncertainties in the event that an SPS program is pursued.

Troposphere*

SPS launch effluents injected into the troposphere could modify local weather and air quality on a short term basis. These changes would be due primarily to the formation and dispersion of a launch site ground cloud which consists of exhaust gases, cooling water, and some sand and dust. While sulfur dioxide, carbon dioxide and carbon monoxide concentrations would not be significant, nitrogen oxides and water vapor are of concern.

Nitrogen oxides (NO_x), especially NO_2 in the ground cloud, might under certain conditions, present problems for air quality. The projected ground cloud concentrations themselves are not thought to violate the short term national ambient air quality standards which are expected to be promulgated in the near future, but if ambient concentrations are already high, a violation could occur. NO_x and SO_x in the ground cloud could contribute to an increase in localized acid rain but this is expected to be small.

The ground cloud will also contain about 400-650 tons of water. While having a negligible impact on air quality, water vapor, especially in

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* Most of this section is derived from Reference 1.

Table D-1

Atmospheric Effects

Known	Uncertainty	Resolution
Launch vehicles will inject large amounts of water vapor and thermal energy into localized regions of the planetary boundary layer. The potential for inadvertent weather modification under suitable meteorological conditions exists.	The frequency of occurrence of suitable meteorological conditions. The extent of injection of cloud condensation and ice-forming nuclei. The duration and scale of the effects of the nuclei and the thermal energy inputs. The importance of anticipated small increases in cloud population, precipitation, haze, and other meteorological effects to the environs of the launch site.	Design and implement appropriate observational programs associated with rocket launches and conduct laboratory experiments to better characterize nuclei formed in the combustion of rocket propellant. Refine, test, and validate theoretical models suitable for simulating the effects of rocket launches. Examine the meteorological conditions appropriate to potential launch sites. Evaluate the importance of changes in those conditions to the environs of those sites.
Exhaust emissions and reentry products from Reference System heavy-lift launch vehicles and personnel orbit transfer vehicles will modify ion densities at high altitudes. In particular, injection of H_2O and H_2 in the F-Region will cause partial depletion of the F-Region.	Chemical-electrical interactions in the ionosphere, the effectiveness of mitigating strategies, and effects on telecommunications.	Design and implement experiments aimed at critical problems. Measure and analyze interactions through rocket experiments combined with telecommunications tests. Apply results to improve theoretical prediction capabilities. Provide guidance for system operational mitigating strategies and alternatives.
Ground clouds formed by HLLV launches will contain relatively high concentrations of nitrogen oxides that, in combination with effluents from sources in the launch site environs, will exacerbate existing air quality problems under certain conditions.	Exact value of NO_2 air quality standard to be set. Actual ground-level concentrations of NO_2 associated with vehicle launches under various ambient meteorological and air quality conditions typical of anticipated launch sites.	Utilize a range of anticipate probable "standard values" fo NO_2 including the existing standard for California. Refine, test, and validate existing modeling techniques for simulating formation and dispersion of NO_2 in ground clouds. Utilize existing and acquire new data related to rocket launches for this purpose. Prepare a climatology of expected NO_2 ground-level concentrations under a range of meteorological and ambient air quality conditions typica of anticipated launch sites.
HLLV flights will deposit a large amount of water and hydrogen above 80 km. The globally averaged water content is likely to be increased by amounts ranging from 8% at 80 km to factors of up to 100 or more above 120 km. The injected water and hydrogen will increase the natural upward flux of hydrogen by as much as a factor of 2.	The quantitative increases. Whether the globally averaged increase in water content will be sufficient to alter thermospheric composition or dynamics in a significant way. Whether the increase will result in a chronic, global-scale partial depletion of the ionosphere of sufficient magnitude to degrade telecommunications. Whether the increased hydrogen flux will significantly increase exospheric density and/or modify thermospheric properties.	Obtain a better understanding of the natural hydrogen cycle and develop and implement models to simulate the effects of rocket propellant exhaust on a global scale.
Injection of water vapor from HLLV launches in the altitude range of about 80-90 km is likely to result in the formation of noctilucent clouds.	The scale and persistence of the clouds, especially in view of poorly understood competing cooling and heating mechanisms. Whether cumulative effects could arise and lead to globally significant effects such as changes in climate.	Design and implement observational programs to obtain data on the occurrence and characteristics of high-altitude clouds formed during rocket launches. Improve knowledge of the natural atmosphere near the mesopause and develop and implement models to better simulate the effects of water and hydrogen injection on cloud formation.
Reference System personnel and cargo orbit transfer vehicles would inject substantial amounts of mass and energy into the magnetosphere and plasmasphere.	Ultimate fate of effluents. Potential impacts such as increased radiation hazards to space travelers, auroral modifications, telecommunications and terrestrial utility interference, enhanced airglow emissions, and changes in weather and climate.	Design and implement experiments in the magnetosphere to obtain data for improving understanding of magnetospheric phenomena of interest and provide system design guidance where appropriate.

Source: Ref. 5

association with launch generated heat and condensation nuclei could have a measureable, although short-term effect on weather. In particular, under certain meteorological conditions, heat and moisture could enhance convective activity, and induce precipitation. While the frequency and degree of such effects are uncertain, none of the projected weather effects are though to be serious. Cloud-condensation and ice forming nuclei would also be produced in the ground cloud. The effects of the latter on weather cannot be reliably estimated at this time. The high abundance of the former in the ground cloud is thought to be meteorologically important; cloud-condensation nuclei could change the frequency and persistence of fog and haziness. It has been suggested that because of the large size and frequency of HLLV launches, cummulative effects might occur. More research is needed not only for SPS, but of weather and climate phenomena in general.

Research needs include:

- Refine and test ground-cloud formation and transport predictive models as well as weather and climate models
- Update ground-cloud composition as systems are developed; conduct appropriate observations of rocket launches
- Study effects on local weather of prospective launch sites including possible cumulative effects
- Consider NO_x effects and possible ways to reduce levels given a range of likely future standard levels and meteorological conditions; refine and validate theoretical models for simulating NO_x dispersion

Stratosphere and Mesosphere

The upper atmosphere has received considerable public attention in the last decade, largely as a result of a number of studies examining the effects on the stratospheric ozone layers (which shield the earth from biologically harmful ultraviolet radiation) of the supersonic transport, fluorocarbons, and the biological generation of nitrous oxide etc.[2,3] There is concern that while the potential effects on climate and terrestrial life of altering the upper atmosphere could be serious, our understanding of the physics and chemistry of the region is incomplete. For example, it is known that the chemical composition of the upper atmosphere plays a key role in maintaining the earth's thermal budget and is directly linked to the dynamics, circulation and climate of the troposphere, but the mechanisms which couple the two regions are extremely complex and not well understood.[4] The SPS assessment relies mostly on theoretical models.[1] One dimensional models predicting global average vertical transport of atmospheric constituents are used most extensively, although less-refined two and three dimensional models are also available. High-altitude experiments are needed to improve atmospheric theory and the data base for the SPS assessment.

The most significant SPS impacts would arise from the injection of rocket effluents, especially water vapor and re-entry nitric oxide directly into the stratosphere and mesosphere. SPS vehicles emit CO_2 into the upper atmosphere but the amount is extremely small relative to existing levels and to the quantities generated by the consumption of fossil fuels. The effects of any impurities in the rocket fuel, such as sulfur would be neglible. Thermal energy is also injected by HLLV and PLV launches, but the effects are thought to be minor and transient.[1]

Increases in water vapor would be of concern because its natural abundance in the upper atmosphere is very low. The most recent estimates indicate that the increase in the globally averaged concentration of water vapor due to 400 HLLV fights per year would be about .4% in the stratosphere (30 km) and 8% in the upper mesosphere (80 km).[1] Increases near the latitudes at which the water vapor was emitted could be higher due to a so-called "corridor effect" with increases in water content up to 15% above 80 km.[5] At 120 km and above, it is estimated that the global water content could be increased by a factor of 100 or more.[11]

The production of nitric oxide from the re-entry of HLLVs is expected to significantly increase the naturally occuring nitric oxide concentration and to exhibit a pronounced long-term corridor effect in the nitric oxide distribution of the mesosphere.[1] Stratospheric nitric oxides levels would also be altered due to downward diffusion from the mesosphere, but would be confined mostly to the lower stratosphere where their impact would be negligible.

In the mesosphere, the injection of water could induce luminous, thin or "noctilucent" clouds of ice crystals in the vicinity of the rocket exhaust. It is estimated that the cloud would expand from a size of 1 km^2 to 1000 km^2 over 24 hours.[5] This finding is based on theoretical calculations and observations of other rocket launches which deposited far less water into the mesosphere than that which is projected for the HLLVs. The clouds are not thought to significantly alter the global climate, but in view of the poor understanding of the coupling between the mesosphere and troposphere, this expectation requires further analysis. A large unknown is the effect of the excess water content on temperature which may affect the likelihood and persistance of the clouds.[5]

In the stratosphere, detectable depletion or enhancement of the ozone layer from the emission of water and nitric oxide would be unlikely. While water vapor tends to decrease ozone, nitric oxide tends to increase it. The net effect of SPS reference system effluents is thought to small (i.e., either a decrease or increase on the order of 0.01%) relative to the natural fluctuations of the ozone concentration.[1] This conclusion requires further verification as it is based on one-dimensional models.

In addition to the formation of noctilucent clouds and perturbations of the ozone layer, the water vapor might contribute to a chronic partial depletion of the ionosphere. However, this is expected to be very small in comparison to the local depletions caused by rocket emissions directly into that region.[5] Climatic effects might occur from changes in the chemical composition of the upper atmosphere, although at present it is not possible to reliably assess any potential effects. Research priorities for SPS upper atmospheric effects include:

- Update emissions inventory and estimates of reentry nitric oxide
- Estimate magnitude of corridor effect and study possible temperature feedback mechanisms
- Identify and augment existing experimental programs to make high-altitude measurements of water and nitric oxide concentrations; study high-altitude water release data
- Assess the possibility and climatic impacts of noctilucent clouds
- Develop scenarios of SPS impacts on a number of different background conditions including future increases of CO_2
- Document and verify effects of effluents which are now thought to have a minor impact on the upper atmosphere
- Determine telecommunications effect of chronic, partial depletion of ionosphere.

Ionosphere

The ionosphere is used extensively in telecommunication systems to propagate and reflect radio waves. The injection and diffusion of SPS launch propellants into the ionosphere could alter the density of the electrons and ions which are responsible for the its unique properties, thereby degrading the performance of the telecommunications systems. Other effects might also occur, such as enhanced airglow and increased electron temperature, but the likelihood and consequences of these impacts are yet to be determined.[1]

A reliable assessment of the effects of launch effluents on the D-region of the ionosphere cannot be made at this time. However, two apparently counteractive effects have been postulated.[1] The emission of water vapor into the D-region is likely to deplete the ionospheric plasma density. This would reduce radio wave absorption in the daytime ionosphere and result in propagation anomalies. On the other hand, nitric oxide, produced by frictional heating during reentry, could engender the formation of ions in the D-region. It is believed that enough nitric oxide would be deposited in the region to compensate for the reduction of the plasma due to water vapor. A recent lower ionosphere experiment suggests that anomolies in the propagation of VLF signals were due to the effects of rocket effluents.[6] While the experiment was not conclusive, it is clear that detectable effects might occur which warrant further study.

As in the D-region, current understanding of the launch effluent effects on the E-region is not very advanced. Rocket propellants would be directly injected only into the lower E-region because HLLV engines would be shut off at 124 km.[1] Some effluents would enter the upper E-region by upward diffusion. Exhaust products emitted above the E-region in LEO by PLVs, POTVs and HLLV could also diffuse and settle downwards. The impacts of these effluents on the E-region, however are very uncertain. It is possible that the deposition of ablation materials during reentry could augment a radio signal altering phenomenon called "sporadic E" in which regions of greatly enhanced electron concentration are created. In addition, the coupling between the ionosphere and magnetosphere, the ozone layer, air conductivity and hence climate could be affected by the effluents but no reliable conclusions can be made at this time.

The effects of rocket exhaust products are better understood in the F-region, but the impact of SPS effluents is still not certain. This region is dominated by atomic oxygen atoms that recombine more slowly with electrons than their molecular counterparts in the lower ionosphere. Exhaust products such as water, hydrogen and carbon dioxide emitted in the F-region are quickly ionized.[7] These molecular ions rapidly recombine with the ionospheric electrons, thereby causing a region of pronounced depletion known as an "ionospheric hole." It has been estimated that for each POTV launch (which would occur once or twice a month), an ionospheric hole with an area two to three times the size of the continental United States[11] would be formed and persist for 4-16 hours.[5] Each HLLV launch (one or two per day) would produce a hole about one-tenth the size,[11] lasting for 4-12 hours. It has been suggested that a long-term low-level depletion on the order of 10% would develop in a ring around the launch latitude as a result of multiple launches.[11] The probable consequence of this depletion ring is a small perturbation of VLF, HF, and possibly VHF wave propagation.

These findings were based on a number of theoretical models of the ambient and perturbed F-region as well as several observations of rocket effluent-induced ionospheric holes. The models are fairly well developed and theoretical mechanisms are well understood, but care should be taken in scaling up radiowave propagation effects. Further study is required in order to accurately predict the location, size, movement and lifetime of the hole as well as the cummulative effects of multiple launches.[1] The first observation of ionosphere depletion inadvertantly took place after a 1973 skylab flight which produced a hole 1000 km in radius.[8] In 1977, experiments were conducted to purposefully produce an ionospheric hole.[9] The experiments, named Project LAGOPEDO tended to confirm the theory. Recently, DOE took advantage of the launch of NASA's High Energy Astrophysical Observatory (HEAO-C) by an Atlas/Centaur rocket in order to monitor the resultant large-scale (one to three million square kilometer) effluent-induced ionospheric hole, which persisted for approximately three hours.[10] The preliminary finding indicates that no severe long-term impacts on HF radio signals occured as a result, but that VLF transmissions (14 KHz) could have been affected.[10] On the whole, not enough is known about SPS-induced ionospheric holes to make conclusions about their impacts on telecommunications. (for how long?)

In addition to telecommunication effects, other potential effects of SPS rocket effluents deposited in the F-region have been suggested.[1] Enhanced air glow emissions could affect astronomy, remote sensing and surveillance systems. Past observations have noted enhancements on the order of 10 kilorayleighs for certain visible and near infrared emissions.[11] The magnitude and significance of SPS airglow emissions warrants further study. The injection of water vapor in the F-region might also perturb the thermal budget of that region. This would increase the ratio of cooling by radiation and perhaps alter the Van Allen belts and the amount of ionizing radiation in space. Also, as noted previously, the number of hydrogen atoms emitted by HLLV launches in the upper thermosphere and exosphere could be comparable to the number naturally present. This could increase satellite drag, alter the Van Allen belts and affect radio communications. The water budget of these regions is not well understood however, and so the probability of these effects is not known.

Research should focus on the following areas:

- o Improve understanding of D&E region effects
- o Refine studies of F-region ionospheric holes in order to predict location, size, movement and lifetime
- o Test effects on telecommunications using D, E and F regions
- o Assess air glow effects perhaps with the involvement of the remote sensing and astronomy communities.[11]

Thermosphere and Exosphere

As discussed above in the Stratosphere and Mesosphere summary, HLLV flights are predicted to substantially increase the natural water content above 80 km. One consequence of this excess could be an increase and perhaps, doubling of the upward flux of hydrogen atoms which result from the breakdown of the molecular water vapor as well as molecular hydrogen emitted above 56 km by HLLVs, PLVs and POTVs.[5] While it is fairly certain that an increase in the hydrogen flux would result, the consequences of a perturbed hydrogen cycle are quite uncertain. The hydrogen escape rate into outer space could increase. Accumulation of hydrogen above 800 km might also occur, thereby possibly altering thermospheric and exospheric dynamics and enhancing satellite drag.

Research is needed to:

- o Improve understanding of the natural hydrogen cycle and dynamic processes of the thermosphere and exosphere
- o Design models to quantify hydrogen increases and simulate SPS effects on a global scale

Plasmasphere and Magnetosphere

SPS reference system effects on the plasmasphere and magnetosphere result primarily from the emission of COTV argon ions and POTV hydrogen atoms as the vehicles move between LEO and GEO.[1] The impacts of these effluents could be great, because the energies and number of ions and atoms injected would be substantial relative to the ambient values. Unfortunately, the magnetosphere and plasmasphere are poorly understood. While some potential SPS impacts have been identified as shown in Table D-2, their probability and severity can not be assessed since no experiments data relevant to SPS exists for these regions. In particular, the consequences and the mechanism of interaction between the argon ions and the ambient plasma and geomagnetic field must be explored.

In addition to the exhaust products, the satellites themselves could also have an impact on the magnetosphere by obstructing plasma flow, or producing dust clouds, electromagnetic disturbances, space debris, visible and infrared radiation and high-energy electrons.[1] Little emphasis has been placed on these potential effects, however, because they are thought to be minor and easily remedied.

If an SPS program is conducted, it is clear that the design of transport vehicles for the outer regions of the atmosphere and the environmental assessment of their impacts in these regions will be closely linked. Possible methods of reducing adverse effects include the use of both chemical

Table D-2

Satellite Power System Magnetospheric Effects

Effect	Cause	Mechanism	System/Activities Impacted
1. Dosage Enhancement of Trapped Relativistic Electrons	O^+ and Ar^+ in magnetosphere due to exhaust and plasmasphere heating	Thermal heavy ions suppress ring-current-ion cyclotron turbulence, which keeps electron dosage in balance in natural state	- Space equipment - Modification of human space activity
2. Artificial Ionospheric Current	Ionospheric electric field induced by argon beam	Beam induced Alfvén shocks propagate into ionosphere	- Powerline tripping - Pipeline corrosion (probably unimportant)
3. Modified Auroral Response to Solar Activity	Neutrals and heavy ions in large quantities	Rapid charge-exchange loss of ring-current particles	- May reduce magnetic storm interference with earth and space-based systems
4. Artificial Airglow	3.5 keV argon ions	Direct impact on atmosphere from LEO source	- Interference with optical earth-sensors
5. Plasma Density Disturbance on Small Spatial Scale	Plasma injection	Plasma instabilities	- Signal scintillation for space-based communications

Source: Ref. 11

and argon ion engines or an alternative propulsion system in the COTV, and lunar mining.

Near term studies include:

- o Design and implement experiments in the magnetosphere and the laboratory to test SPS effects and increase theoretical understanding of magnetospheric phenomena.

NOTES

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

2. "The Aerosol Threat", Newsweek, October 7, 1974, pp. 74-75.

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6. Meltz, G., and J.A. Darold, "VLF OMEGA Observations of the Ionospheric Disturbance produced by an Atlas HEAO-C Launch", in Mendillo, M., and B. Baumgardner, Proceedings of the Workshop/Symposium on the Preliminary Evaluation of the Ionospheric Disturbances Associated with the HEAO-C Launch, with Applications to the SPS Environmental Assessment, DOE/NASA Report Conf. -7911108, August 1980.

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9. Pongratz, et. al., Lagopedo-Two F-Region Ionospheric Depletion Experiments, Los Alamos Scientific Laboratory, LA-UR-77-2743.

10. Mendillo, M., and B. Baumgardne, Proceedings of the Workshop/Sumposium on the Preliminary Evaluation ofthe Ionospheric Disturbances Associated with the HEAO-C Launch, with Applications to the SPS Environmental Assessment, DOE/NASA Report Conf. -7911108, August 1980.

11. Environmental Assessment for the Satellite Power System - Concept Development and Evaluation Program - Atmospheric Effects, DOE/ER-0090, November 1980.

III. The Electromagnetic Characteristics of the Alternative SPS Satellites

Microwave Satellites

The satellite will generate microwave power at a frequency of 2.45-GHz or some other central radio frequency, thermal radiation, and reflected sunlight at all wavelengths. In addition, it will generate some power at a finite number of multiple of the central frequency (harmonics), and also spurious noise on either side of the central frequency. Because the reference system is the only system for which an attempt has been made to characterize a system completely, this report will use its characteristics as an illustrative model for all microwave systems.

The space antenna would radiate a total of 6720 MW of microwave power towards earth. The reference system design calls for a 2.45 GH_Z Gaussian beam with a 10-dB taper (see Figure D-1). Atmospheric scattering and attenuation due to absorption, in addition to losses at the rectenna would reduce the useable power at the rectenna to 5000 MW. The following radiative effects are the most important for the reference system: (see Figure D-2)

- o Out-of-band radio frequency emissions. The reference system's klystrons are estimated to radiate energy at the following harmonic frequencies:[1]

Frequency (GHz)		Power Level (times 6720 MW)
2.45-	(central frequency)	1
4.90-	(2nd harmonic)	-50dB(10^{-5})
7.35-	(3rd harmonic)	-90dB(10^{-9})
9.80-	(4th harmonic)	-100dB(10^{-10})

Although it is known that the antenna patterns for these frequencies would be rather different from the Gaussian beam of the reference

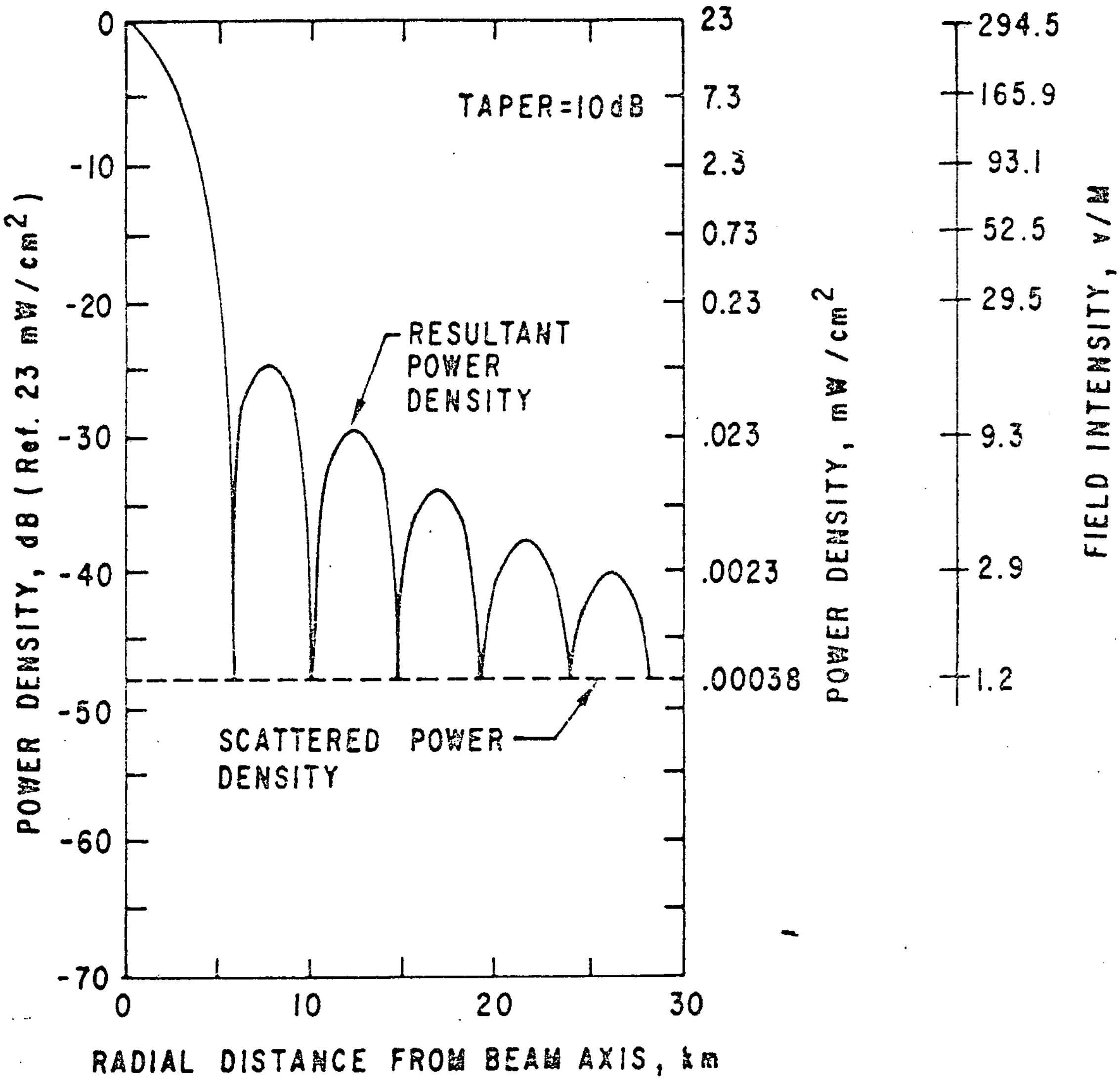
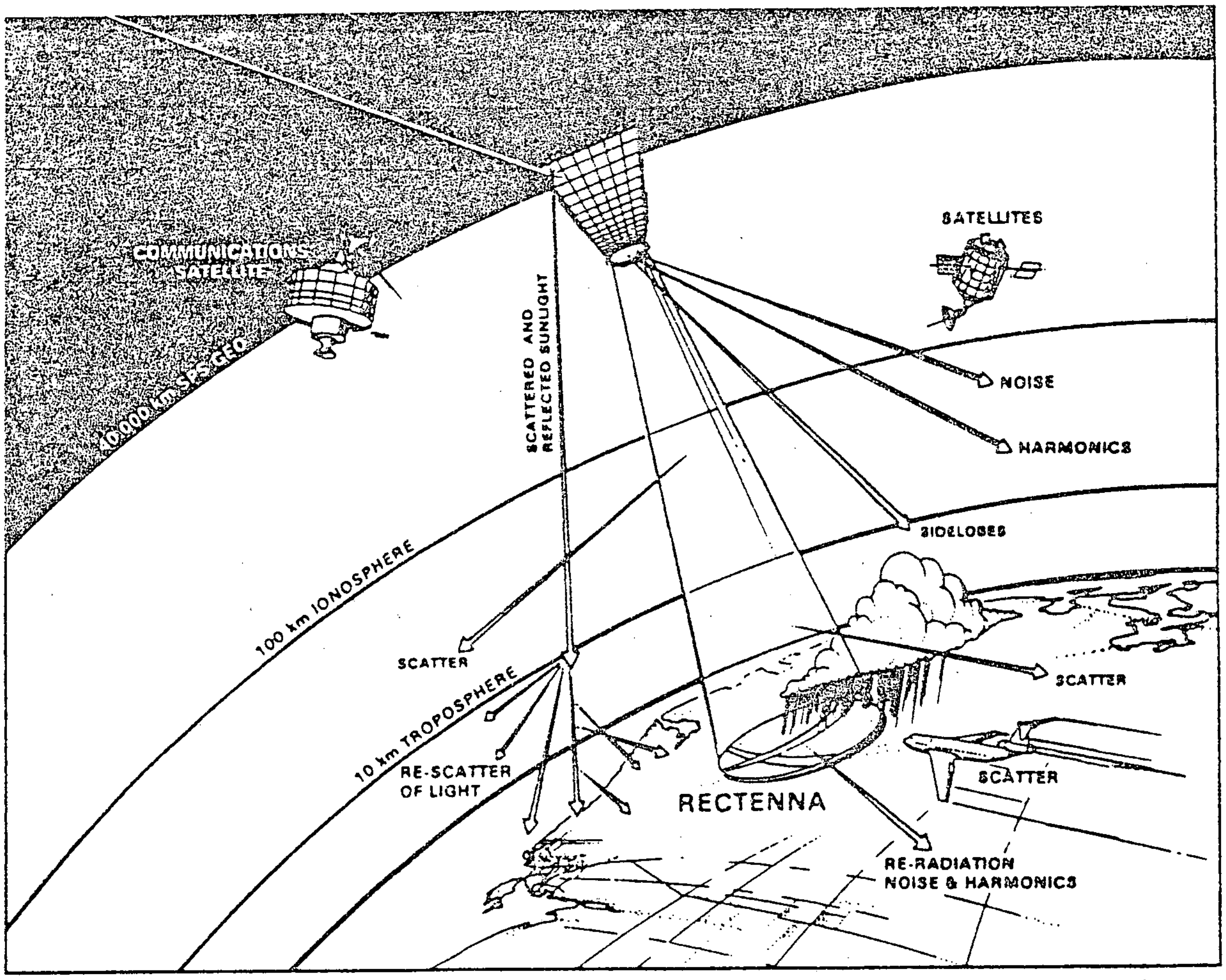


Figure D-1

Source: Ref. 2



Overview of Potential SPS Electromagnetic-Compatibility Impacts

Figure D-2

Source: Ref. 2

system, current antenna theory is inadequate to predict just how they may differ.

Spurious noise generation from the klystrons outside of the central frequency is estimated to be no greater than -200 dB of the central frequency. Filtering may be able to reduce this to levels which would not cause appreciable interference in most cases.

The reflected beam at 2.45-GHz, in the harmonics, as well as at other frequencies generated by the rectenna structure itself, would result in a complicated power spectrum which would change in time as the rectenna ages. The radiation patterns are expected to be 10^{o} or broader and partially directive.

- Optical and thermal emissions. The reference satellites would reflect sunlight in three major ways:[3, 4] 1) diffuse reflections from the solar arrays, the antenna and the underlying structure; 2) specular mirror-like reflections from the solar arrays and the antenna; 3) glints or specular reflections from the underlying structure. Diffuse reflections would cause each satellite to appear as bright as the planet Venus at its brightest phase (magnitude = -4.3). Specular reflections would occur near the equinoxes just at local sunrise or sunset (i.e. on the same meridian as the satellite) and would cause a 330 kilometer-wide spot of light several times brighter than the full moon to sweep across the affected area in a few minutes. Glints from components of the satellite's structure are not expected to be as serious as the diffuse or specular reflections and in any event, may be significantly reduced or eliminated by proper structural design.

In addition to reflecting sunlight, the satellite would also emit thermal radiation of an estimated intensity of 6.3×10^{-6} watts per square meter at the earth. The precise wavelength peak depends on the details of the characteristics of the satellite's components (e.g., type of cell, type of antireflection coating, etc.) but would likely fall in the 5-10 microns band.

Laser Satellites

As with the other characteristics of laser systems, the electromagnetic characteristics of the laser satellite are ill defined. However the following general radiation effects can be expected. Quantitative data will be available only after the systems become more highly defined.

In general, laser systems would reflect sunlight from the laser platform and from the relay mirrors in LEO and GEO, if any. In addition, they would radiate thermal energy, most probably in the 5-10 micron region of the infrared. They would not reflect or emit detectable amounts of microwave power.

- Reflected sunlight. The brightness of laser satellites at GEO or LEO would depend on the mode of power collection and conversion (e.g., photovoltaic or direct solar pumped) and the overall size of the satellite. Optically, the most important differences are that the LEO satellite would be brighter and perceived as moving slowly by terrestrial observers.

  Because they would be smaller than the reference system satellites, individually they would also be less bright. However, there will be more of them. (If laser satellites could be made to operate with the same efficiency as the microwave designs, 5 1000 MW or 10 500 MW satellites would be needed to equal reference system capacity.) Laser relay mirrors in LEO and GEO would contribute both stationary and moving sources of light. However, because of their small size (several meters), they are not expected to be readily visible from the earth.

- Heat radiation. Because an appreciable amount of the sunlight which is intercepted by the laser satellite would be absorbed and reemitted as heat, the satellite, whether in GEO or LEO, would be a diffuse infrared radiator.

- Laser beam characteristics. The two major current laser alternatives operate near 5 microns (CO laser) or 10 microns (CO_2 laser) infrared wavelengths. Because the beams are highly directive, they would not be very observable in the infrared except for receivers placed very near the laser ground stations. Scattered light from the beam would be detectable in the lower part of the atmosphere.

Mirror Satellites

Because the mirrors are designed to simply reflect sunlight, their emissions would be only slightly altered from the original solar spectrum (i.e. they wouldn't radiate appreciable infrared or microwave radiation). Those emisssions would be large, however, for the ground base into which the sunlight is directly reflected (i.e. the equivalent of one sun).

- Terrestrial observers away from the ground site would see moving patches of light about 0.5 min arc across. The precise apparent brightness of the mirrors will depend on a number of factors, e.g., the orientation of the mirror with respect to the observer, the relative position of the sun from both the mirror and the observer, the albedo of the reverse side of the mirrors, and the atmospheric conditions above the ground station. Scattered sunlight from aerosols and dust high in the atmosphere would be observable at up to 150 km from the ground station.

NOTES

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only RF (not microwave)

IV. The Interaction Between Biological Systems and Electromagnetic Waves

Microwave radiation is a form of electromagnetic energy which is used in numerous commercial, industrial, military, and medical devices including microwave ovens, radar, diathermy equipment, and sealing instruments. The microwave band accounts for frequencies ranging from 300 MHz to 300 GHz. Who says?

The extent and consequence of exposure of biological systems to microwaves depends on the following characteristics of the incident energy, the biological organism and surrounding environment. The reader is referred to Reference 1 for a more detailed discussion of the biophysics of RF interaction w/ biological systems.

- Frequency of Electromagnetic radiation - The frequency of radiation is related to the energy of the incident wave. Microwaves are called "nonionizing" because they do not posses enough energy to ionize, i.e., to eject an electron from a molecule or atom. The bioeffects of x-rays and other ionizing radiation are ~~thought~~ known to be more severe than those resulting from the nonionizing portion of the spectrum.

  The frequency also determines the depth of penetration when an electromagnetic wave is incident on biological material. In general, the lower the frequency, the greater the depth of penetration. For example, infrared waves penetrate no deeper than human skin, whereas microwaves are absorbed in human muscle.[2] The relationship between frequency or wavelength (frequency is inversely proportional to wavelength) and the size of the irradiated body is also important. Resonance (i.e., most efficient absorption) will occur when the length of an organism measures approximately half of a wavelength of the incident electromagnetic field. For example, the resonance frequency (SAR) for the male human body is on the order of 70-100 MHz, whereas the maximum absorption rate for rats occurs at 2.45 GHz.[3] Thus, an electromagnetic wave may elicit a very different response from organisms of two different sizes (assuming that the amount of energy absorbed is the dominant determinant of a biological response).

  Understanding of the functional dependence of bioeffects on frequency is not complete. The existance of frequency windows, i.e., effects observed over one specific range of frequencies is not well understood.

- Intensity of Incident Wave. The energy carried by an electromagnetic wave per unit area and time is called its power density and is measured in units of milliwatts per square centimeter (mW/cm^2). Heating or thermal effects are generally thought to occur at power

ē fat ē skin!

densities greater than 10 mW/cm2. Effects at much lower power densities have been postulated but the existance and consequence of "nonthermal" phenomena remains in dispute. Power density windows have been observed experimentally in which bioeffects are noted only over a specific range of power densities and not above or below.

Recently, the microwave community has adopted the specific absorption rate (SAR) as a measure of the energy absorbed by a biological organism. The SAR is expressed in units of milliwatts per gram (mW/gm). It is a function of the power density and weight of the irradiated organism. While the SAR provides more information about the bioeffects of microwaves than does of the power density alone, it cannot be used to wholely predict the effects of exposure to microwaves. The SAR is averaged over the entire body; it does not reflect energy absorbed differentially in specific body parts. It also does not account for possible nonthermal effects. Furthermore, it does not measure the "biological effectiveness" of a microwave, i.e., its ability to induce an effect which is dependent on parameters such as the relation between the frequency and size of subject or body part.

entirely

consider?

- Duration of Exposure. For thermal effects, the length of exposure may influence the body's ability to cool. Heating resulting from long duration exposure of high intensity waves may overwhelm the natural cooling system. At lower power densities, i.e. "nonthermal" levels, the cummulative or long-term effects are not known.

- Waveform. It is thought that the biological consequences of exposure to continuous wave radiation is usually less severe than from that which is pulsed or modulated, although basic appreciation of the mechanisms of interaction is lacking.

- Subject Characteristics. Bioeffects are species-specific, primarily because the factors which determine energy absorption such as size, structure, body, insulation and heat dissipation and adaptive mechanisms vary with species. The composition and geometry of biological matter also determine the depth of penetration and wave characteristics; tissue, muscle and fat each exhibit different dieletric and conductive properties. Thus, without adequate theories of interaction, extrapolations from animal studies to human bioeffects are extremely difficult. The sex, age and state of health of an irradiated subject may also be an important factor, since size and susceptibility to certain kinds of effects may differ with respect to these parameters. It also appears that electromagnetic radiation may act synergistically with drugs. The differential absorption of energy may result in hotspots. This relatively increased energy deposition in cells, organs or parts of the body relative to its surroundings could lead to very specific biological effects after exposure.

  The orientation of the organism with respect to the electric field component of the wave is also important - the most energy is absorbed when the electric field is parrallel to the long axis of the body. In animal experiments, physical restraints or sedation might influence study results. Measurement devices such as implanted probes could also alter the field distribution. The prediction of bioeffects may also be complicated by movement of the subject in the field which changes the absorbed energy dosage and may result in modulation of the field.

Finally, the effects of whole body irradiation may differ from partial body exposure especially since resonance might occur for smaller body parts such as the head or testes.

- Environment. The humidity, temperature, and air circulation of the surrounding environment will affect the ability of a heated biological entity to cool. Objects near the electromagnetic field could also enhance, reflect, absorb or distort it. For SPS, the effects of the space environment on the biological response to microwaves are not known.

NOTES

1. Baranski, S., and P. Czeiski, Biological Effects of Microwaves, Dowden, Hutchinson and Ross, Inc., Pennsylvania, 1976.

2. Phillips, R.D., et. al., Compilation and Assessment of Microwave Bioeffects: A Selective Review of the Literature on the Biological Effects of Microwaves in Relation to the Satellite Power System (SPS), Final Report, DOE/NASA, May 1978.

3. Berman, E., "A Review of SPS-Related Microwaves on Reproduction and Teratology", in The Final Proceedings of the Solar Power Satellite Program Review, April 22-25, 1980, DOE/NASA Report Conf. -800491, July 1980.

V. SPS Related Microwave Bioeffects Experiments

In conjunction with the SPS DOE assessment, three studies were initiated and managed by EPA.[1]

- Exposure of bees to 2.45 GHz at 3, 6, 9, 25 and 50 mW/cm^2. No statistically significant effects on behavior, development or navigation have been observed following short term exposure. However, the experiment has suggested that some type of electromagnetic effect acting on the more sensitive individuals within the population might occur. Long term exposures are planned and should clarify this possible effect. It has also been proposed that tests of effects on bee navigation be carried out in the absence of sunlight (which may possibly mask microwave induced effects).

- Immunology and hematology studies of small mammals exposed for short durations to about 20 mW/cm^2, 2.45 GHz microwaves. No effects have been reported so far.

- Experiments testing the effects on the behavioral and navigational capability of birds subjected to acute and chronic exposures of 2.45 GHz fields. Some mortality has resulted from exposure to 130 - 160 mW/cm^2 microwaves and has suggested that species and body geometry determine tolerance levels. Generally, no statistically significant effects have been detected at power densities of 0.1 - 25 mW/cm^2. Some birds chronically exposed to 25 mW/cm^2 have exhibited an increase of aggressive behavior, attributed to hot spots.

NOTES

1. Dodge, C.H., Rapporteur, Workshop on Mechanisms Underlying Effects of Long-Term, Low-Level, 2450 MHz Radiation on People, Committee on Satellite Power Systems, Environmental Studies Board, National Academy of Sciences, July 15-17, 1980.

VI. Laser Bioeffects

Lasers are unique among light sources because of their capacity to deliver an enormous amount of energy to a very small area at a great distance.[1] The primary biological consequence of this property is heating. However, nonthermal mechanisms have also been suggested.[2] For example, photochemical reactions are thought to be responsible for damage of biological organisms exposed to ultraviolet lasers.[3] High laser power densities may also cause injury from shockwaves or high electric field gradients.[3] Biological electromagnetic interference effects have also been proposed.[4] Clearly, the mechanisms of interaction between laser light and biological entities are not completely understood. Like microwaves, little is known about the cumulative or delayed effects of chronic exposure to low levels of laser light.[5] In general, the higher the power and the shorter the period, the greater the damage.[1] The extent of the effect also depends markedly on the characteristics of the irradiated biological material. Of primary importance is a tissue's absorptivity, reflectivity, water content and thermal conductivity.

The organ of the body most sensitive to laser radiation is the eye. The ocular media of the human eye transmit light with wavelengths between 400 and 1,400 microns.[6] There are two transmission peaks in the near IR at 1,100 and 1,300 microns. Light in the visible and near IR spectrum is focused towards the retina. The refraction of the laser beam by the ocular media amplifies the light intensity by several orders of magnitude.[7] As a result, in this spectral region the retina can be damaged at radiation levels which are far less than those which produce corneal or skin damage.

For lasers that emit wavelengths outside of the visible and near IR range, the ocular effects are quite different. At UV wavelengths, for example, light is absorbed primarily by the cornea, which can be injured by photochemical reactions. Infrared radiation is not focused on the retina either, but is absorbed by the cornea and lens. Most of the radiation from the CO_2 laser is absorbed in the 7 micron tear layer of the cornea.[8] Continuous irradiances of the order of 10 w/cm^2 could produce lesions within the blink reflex.[9] Corneal damage may be reversible or repairable but severe damage may result in permanent scarring, blurred vision and opacities.[3] The lens is particularly susceptible to injury because of its inability to eliminate damaged cells. Lenticular damage characterized by cataracts or clouding may occur at irradiance levels which do not produce corneal injury. For example, "glassblowers cataracts" are thought to result from chronic exposure to 0.08-0.4 W/cm^2 infrared radiation.[7] Proposed thermal limits for pulsed CO_2 lasers range from 0.2 W/cm^2 to 1.0 W/cm^2,[3] but this recommendation requires further study.

Effects on the skin from absorbed radiation may vary from mild erythema (sunburn) to blistering and/or charring.[3] The principal mechanisms of injury by IR radiation is thermal and is a function of tissue reflectance, spectral depth of penetration and the size of irradiated area. Since thermal burns are produced at temperatures higher than that which causes pain, in most current occupational situations the pain can serve as warning. A definite sensation of warmth is produced from CO_2 lasers at 0.2 W/cm^2 over an irradiated area, only 1 cm diameter, or 0.01 W/cm^2 for full body exposure.[7] Heat stress should not be overlooked. More research is needed to determine the effects of chronic or repeated exposures.

As was the case for exposure to microwaves, the determination of laser thresholds and standards is exacerbated by problems of detection and measurement, instrument sensitivity, dosimetry, interspecies and interfrequency extrapolation, and lack of complete knowledge of physiological systems, mechanisms of interaction, and synergistic effects. Experiments also make clear that the extent of the superficial or immediate lesion is no guage of total damage.[1]

The exposure limit for continuous wave IR lasers as recommended by ANSI is 100 mW/cm^2 for exposures over 10 seconds and for small spot sizes on the skin or eyes.[10] A whole body irradiance limit of 10 mW/cm^2 has been suggested.[9] It should be stressed that the protection standards for repetitive and chronic exposures and for wavelengths outside the visible band are based on a considerable amount of extrapolation. Data obtained from nonlaser sources, such as bright, small-source lamps and high luminance extended sources cannot accurately and wholly represent the effects of laser radiation in determining injury thresholds for UV and IR lasers directly.

NOTES

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10. American National Standard for the Safe Use of Lasers, ANSI (R) Z136.1-1979, American National Standard Institute.

11. D.H. Sliney and D.L. Conover, "Nonionizing Radiation" in L.V. Cralley and P.R. Atkins (eds.) Industrial Environmental Health, Academic Press, N.Y., 1975, pp. 157-172.

VII. General Health and Safety of SPS Space Workers

The human body's tolerance to acceleration depends on the duration and magnitude of the acceleration, the positioning of the body relative to the accelerating force, the restraint and support systems of the spacecraft and the time spent in a weightless state.[1] Research is needed to quantify effects as a function of these parameters and to determine the tradeoffs between short duration, high acceleration and longer duration, lower acceleration effects. Studies should also evaluate the tolerance in the population that may fly in space (since variation in individual response levels are great) and explore possible ways to reduce harmful effects (e.g. control oxygen pressure and temperature).[1]

Weightlessness is known to induce a number of physiological responses such as decreased heart rate, shifting of fluids to the upper body, decrease of muscle mass and loss of bone proteins.[2] Most of the observed effects have been temporary; only bone calcium loss appears to require a long period of recovery following return from space.[2] For SPS, however, the effects of periodic weightlessness over a long time period needs to be investigated. Moreover, ameliorative measures suitable for a large number of people with broad physiological characteristics must be investigated.[2]

Workers would be exposed to electric fields generated by the collection and transmission of large amounts of electricity across the solar panel and antenna, but effects of electric and magnetic fields on biological systems are not well understood.[1] Research is needed to determine the bioeffects of magnetic fields generated by satellite electric currents, as well as to assess the effects of field absence, as GEO is largely outside of the earth's magnetic field. Some space workers could also be exposed to high levels of microwaves. The effects of microwaves in a space environment deserves special attention. It is known, for example, that microwaves can work synergistically with ionizing radiation to increase the biological effectiveness of the latter.[3] Research would be required to determine bioeffects and if possible, to develop suitable exposure limits and protective clothing.

Psychological impacts must also be assessed, especially since there is little information on large, mixed gender groups working in close confinement for prolonged periods. Studies should also consider the effects on worker's families and friends and possible mitigation measures such as screening techniques, recreation facilities, social management, etc. selection

Space workers could be prone to greater safety risks than their terrestrial counterparts because of the possible awkwardness of working without gravity.[1] Risks also stem from the high voltage equipment and handling of toxic materials. There is a danger that spacecraft charging could produce electric shocks great enough to injure or kill workers, although this might be avoided by a judicious choice of spacecraft material. Catastrophic collisions with meteoroids or space debris are also possible, given SPS's large size. Extra-vehicular activity may also create hazards.

NOTES

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

2. Program Assessment Report, Statement of Findings, Satellite Power System Concept Development and Evaluation Program, DOE/ER-0085, November 1980.

3. Baranski, S. and ~~P.~~ Czerski, Biological Effects of Microwaves, Dowden, Hutchinson and Ross ~~frey~~, Inc., Pennsyvania, 1976.

VIII. DOE Comparative Environmental Assessment

DOE has sponsored comparative environmental assessments between the following energy technologies: conventional coal (CC), coal gasification/combined cycle (CG/CC), light water reactor (LWR), liquid metal fast breeder reactor (LMFBR), magnetically confined fusion (MCF), central station terrestrial photovoltaics (CTPV), and the reference system solar power satellite (SPS). An analysis was performed to quantify and compare the effects of these technologies on environmental welfare (i.e., effects which are not directly related to health and safety such as weather modification, resource depletion and noise), health and safety and resource requirements. Unquantifiable health impacts were also identified, but were not ranked (see Figure D-3). The major conclusions include:[1]

- With respect to effects on the enviornmental welfare, all of the energy options except for coal (because of CO_2 climatic alterations and acid rain) are roughly comparable in magnitude, while different in nature.
- As shown in Figure D-4, it is apparent that the quantified public and occupational health risks of all of the technologies except coal are about the same in magnitude, but different in cause. The health effects which were not included in this analysis are listed in Figure D-3.
- Land use comparisons indicate that the land area required for SPS would be similar to that for CTPV. Coal utilizes slightly less total land area. This is distributed among many mining sites as opposed to the large contiguous land space needed for SPS and CTPV. The nuclear technologies require the least total land area.
- While each technology would encounter material constraints, none appear insurmountable. Water requirements are listed in Figure D-5.
- All technologies considered are not energy producers when operating fuel requirements are excluded form the calculations. Otherwise, only the inexhaustible technologies are net producers.

NOTES

1 Program Assessment Report, Statement of Findings, Satellite Power Systems, Concept Development and Evaluation Program, DOE/ER-0085, November 1980.

Figure D - 3 Unquantified Health Effects[a]

Solar Technologies (CTPV, SPS)	Nuclear Technologies (LWR, LMFBR, MCF)
Exposure to cell production emissions and hazardous materials	System failure with public radiation exposure (including waste disposal)
Chronic low-level microwave exposure to the general and worker populations (SPS)	Fuel cycle occupational exposure to chemically toxic materials
Exposure to HLLV emissions and possible space vehicle accidents (SPS)	Diversion of fuel or byproduct for military or subversive uses
Worker exposure to space radiation (SPS)	Liquid metal fire (LMFBR, MCF only)

[a]No unquantified health effects were identified for the coal system used.

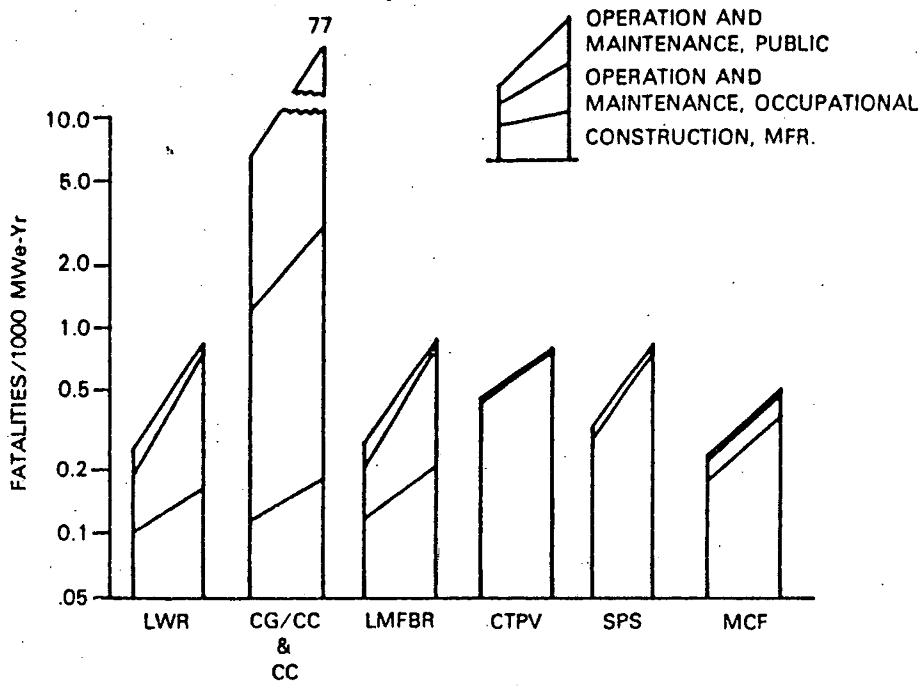

Figure D - 4 Quantified Health Effects

Figure D - 5 Water Requirements for Alternative Energy Technologies

Technology	Cubic Meters per Gigawatt Year
Conventional coal	77×10^6
Light water reactor	37×10^6
Liquid metal fast breeder reactor	32×10^6
Coal gasification/ combined cycle	14×10^6
Magnetically confined fusion	39×10^6
Satellite power system	$\approx 1 \times 10^3$
Central station terrestrial photovoltaics	$\approx 1 \times 10^4$

Source: Ref. 1