CHAPTER 7

THE INTERNATIONAL IMPLICATIONS OF SOLAR POWER SATELLITES

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INTRODUCTION

The development of solar power satellites (SPS) requires consideration from the perspective of its international implications. First, as a space technology SPS would operate in a global medium, outside of any national territory, which is subject to international law embodied in existing treaties and agreements. Secondly, as a major energy project the SPS would affect supply and demand for what is by far the largest commodity traded on international markets, one that is of vital interest to all countries. Thirdly, because of its tremendous cost and technical sophistication an SPS system could have a strong effect on the economies of states involved in its construction. And finally, development of an SPS and of the launchers needed to build and maintain it may give its builders significant military and/or economic leverage over other states.

This chapter will look at the SPS primarily from a political perspective, because in the final analysis SPS development will depend on national efforts, instigated by national leaders, paid for– in large part– by public funds. The United States is the only country in which there is any likelihood that there would be significant private-sector responsibility for SPS decisions. The importance of national efforts would be especially crucial in the near future when SPS projects are in the R&D and prototype construction phases.

Actors. – If SPS is developed, Government involvement would be guaranteed because SPS would affect vital national interests in a number of areas, e.g., external security, prestige and influence, and economic growth. Energy policy in itself has become a central component of national planning in most countries.

Nonstate actors would be involved as well. On the international level these include global organizations such as the United Nations and its specialized agencies; multilateral groups such as the Organization for Economic Cooperation and Development (OECD) and OPEC; and regional groupings such as the Common Market and the European Space Agency (ESA). On the substate level there are numerous interests, including those of private companies, public utilities, and governmental agencies, that often conflict and that seek to influence national decisions. Furthermore, the role of the large multinational corporations in international relations is in some areas very great and often independent of direct government control

However, for the SPS, national decisions and interests are likely to predominate. Although the rise of energy as a major global concern has led to the formation of numerous international organizations (such as the International Energy Agency) and to intense discussion of the global dimensions of energy prices and shortages, the overall impact has been to place decisions about energy consumption and production more and more firmly in the hands of national governments. In general, it seems that the role of the state in furthering peace and security, stability, prestige, and economic well-being has not been supplanted by other entities.

Forecasting. – Because SPS is a project which, if pursued, will not reach fruition for at least 20 years, assumptions must be made about future political and economic developments. Since radical changes are by definition unpredictable, these will be unavoidably conservative. In general, it is assumed that the basic political and socioeconomic alinements of today's world are likely to continue. In the past, fundamental realinements of the international political structure have often been the result of major wars or of deep-seated alterations in political and social expectations, neither of which can be confidently predicted. Even relatively small shifts in public support for various programs can have large effects; increasing skepticism in American and European attitudes towards the space program and nuclear energy in the late 1960's and early 1970's, for instance, has decisively affected our current space and energy capabilities.

DEGREE AND KIND OF GLOBAL INTEREST IN SPS

National and regional interest in the SPS will stem from an evaluation of the ways an SPS system would affect all the components of national interest outlined above. The degree and kind of interest shown will vary from nation to nation. In deciding what institutional structure to use for SPS development, it is crucial to take these various foreign interests into account. In this case, interest can be divided — somewhat arbitrarily— into economic and noneconomic components. The economic interest in SPS would be focused on SPS's ability to provide electricity, and hence on the local demand for electricity over the time SPS becomes available. Noneconomic concerns would include prestige and national security interests.

Economic Interest

A recently completed study by the international Institute for Applied Systems Analysis (IIASA), Energy in a Finite World,[1] provides the most up-to-date projections of long-range future global energy demand. The IIASA study uses a global model with several different scenarios, broken down on a regional basis. We will present the high and low estimates to give the entire range of predictions; it should be noted that the lower estimates are closer to those of some recent U.S. studies, such as Energy in Transition 1985-2010, by the National Academy of Sciences.[2] (See app. C.) In general the slowdown in gross national product (GNP) growth over the past several years, and the sharp rises in oil prices in 1979, have caused recent energy forecasts to be much lower than those of only a few years ago. Since OTA believes that IIASA's analysis may tend to overestimate future energy demands (see app. C), especially in the advanced industrialized countries, the following figures should be used with some caution.

The IIASA projections for primary energy demand are based on an integrated model in which supply and demand are matched on a global basis (see table 24). (See app. C.)

Historically, the rate of growth in electrical demand has been approximately twice as high as that of total energy demand. IIASA predicts that it will remain higher, but by a factor of 1.4 instead of 2.0.[3]

Currently, electricity accounts for an average of 11 percent of global end-use energy, ranging from 6.5 percent in developing countries to 12 percent in the OECD. By 2030, IIASA expects this figure to rise to 17 percent (in both high and low scenarios), with developing countries using 13 percent and OECD 21 percent, reflecting an annual increase in usage of 2.6 percent (low) to 3.4 percent (high).[4]

[1] Energy *in a* Finite *World,* A *Global* Systems Analysis, Energy Systems Program Group, International Institute for Applied Systems Analysis (Cambridge, Mass.: Ballinger Publishing Co., 1981).

[2] *Energy in Transition 1985-2070* (Washington, D. C.: National Academy of Sciences, 1979).

[3] Finite *World,* op. cit., p. *482.*

[4] Ibid

Table 24.—Primary Energy Demand (Quads)

	1975	2000		2030	
	—	Low	High	Low	High
OECD	146.8	200.3	224.5	266.3	393.4
SU/EE (Soviet Union, E. Europe)	55.0	98.9	110.3	149.4	219.1
Developing	37.7	107.0	148.9	253.8	453.1
Global Total	239.5	406 .2	503.7	669.5	1,065.6

SOURCE: *Energy in a Finite World;* conversion to Quads done by the Office of Technology Assessment.

Electricity use is affected by many factors, including changes in end-uses, (such as heat pumps or electric cars), saturation of demand, and the cost and availability of fuel (see ch. 6). Table 25 shows the IIASA figures for end-use electricity demand.

Assuming 70-percent load factors and 15-percent losses in transmission and distribution, IIASA estimates for installed generating capacity in 2030 are shown in table 26.

Although the IIASA report is pessimistic about the possibility of extensive use of alternative energy sources, such as fusion or ground-based solar, by 2030, it points out that a breakthrough in fusion or solar-cells would change the supply and cost of electricity drastically. Cheap photovoltaics might encourage a shift towards a "hydrogen economy, ''with electricity produced in high-insolation desert areas being "stored" and transported as hydrogen.[5]

Barring such developments, future baseload electrical demand will be met overwhelmingly by coal and nuclear sources (see app. C). IIASA also predicts that coal will be used extensively for producing liquid fuels, especially in coal-rich regions such as North America and the Soviet Union — up to 55 percent of coal production in North America by 2030[6] (see app. C).

[5] Ibid., p. 163.

Table 25.–End-Use Electricity Demand (Qe)

	1975	2030	
	—	Low	High
OECD	12.5	35.3	50.2
SU/EE	3.9	15.5	25.4
Developing	1.8	23.3	41.3
Global Total	18.2	74.1	116.9

SOURCE: *Energy in a Finite World,* p. 659. These numbers should be taken as approximations, since they are based on IIASA estimates of the percent of end-use demand that will be met by electricity. For graphic presentation, see *Energy,* p. 481.

Table 26.—Amount of Global Installed Capacity (GWe)

1975	2000		2030	
	Low	High	Low	High
1,600	3,550	4,390	6,320	9,845

SOURCE: *Energy in a Finite World,* p. 483.

Regional Variations

In order to understand how different countries might view SPS, it is crucial to highlight the major regional differences that will affect demand for electricity. Foremost among them is the question of regional or national self-sufficiency.

SELF-SUFFICIENT AREAS

In the 50-year time-frame considered, it appears possible for three major consuming regions — North America, Soviet Union/Eastern Europe, and China –to achieve energy self-sufficiency. This would require rapid development of indigenous sources of North American oil shale, tar sands, and Western coal; for the Soviet Union, untapped oil, gas and coal reserves in Central and Eastern Siberia; for China, development of oil and coal deposits and expanded exploration in Western China. In all three cases very substantial growth in nuclear and/or solar, hydro, and other generating sources would also be required. With the possible exception of U.S. and Soviet coal, none of these regions is likely to export significant energy supplies, since indigenous growth will absorb most new capacity even under optimistic scenarios.

The costs of achieving regional self-sufficiency would be very high. Development of North American oil shale and tar sands, for instance, on a scale sufficient to produce oil and gas in quantities comparable to the large commercial oilfields of today, will cost hundreds of billions of dollars. Such development will also be "dirty" environmentally, involving extensive surface-mining, and hence expensive to clean up and to regulate.

In the Soviet Union, currently the world's largest oil producer, finding the capital for major energy investments during the 1980's will be difficult. Inefficiencies in central planning practices are likely to be magnified as de-

[6] Ibid , p 669,

mands for consumer goods and services increase.

China's energy production potential is not well enough known to predict future supplies with any certainty. Oil, coal, and oil shale are known to be present in large quantities. Current modernization plans call for sizable energy investments.

ENERGY-DEPENDENT AREAS

Regions without sufficient local resources will include Western Europe, Japan, and large portions of the (currently) developing world. Western Europe and Japan can be expected to invest heavily in nuclear plants, especially fast breeders.

Unfortunately neither Western Europe nor Japan is in a good position to exploit alternate nonnuclear technologies to alleviate dependence on imported oil. Except for a relatively small part of Southern Europe, average annual insolation is low—only 1,000 kWh/m^2 in Central Europe, compared to 2,500 kWh/m^2 in Arizona. ' Hydroelectric resources are limited and already extensively developed. There are no large wooded areas to provide biomass, and regional cropland in densely populated regions is scarce.

It is likely that Western Europe and Japan will try to develop assured foreign sources for future needs. This may take the form of joint development of capital-intensive North American energy projects, gaining through partial ownership an assured source of supplies. Foreign interest in U.S. coal, including investment in mines and shipping facilities, has accelerated since the 1979 rise in oil prices.[8] However, it is unlikely that national policy in the United States and Canada will permit extensive ownership of energy resources by foreign countries or enterprises, or significant exports of nonrenewable fuels, even to friendly countries. Though the size of the capital requirements may allow for foreign participation, it will not be enough to alleviate European or Japanese shortages. Investment in or legal control of foreign assets provides little insurance against price rises or expropriation, when the local government is so inclined.

The underdeveloped energy-poor regions vary greatly in their levels of development and their degree of energy dependence. In virtually all cases oil-price rises have seriously hampered economic growth.[9] In some instances the increases have spurred development of indigenous sources– nuclear plants in Brazil, Argentina, and India; biomass in Brazil; numerous small-scale hydro and solar projects suited for decentralized generation. It is in the less developed countries (LDCs) that the greatest proportional surge in energy demand and electrical usage will come over the next 50 years, rising from 12 percent'" to 31 to 35 percent of global electrical demand (see app. C). Decentralized systems can be effective in regions without developed utility grids and where demand is for small units for domestic, agricultural, and light industrial use. But the baseload power needed for extensive growth and modernization will be expensive and in short supply.

ENERGY-EXPORTING AREAS

Current energy-exporters include OPEC members as well as a few non-OPEC oil producers, such as Mexico, Malaysia, and the Soviet Union. Over the next 50 years, many current oil-surplus states will cease to export, due to increased domestic consumption and/or decreased output. The time and rate at which current oil production in exporting countries will diminish depends on the rate of consumption as well as future discoveries. IIASA predicts only small increases in exporting country production through 2030, with demand increases being met primarily by coal liquefaction and unconventional oils. The report emphasizes that: "The 'energy problem,' viewed with a sufficiently long-term and global perspective, is not an energy problem, strictly speaking, it is an oil problem, or, more

'K. K. Reinhartz, "An Overview of European SPS Activities, " *Final Proceedings of SPS* Program Review, Department of Energy, April 1980, p. 79.

[8]See "The Coal Ships," *Washington* Post, Oct. 13,1980, p. 1.

'See Energy *in* the *Developing Countries,* World Bank, August' 1980, pp 3-6

'"I bid , p 44.

precisely, a liquid fuels problem.''[11] As demand grows over the next 50 years, the ability of countries to import such fuels to make up for local shortfalls will dwindle, and prices will rise sharply.

In summary then, the 50-year forecast is for an increase in demand for energy of some three to four times, and an increase in demand for electricity of some four to six times with rates being somewhat higher in the currently developing regions. These forecasts are based on a declining rate of growth in GNP, averaging some 2.7 percent (in the low scenario) to 3.7 percent (high scenario) per year. (Compared to a global average of 5 percent from 1960 to 1975.) In general, energy scarcity will cause higher prices, reducing demand and increasing supply. The question is whether future supplies will be so high cost as to force a radical change in living standards and growth rates. Maintaining a moderate rate of growth in the developed countries and a somewhat higher growth rate in the developing world —to provide for population increases as well as the prospect of real increases in living standards —will place demands on energy resources that guarantee that energy costs will consume a larger proportion of national income than in the past. IIASA predicts an increase of 2.4 to 3.0 times in the proportion of gross domestic product (GDP) spent on energy. Even if IIASA's projections prove to be on the high side, future energy sources can expect to be competitive within a very high-cost ceiling.

SPS Contribution

SPS could begin to provide electricity by 2010-20 and could be a substantial source of new power within the selected 50-year period. None of the global projections to date has considered the possible impact of an SPS system on future energy scenarios. The rise in electrical consumption is expected to be met by large increases in coal-fired generators and nuclear plants. However, there are serious problems with both methods.

Coal, like oil, is abundant only in certain areas. Unlike oil, it is expensive to ship compared to the cost of mining (because of its bulk), especially overseas and in areas without extensive rail links, While oil and gas are suitable for small-scale household use, coal is expensive to store, and prohibitively dirty to use (especially in urban areas). And increased burning of coal could have disastrous environmental consequences, including acid rain and global temperature increases (see ch. 6). IIASA predicts a 10 to 1.50 C average increase, through 2030, depending on high or low growth rates,

Nuclear plants are characterized by widely publicized environmental dangers. Even if these can be resolved, public opposition to nuclear power, as well as the rapidly increasing costs of building new nuclear capacity, have already delayed the production of nuclear generators, especially in the United States (where alternative fuels are more readily available than in many other countries). Furthermore, the spread of nuclear technology, especially breeders, into more and more parts of the world will almost inevitably make it easier for more states to manufacture nuclear weapons. Since uranium is concentrated in scarce deposits, largely in North America, the Soviet Union, and parts of Africa, many areas will be inclined to depend increasingly on breeders. The safeguards and restrictions set up by the United States to prevent proliferation have been only partially successful when the main reason for building reactors has been prestige-they will be even less effective as energy needs make nuclear plants essential.

For these reasons, SPS may be attractive as an alternative to other methods of generating electricity. In addition, unpredictable factors such as a major nuclear accident or the failure of alternative energy sources could spur interest in the SPS. SPS would by no means replace coal or nuclear power within the next 50 years, but could reduce otherwise excessive reliance on these technologies.

Economic acceptance of an SPS system would depend on several factors. Overall costs of delivered power will be crucial; these must be competitive with other systems. Perhaps equally important would be the division of

[11] *Finite World,* op. cit., p. 653.

these costs between developers, owners, and users and the way these are shared between participating countries. Development of an SPS system would require large amounts of capital and a high level of technical/engineering expertise. There are three distinct areas with capital and expertise: 1) North America; 2) the rest of the OECD countries (i.e., Western Europe and Japan); 3) the Soviet Union and Eastern Europe. Assuming that extensive cooperation between the Soviet Union and other countries is unlikely (see p. 161), the two possible collaborators have somewhat different interests. North America has the requisite technical/industrial capacity in space transportation and related areas, but is potentially energy rich, while Europe and Japan have increasing expertise in aerospace and face continued large energy shortfalls. If the future interest of these possible participants were estimated, North American interest would rate as potentially moderate to high and West European and Japanese (along with some other industrialized areas–South Korea, Taiwan, South Africa, Australia) as potentially very high. In North America, capital and interest in SPS would be competing with coal and synfuel development, as well as nuclear energy; in the rest of OECD, primarily with nuclear development. In general, development of technologies using renewable or inexhaustible fuel sources, (such as SPS, but also fusion, ground-based solar, and biomass) would be preferred to depletable ones.

The possible cooperative mechanisms for SPS development and operation will be discussed later (see Advantages and Disadvantages of Multinational SPS, pp. 159-163). It is important here to see that potential SPS users with limited initial capital and expertise to contribute to an SPS system might need special incentives to participate in buying SPS power. A major economic consideration for such SPS users might be the lack of direct and indirect spinoffs from SPS participation. Ground-based antenna construction would require large amounts of unskilled labor, but would provide few technical or managerial posts. The capability to participate directly in building and deploying the satellite portion of the system is probably beyond the reach of most of the present LDCs over the next 50 years, so that relying on SPS power might be seen as undercutting efforts to develop an indigenous energy infrastructure. Payments to foreign companies for such power would be a drain on scarce foreign exchange reserves compared to development of local resources, which cause ripple effects in the economy. User governments would be sensitive about depending on a foreign high-technology energy source, even if costs and other aspects are favorable.

What is the potential global market for SPS? To date, only the studies by Maurice Claverie and Alan Dupas have attempted to estimate this in any detail. Their recent papers[12] present a possible methodology for making SPS projections. Unfortunately, their results are based on energy demand projections completed in 1976 and 1978 that are now considered to have considerably overestimated future electricity demand'[13,14] (see app. C).

From these projections Claverie and Dupas estimate the maximum demand for large electric powerplants (LEPP) (see map in app. C), and calculate SPS demand assuming either 10-percent or 50-percent market penetration by 5 gigawatt (CW) SPSs (see table 27).

Even allowing for the high estimates of the energy projections used, the Claverie-Dupas calculations must be considered very rough upper estimates of future demand; in particular, cost comparisons with alternative sources were not taken into account. Claverie and Dupas attribute much of SPS's potential attractiveness to environmental and political factors rather than strict cost advantages.[15]

[12]M Claverie and A. Dupas, "Preliminary Evaluation of Ground and Space Solar Electricity Market in 2025," 29th IAF Congress, October 1978; "The Potential Global Market in 2025 for Satellite Solar Power Stations, " May 1979; "Possible Limitations to SPS Use Due to Distribution of World Population and World Energy Consumption Centers, " 31st IAF Congress, September 1980

[13]Edison Electric Institute, *Economic Growth in the Future (New* York McGraw-Hill, 1976), pp. 215-234

"World Energy Conference, *World Energy Demand (New* York: IPC Science and Technology Press, 1978)

'5Claverle and Dupas, "Potential Market, " op cit., p. 4.

Table 27.–SPS Market in 2020/2025 (G We)

	10% of New LEPP		50% of New LEPP	
	CWE[a]	WEC[b]	CWR	WEC
OECD.	135	75	685	365
SU/EE.		40	260	195
Developing . . .	50	85	430	435
Global	275	200	1,375	995

[a]CWR - Case Western Reserve.
[b]WEC - World Energy Conference.

SOURCE: Adapted from Claverie and Dupas, *Potential Global Market,* p. 4.

Within the limits of this study the Claverie-Dupas estimates using the IIASA projections cannot be duplicated. However, by using IIASA'S estimates of installed capacity in 2030, a rough estimate of global demand can be made. We can assume that 20 percent of capacity will be reserve, to guard against outages, and that of the remaining 80 percent, 65 percent will be baseload. Moreover, if we accept Claverie and Dupas' estimate that 10 percent of world demand will be met by decentralized sources, then the global estimate of the maximum possible demand for installed baseload capacity in 2030 would be: 80 percent (peakload) x 65 percent (baseload) X 90 percent = (approximately) 47 percent of total installed capacity.[16] Using the IIASA estimates (table 26) of 6,320 (low scenario) to 9,845 (high) GWe, then we get 2,970 to 4,627 GWe as the potential demand for baseload capacity.

The amount of new capacity supplied by SPS would depend on the percent met by SPS as opposed to alternate generating sources. If we assume 10-percent market penetration there would be demand for 295 GWe (low) to 465 GWe (high); if market penetration were as high as 50 percent (which is not probable, at least by 2030) there would be demand for 1485 to 2315 GWe. However, it should be noted that conventional generators built from 1990-95 on will still be in operation by 2030; since SPS would not be available until 2010-15, the new capacity market will be considerably smaller than the total demand.

The number of satellites this demand represents would depend on their size; estimates range from 5 GW down to 0.5 GW (see ch. 5). Development of smaller sizes would greatly improve the market penetration of SPS by mitigating two serious obstacles: the large size of reference rectennas, and the problems of inserting large blocs of power into utility grids.

Rectenna size in the 5 GW reference design is 10 x 13 km at 350 N., including a 2 km buffer zone. Reducing the size of the design to 1.5 GW would necessitate a receiving antenna only 6.5 X 5.5 km, lowering costs and making siting more feasible. In European demand centers, mostly located from 450 to 650 N., rectennas would need to be much larger. Given Europe's high population densities, many experts have suggested placing rectennas offshore in shallow North Sea waters.[17] Similar problems would be faced in the North-eastern United States, Japan, Eastern China, and India. Though apparently feasible, placing rectennas offshore would add considerably to their cost.

Even more important, a reduction in size would enable SPSs to be used by smaller utility grids, since utilities in developed countries do not generally make use of single generating units supplying more than 15 percent of the utility's total capacity, because of the need to ensure against generator failure (see ch. 8). Conversely SPSs, even in less than 5 GW units, may be a spur to integration of utility grids in order to make use of the SPS's large power increments. Currently, there is widespread integration of national grids in both Eastern and Western Europe. Western Europe has an interconnected high-voltage network, with routine commercial exchanges of power, which is coordinated by organizations such as the "Union pour la Coordination de la Production et du Transport de l'Electricity."[18] In Eastern Europe, Comecon has established an integrated 150-GW grid including all of Eastern Europe and the Ukraine.

[16]See: "SPS—The Implications for the Utility Industry," working paper for OTA workshop, July 1980, p. 12,

[17]P Q Collins, "Potential for Reception of SPS Microwave Energy at Off-Shore Rectennas in Western Europe," *Final Proceedings,* p. 529.

[18]Arnaldo M. Angelini, "Power for the 80's: A Challenge for Western Europe," *Spectrum,* September 1980, p. 44.

Successful integration of national grids is possible only where there is an expectation of long-term stable relations with neighboring countries. Unfortunately, though LDCs could benefit greatly from regional interconnections, such expectations are rare in developing regions where integration may be necessary to accommodate large blocs of power, and to share the costs of building expensive rectennas. Countries and regions with a successful history of cooperation in other areas would be most likely to join together for SPS integration as well.

In many developing regions, where the bulk of the population lives in rural areas, the feasibility of large centralized power plants is reduced by a lack of costly infrastructure, especially transmission lines and end-use capabilities. In such an environment decentralized generating capacity is preferable to SPSs or other large plants. It has been suggested[19] that such countries may be able to make use of large amounts of electricity for producing liquid fuels, such as methanol, directly from the basic elements; such fuels can be easily integrated into economies that currently depend on kerosene or wood for cooking and heating. However, using electricity in this fashion would not be economically feasible. Methanol can be produced from coal at a projected cost of $0.50 to $1 .00/gal. But at 5q/kWhr, the cost just to separate from water the amount of hydrogen necessary to make a gallon of methanol also lies between $0.50 and $1.00. There would be the further expense of providing the necessary carbon (which could be provided from carbon dioxide taken from the atmosphere). However, producing methanol from biomass or from coal (in which the hydrogen, carbon, and oxygen necessary to manufacture methanol are already present) would be far more cost effective. A more reasonable need for SPSs might be for energy-intensive uses such as desalination of seawater or fertilizer production. 20 These projects might be coordinated on a regional basis.

"J. Peter Vajk, *Doomsday Has Been Cancelled,* Peace Press, 1978,

[20]"D. Criswell, P. Glaser, R. Mayor, et al., The Role of Space Technology in the Developing Countries," Space *Solar Power Review, vol. 1,1980,* p. 99.

Geographical location may also be an important factor to developing countries. If the SPS were located in geostationary orbit, it would cost more to beam power to areas located far north or south of the equator. Europe, as we have seen, is at a disadvantage; the Soviet Union is in a similar position. Equatorial and tropical states, on the other hand–most of them LDCs–would be in better positions to build small-size rectennas. Cheaper power could be an incentive to industrial development and foreign investments.

In addition, an equatorial position is optimal for launching payloads into orbit, since the Earth's rotational speed at the equator (approximately 1,000 mph) is higher than at other places on the Earth's surface. Spaceports for sending up SPS construction material might profitably be located near the equator, providing benefits for the countries in which they are placed in the form of rents, infrastructure investments, and training of local administrators and technicians.

Earlier it was assumed that the Soviet Union, barring some radical change in its political and social institutions, would not participate in a cooperative SPS venture, except with its East European allies. As a major space power, the Soviet Union has the ability to go it alone, though without a global market for its product the costs would be considerable. The Soviet Union has a number of economic reasons to consider an SPS system, including its increasingly remote and expensive conventional energy resources, and the large investment it has put into its space program (currently estimated at some 1.5 to 2 percent of GNP, compared to 0.3 percent in the United States[21]). The large distances involved in providing electricity to many areas within the Soviet Union are an incentive to develop a system in which power can be sent directly to the area being served, without transmission lines and without transporting fuel long distances, The Soviet Union has a penchant for big projects, especially when competing with the West. However, currently there is no firm indication that

"Walter A McDougall, "The Scramble for Space," *Wilson Quarterly*, fall 1980, p. 81.

the Soviet Union intends to proceed with an SPS.

Noneconomic Interest

Any SPS system would have numerous noneconomic aspects relating to national prestige and security, and different national and regional interests can be expected to conflict. There are three separate "arenas" in which such conflicts might arise.

Within OECD

Although cooperation between the United States and other OECD allies is probable, there would likely be a high degree of competition centered around economic interests. Control of any joint program, the division of responsibilities between countries, and the apportionment of economic benefits to be gained from contracts let during R&D and construction, are all potential problem areas. In the case of SPS, the industries involved —aerospace and energy—are high-prestige ones in which many countries wish to develop independent capabilities. Fear of economic and technological dominance by the United States, or of U.S. failure to follow through on program commitments, may be a spur to accelerated development of European or Japanese launch vehicles and construction facilities. The ESA's Ariane expendable launcher program has been largely motivated by worries about such dependence, especially by France, Ariane's prime mover. Japan has announced plans for a new generation of launchers, and non-OECD countries such as Brazil and India have built sounding rockets and satellites. Increased competition with the United States can be expected over the period of SPS development.[22]

East-West

Development of an SPS by the Soviet Union would have major international consequences. Since Sputnik, each side has reacted to the actions and statements of the other. Although space successes may no longer be seen as proof of the superiority of one social system to another, as Khrushchev used to claim, they are still a vehicle for peaceful competition, and a way of impressing allies and potential allies with individual achievements. Because of its scope and visibility, the SPS would be a major symbol of successful efforts in advanced technology. "Visibility" here is meant literally:[23] a completed SPS, even in geosynchronous orbit, would be easily visible to the naked eye. The impact of such an effort would be direct and great. It is unlikely that the Soviets could allow a U.S. or Western SPS to go unchallenged. If they felt they could not compete successfully, they would be likely to try to block construction by emphasizing environmental dangers or supporting Third World demands for shared control over orbital positions. On the other hand, a Soviet SPS effort would encourage U.S. projects by acting as a spur to public opinion and raising fears of Soviet ascendancy.

North-South

Many Third World states would be antagonistic to SPS development, insofar as control of the system rests with industrialized countries, West or East. These states would be concerned about increased economic and technical dependence on the "North," and the limited opportunities for meaningful participation in an SPS system. The SPS could be charged with diverting funds from development projects and with increasing the gap between the developed and underdeveloped worlds. International forums such as the United Nations and its specialized agencies could be used as foci for investigations of any proposed SPS systems and for discussion of legal measures to bloc them or to give the LDCs various sorts of leverage.

Many developing countries have invested heavily in industries such as steel and oil refining in part because of the prestige value of such large and advanced sectors. Energy production is a prominent example–witness atomic reactors and hydroelectric projects such as Egypt's Aswan Dam. The SPS could be resented because it is unavailable to LDCs;

[22] 1 bid., pp. 71-82.

[23] See: Jerry Grey, *Enterprise* (New York: William Morrow & Co., 1979), p 225

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only the receiving antennas could be built on home territory with local resources. Conversely, large amounts of scarce capital might be spent trying to buy an SPS (if they are for sale) and the lift capacity to service it in an attempt to "keep up" with the advanced countries.

The "South" is by no means monolithic, and, if SPS were built, many states would be potential supporters, some because of the benefits of less expensive electricity and others because of the prospects for future participation. The most likely supporters of an SPS would be energy-poor countries with a rapidly developing urban-industrial base, such as Brazil, Argentina, Kenya, Turkey, India, and South Korea. Any system that reduces Western imports of OPEC oil reduces pressure on prices and means less expensive supplies for vulnerable LDC importers. It has been argued that firm plans for building an SPS would of themselves put a "cap" on oil price rises by sending a signal to exporters that Western imports will drop in the future. [24]

The oil-exporting states are in a special position. An SPS would by no means eliminate oil demand and may prove beneficial by helping to reduce pressure on exporters to increase production to satisfy rising export needs. Countries with large populations and relatively small reserves, such as Nigeria, Indonesia, China and Malaysia, may view SPS as insurance against the upcoming depletion of their oil supplies and may choose to invest some of their current earnings in the hope of long-term gains. On the other hand, exporting countries, especially those with long-term reserve potential such as Saudi Arabia, have no immediate use for an SPS and may be tempted to side with other LDCs —for political and cultural reasons — in attempts to put pressure on the West for greater LDC control. Soviet support for such measures could cause the SPS to become a highly polarized issue in which the Soviet bloc and the nonalined states seek concessions from the West— a not uncommon phenomenon in recent international affairs.

[24] House Committee on Science and Technology, *SPS Hearings on H. f?. 2335*, 96th Cong., March 1979, pp 132-180,

LEGAL ISSUES

The United States and other space-capable states are currently bound by a number of agreements that would affect SPS development.[25] Much of existing international law has been formulated at the United Nations (U. N.) by the Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS). COPUOS has been in existence since 1959, when it began with 24 members. It now has 47, with membership expanding as international interest in space matters has increased. COPUOS decisions have been made by consensus rather than by outright voting.[26]

The most important and comprehensive of the currently applicable agreements, all of which have been ratified by the major space powers, is the 1967 Treaty on Principles Governing the Activities of States in the Exploration *and Use of Outer Space, Including the Moon* and other Celestial Bodies . In 1979, COPOUS agreed on a final version of a new treaty, the so-called "Moon Treaty, " which has so far not been signed by the United States or other major powers. The Moon Treaty applies to the Moon and other celestial bodies, but not to Earth orbit. In addition to COPUOS, important decisions on frequency allocations and orbital positioning are made by the International Telecommunications Union (ITU), a specialized U. N. agency.

[25] See Stephen Gorove, *SPS International Agreements*, DOE/NASA contract No. EG-77-C-01-4024, October 1978; Carl Q. Christol, *SPS International Agreements*, DOE/NASA contract No EG-77-C-01-4024, October 1978.

[26] Eilene Galloway, "Consensus Decisionmaking of UNCOPUOS," *Journal of Space Law*, vol. 7, No. 1

As a new arena of human exploration, legal norms with respect to outer space have had to be defined. This has been done through a gradual process shaped by actual usage, the extension of existing law, and the explicit adoption of common principles and regulations.

The outstanding international legal issues that might affect SPS development are:

1. the status of the geosynchronous orbit, and the source of jurisdiction over the placement of satellites;
2. provisions against environmental disturbances;
3. the military uses of space and arr- trol implications; and
4. issues relating to the ... facilities and ber ... tion of the ... kind" p...

S...

... uer ... act uelimitation between ... ıder the jurisdiction of the ... ying underneath the area con- ... d-and outer space has never been de- ... ıed. In recent years a number of states located on the Equator have claimed jurisdiction over the geosynchronous orbit on the grounds that it is not part of "outer space" but is determined by the Earth's gravitation, and is a limited natural resource requiring national control. In December 1976 eight equatorial countries issued the Bogota Declaration asserting their position and laying claim to the orbital segments lying over their respective territories.

The equatorial states' claims have been rejected by the majority of other nations—including the Soviet Union, the United States, and Western Europe—as legally and scientifically untenable. Control over the orbit by a few states would prevent free and equitable access to a crucial position by space-capable countries.

The equatorial claim must be see... context of various attempts by t... to gain leverage over ec... activities otherwise o... seven Bogota sig... Ecuador, Indo... (Brazil

... is ... torums ... y of special ... geosynchronous use ... upport among many coun- ... likely to be discussed further when ... considers the definition of outer ... ace next year,[28] and when the ITU convenes a special administrative radio conference on orbital use in 1984 or 1985.

Even if parts of the orbit cannot be appropriated by sovereign states, there is still the problem of allocating positions and of deciding competing claims to scarce orbital slots. The question here is part technical and part legal: How much space is there, and what constitutes infringement? This is dependent on the state of technology, since "infringement" is not so much a problem of two or more objects trying to occupy the same place as of electromagnetic interference between nearby satellites (see ch. 8). SPS satellites would not only be very large but would, especially if using microwaves, radiate a great deal of energy at radio frequencies. Each SPS would have to be allocated a position and frequency to mini-

[27] *Space Law Selected Basic Documents,* 2d cd,, U.S Government Printing Office, 1978, p 26

[28] See Gorove, *SPS Agreements,* op. cit., pp. 14-21; and Delbert Smith, *Space Stations: International Law and Policy,* Westview Press, 1979

mize interference with a rapidly growing number of satellites (see ch. 8). Many spectrum users have worried that SPS operation would disrupt communications and sensing tasks, others that the initial SPSs would use up the available electromagnetic space, preventing exploitation by latecomers. Since the acceptable limits vary with the size and type of SPS used, the size and type of future communications satellites, and advances in transmission technology, it is impossible to say at this time how many SPSs could be built without unacceptable interference.

Allocation of frequencies and positions has to date been the province of the ITU, whose 1973 convention states that stations "must be established and operated in such manner as not to cause harmful interference of other members, or of recognized private operating agencies, or other duly authorized operating agencies which carry on radio services, and which operate in accordance with the provisions of the Radio Regulations."[29] Whether the ITU would have jurisdiction over noncommunications satellites such as SPSs is unclear.[30] In November 1979, at the ITU's World Administrative Radio Conference, the United States raised the question of allocating a frequency position for future SPS testing; the proposal was referred to a specialized study group for evaluation and future decision.

Allocation decisions by the ITU have been characterized by debate over the first-come first-served tradition, whereby first users have priority in the use of frequencies and orbital slots. Newly space-capable states as well as LDCs and others who intend to develop such capabilities in the future have urged, since 1971, that all states have "equal rights" to frequencies and positions, and the ITU has called both the radio spectrum and the geostationary orbit "limited natural resources" that "should be most effectively and economically used." A number of LDCs have proposed that space be reserved for their future use. Since there is no legal basis for permanent utilization or ownership of positions, the possibility of future reallocation clearly has considerable support among have-not states. Established users such as the United States remain opposed to a priori assignment of slots and frequencies. Again, the ITU debate is part of LDC attempts to gain leverage. SPS development could be affected by attempts of disaffected states to block development by denying frequency allocations, or by making consent contingent on concessions by states with the most interest in SPS.[31]

[29] *Space Law*, op. cit., p. 87.
[30] Gorove, op. cit., pp. 27-33.

Environmental Considerations

The 1967 treaty states, in article VI 1, that each state is "internationally liable for damage" to others caused by its activities in space.[32] The 1973 "Convention on International Liability for Damage Caused by Space Objects" amplifies on these responsibilities.[33]

Hence, SPS developers might face lawsuits or other forms of grievance if the SPS damaged the global or local environment. The extent of various environmental effects is unknown and in need of further research (see ch. 8). Even if operation of any one SPS had no effect outside of the state making use of it, designing a globally marketable system to meet widely varying national standards could add significantly to costs. The possibility of large lawsuits could make insurance expensive or impossible to procure; large risks in the nuclear industry made it necessary for the Federal Government to provide insurance, and similar provisions might have to be made for SPSs.

Military and Arms Control Issues

The 1967 treaty commits states "not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction" (art. IV) and in general to carry on activities "in the interest of maintaining international peace and security and promoting international cooperation and understanding" (art. III).[34] The 1977 "Conven-

[31] Ibid, pp. 21-33,
[32] *Space Law*, op. cit., p. 28.
[33] Ibid, pp. 49-69.
[34] Ibid, p. 26.

tion on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques" prohibits the activities implied, with "environmental modification techniques" defined as "any technique for changing the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere." (art. 11).35 These general principles obviously allow for criticism of some SPS designs as having weather modification potential, requiring restrictions or redesign to reduce such effects. Whether an SPS's microwave or laser capabilities would class it as a weapon of "mass destruction" and hence make it illegal under the 1967 treaty is unclear, but it is very likely that such charges would be made in the event of SPS deployment. Development of an SPS might entail renegotiation of relevant treaties or special system design to minimize its usefulness as a weapon.

Military satellites for communications and remote sensing are currently used by several countries, and presumably use of the SPS platform for such purposes would not constitute a change in accepted practice. The Soviet Union has tested antisatellite satellites on several occasions, and the United States and Soviet Union have conducted informal talks (currently suspended) on limiting antisatellite weapons. The Soviet Union has complicated matters by stating that it considers the Space Shuttle an antisatellite system, an unacceptable proposal for the United States.[36] U.S. Air Force involvement in the shuttle program and Department of Defense (DOD) plans for military missions provide Soviet negotiators with their rationale. Insofar as the Soviet Union is making this argument for bargaining purposes in the absence of a similar Soviet system (similar to Soviet proposals to ban atomic weapons in the period when it lacked its own and to prohibit satellite reconnaissance in the early 1960's) such a charge could also be made against heavy lift launch vehicles (HLLVs) used for shuttle construction. In the absence of their own SPS program, obstructionist tactics by the Soviet Union could be expected.

Although unlikely, use of the SPS for directed-energy weaponry, either directly, or as a source of energy to be transmitted to remote platforms, or for tracking, would be regulated by the 1972 Anti- Ballistic-Missile (ABM) Treaty between the United States and the US.S.R. Article V of the treaty states that "each party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based."

Use of the SPS for ABM purposes would hence be banned. Since any laser or microwave SPS is potentially capable of being so used, the Soviet Union (or the United States if the tables were turned) would undoubtedly insist on assurances and inspection provisions to prevent such developments. The ABM treaty provides for inspection and verification by "national-technical means, " i.e., by remote surveillance. Onsite inspection has historically been refused by the Soviet Union, although the 1967 treaty, and the "Moon Treaty," include provisions for mutual inspection of lunar and celestial facilities. SPSs would need to be monitored by Earth- and space-based reconnaissance means.

Although the ABM treaty is of "unlimited duration" there has been considerable sentiment in the United States for its abrogation or renegotiation in order to provide a defense for America's increasingly vulnerable land-based ICBMs.[37] Abandonment or substantial change in the treaty might allow for development of directed-energy weapons in conjunction with an SPS system. Renewed negotiations may have to take SPS development into account, perhaps by specifying SPS designs that make it unusable as a weapons system. An SPS that used lasers as its energy-transmission medium would be particularly destabilizing and it is possible that arms control considerations would prevent such a system from being built.

[35] *Agreement Governing the Activities of States on the Moon and* Other *Celestial* Bodies, pts. 1 and 2, U.S Government Printing Off ice, May 1980, p. 256.

[36] "Soviets See Shuttle as Killer Satellite, " *Aviation Week and Space Technology,* Apr. 17,1978, p. 17

[37] See Carries Lord, "The ABM Question, " *Commentary,* May 1980

Common Heritage and the Moon Treaty

The 1967 treaty states, in article 1, that "The exploration and use of outer space . . . shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind."[38] The draft version of the Moon Treaty adds (art. IV). "Due regard shall be paid to the interests of present and future generations as well as to the need to promote higher standards of living and conditions of economic and social progress and development in accordance with the Charter of the United Nations."[39] The exact meaning of these provisions is unclear, beyond a negative duty not to interfere with the activities of other states or to harm their interests. A positive interpretation that "would impose on space powers the obligation either to permit other countries to use the former's space vehicles or to share the financial benefits of its space activities,"[40] has been made by some LDCs but has not received widespread support. Since 1958, U.S. policy has been to encourage international cooperation. U.S. launch capabilities have been available to all countries, on a reimbursable basis, for peaceful and scientific purposes.

In 1970, A. A. Cocca of Argentina proposed a draft treaty in UNCOPUOS which provided that the natural resources of the moon and other celestial bodies be "the common heritage of mankind." This terminology was borrowed from similar language used in the Law of the Sea negotiations in 1967 for regulating seabed resources that lie outside of national jurisdiction.

In the course of the Law of the Sea negotiations (not yet concluded) "common heritage," has come to mean common ownership, "by mankind as a whole" (art. CXXXVII),[41] with commercial exploitation to be regulated by a yet-to-be-formed "international regime" which will distribute part of the returns among participating countries. In 1970, the United States voted for a "declaration of principles" that prohibited activities "incompatible with the international regime to be established."[42] Until the regime is more clearly defined, it is impossible to tell whether current activities will be incompatible or not. The effect of this climate of uncertainty and of the possibility that future regulations may make mining unprofitable has been to keep sea-bed mining consortia—several of which were formed in the 1970's—from proceeding with the large capital investments needed for commercial exploitation.

Article XI of the draft Moon Treaty provides for a regime (to be established sometime in the future) with the following provisions:

1, The Moon and its natural resources are the common heritage of mankind . . .
5. States parties to this agreement hereby undertake to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the Moon as such exploitation is about to become feasible . . .
7. The main purposes of the international regime to be established shall include . . .
   (d) an equitable sharing by all States Parties in the benefits derived from those resources, whereby the interests and needs of the developing countries, as well as the efforts of those countries which have contributed either directly or indirectly to the exploration of the Moon, shall be given special considerate ion. 43

Moon Treaty opponents have argued that the treaty, like the proposed Law of the Sea, would delay or prevent commercial investment in space activities, and would in any case substitute a state-run international body for private enterprises.[44] Because of the already developed technology for deep-sea mining (most of it U.S.), the Law of the Sea negotiations have become absorbed in detailed discussion of the regime to be established, while

[38] *Space Law,* op. cit., p. 25
39 Agreement, op. cit., pts. 1 and 2, PP 88-89
[40] Smith, op. cit., p. 92.
"*Agreement,* op. cit., pts. 1 and 2, p 74

"*Agreement,* op cit , pt. 3, August 1980, pp. 295-307
"*Agreement,* op cit , pts. 1 and 2, pp 91-92,
[44] See ' 1-5 Memorandum" in *Agreement,* op cit., pp. 377-378

in the Moon Treaty such details have been left to the time when exploitation of lunar or other celestial resources is "about to become feasible." The eventual outcome of the Law of the Sea may have an important bearing on the shape of a future outer space regime.

Since the Moon Treaty would not apply to objects in Earth orbit, SPS would not be directly affected. However, the Treaty could have several indirect effects. First of all, in several scenarios large-scale SPS construction beyond an initial demonstration system is economically feasible only if the satellites are built from lunar or asteroidal material (see ch. 5). Such prospects would be dependent on a regime such as is envisioned in the Moon Treaty, which would have to grant permission to mining companies to extract minerals and build facilities.

Secondly, it can be argued that solar energy is a celestial resource under the jurisdiction of the proposed regime, and that SPSs (and other space-craft) must be granted permission to use it.[45] Though such an argument is unlikely to find general acceptance, it could be used by interested states to try and gain additional leverage.

Thirdly, adoption of the Moon Treaty would provide a powerful precedent that could affect the evolution of a future SPS project. It would legitimize developing countries' claims to receive benefits on a par with states that have actually invested in launch or construction facilities, and give impetus to arguments that the geostationary orbit is a "common heritage" resource requiring explicit allocation by an international body.

In the course of the Moon Treaty negotiations the United States was a consistent supporter, along with virtually all the Third World participants, of the common heritage provisions, while their most persistent opponent was the Soviet Union.[46] The U.S.S.R. did not accede to these provisions until 1979. While the United States generally interpreted common heritage in such a way as to allow for some degree of private unilateral commercial development, the Soviet Union expressed fears that the treaty would lead to an unacceptable suprastate body. The Soviet position was that such a body would infringe on the sovereign rights of states. The Soviets have also opposed allowing private or nongovernmental bodies to engage in space activities. Both the 1967 treaty (art. VI) and the proposed Moon treaty (art. IXV) provide for state supervision of and responsibility for the activities of nongovernmental entities. This "state-centric" approach is typical of Soviet attitudes in international negotiations.

As a result of concerns generated by the Law of the Sea negotiations, as well as antitreaty lobbying by "pro-space" organizations such as the L-5 Society, U.S. support for the draft Moon Treaty has been limited. U.S signature has been discussed in the Senate Subcommittee on Science, Technology, and Space, and by a special interagency committee chaired by the State Department. Prospects for U.S. approval currently appear to be slight.

"Conversation with Eilene Galloway, September 1980,

"Agreement, op. cit., pts 1 and 2, pp 27-38

ADVANTAGES AND DISADVANTAGES OF MULTINATIONAL SPS

No matter what country or organization were to build an SPS, it is clear that construction would involve some cooperation with and accommodation of the interests of other states and regions. However, from the point of -view of any national government— and to a lesser degree of private corporations as well–it would be preferable, other things being equal, to build the SPS as a strictly national venture and to own and operate the system on a unilateral basis.

Unilateral Interests

From a corporate viewpoint, it is much easier to do business within a country than to do so across national boundaries. Multinational ownership or control would complicate decisionmaking, reduce flexibility, and introduce a multitude of political strains that any company would prefer to avoid. To the extent that foreign markets are attractive, the company would prefer to retain domestic ownership and to sell completed units abroad, minimizing foreign entanglements.

From the point of view of governments that might consider investing in SPS, the desire to do so alone would be very strong, for reasons of prestige, security, and economics. At present only the United States and the Soviet Union could even consider such a unilateral effort. In the longer term, however, it is conceivable that a European consortium or perhaps even a single European state—most likely France– could also undertake such a project. So could Japan, with possible cooperation from China, South Korea, and other regional powers with technical expertise and financial resources.

Is it likely that the United States or the Soviet Union would build an SPS in the near future? Such a program would be undertaken only if there were serious doubt that alternative energy sources will be available in the future, or that their costs will be acceptable. This would have to mean that the CO_2 and environmental problems of large-scale coal use were seen to be acute and imminent, or that nuclear reactors were deemed unacceptable due to a major accident and public disapproval. In addition, alternatives to the SPS such as fusion, ground-based solar cells, and possible other future technologies, would have to fail to fill the gap (see ch. 6). In the event of some such crisis SPS studies must be sufficiently advanced to provide very high assurance that such a system would work. Given this combination of events, and if cooperation with foreign governments or corporations is rejected because of fears that it might slow down the project or otherwise reduce its domestic usefulness, it is possible that a unilateral effort would be undertaken.

There are several other factors that might increase the attractiveness of a unilateral crash project similar to the Manhattan or Apollo programs. Three requirements for such decisions are: 1) a crisis, requiring immediate action, which threatens basic national interests; 2) the existence of a workable plan to resolve the crisis; 3) decisive leadership by persons in positions to implement such plans. " In the Manhattan and Apollo cases, the crises involved challenges to national interests that placed a premium, not only on developing the atomic bomb or the ability to go to the Moon, but on doing so first.

The SPS would have important economic, prestige, and security implications. Unilateral development by the Soviet Union or the United States would provide a strong impetus for the other to do so as well, as long as the project could also be justified on other grounds. The strength of this impetus would depend on the state of future U.S.-Soviet relations. In the 1950's nuclear weapons and their delivery systems were seen as vital to the existence of the state; the space programs of the 1960's as symbolic of each state's social and economic superiority. It is unlikely that the SPS would be as crucial to East-West competition as these earlier technologies, unless the SPS or the launchers needed to build it become vital elements of military systems. For the reasons given in the next section, Nationa/ Security Implications of SPS this is possible but unlikely. Hence an equivalent desire to build the first system–an SPS "race"- is improbable.

Within the United States certain interests would favor unilateral as opposed to multilateral development. Businesses likely to benefit from development, such as aerospace indus-

[17] John Logsdon, *The* Decision *To Go To the* Moon (Cambridge, Mass MI T Press, 1970), p 181

tries or large construction firms, might prefer a unilateral effort that would provide them with most or al I of the contracts, as well as the prospect of foreign sales. However, others might fear that a unilateral development would discourage foreign buyers. Some utilities and oil companies might oppose an SPS altogether if it competes with energy sources in which they have already invested. Since unilateral development would almost undoubtedly mean a government-dominated and financed project, such businesses would be likely to argue that the SPS is unfairly competitive and to demand compensation.

In the Soviet Union there is no private sector and hence no question of public v. private development. Though it is possible that non-Communist states such as India and France, both of whom have engaged in cooperative space projects with the Soviet Union before, might participate in small ways, it would be unprecedented for the Soviet Union to engage in extensive joint planning or operations with nonallied states. Such cooperation in sensitive, high-technology areas involving space capabilities, which in the Soviet Union are run by the armed forces and considered top-secret military programs, is especially unlikely. Hence an international SPS program is not a real option for the Soviet Union, given its present political and economic institutions.

Within both the United States and Soviet Union, the military may argue for a unilateral program in order to enhance SPS's military usefulness, which would be destroyed if sensitive information had to be shared among neutral partners or partners who could not be trusted not to reveal technical or other details to unfriendly states. In the United States, resistance to military involvement is likely to be strong, partly to avoid foreign charges of aggressive intent, and also to prevent possible military interference in the project's efficiency, as with the Space Shuttle.[48] However, given the military's role in the Soviet space program, such arguments are likely to be less telling there than in the United States. Although various Soviet ministries would seek a say in SPS development, none has the technical or managerial competence to displace the military in such a project.[49]

In the United States, the Government sponsors two largely separate space programs, a civilian one run by the National Aeronautics and Space Administration (NASA), and a military one run by the Department of Defense. Both draw extensively on expertise and experience from a large number of private firms. While an SPS project in the Soviet Union could not help but be dominated by the military, a U.S. project, even one run by the Government, could be shared between the military, Government-civilian, and private sectors. Various combinations could be developed to provide a desirable mix between public and private, military and civilian authorities.[50] In the past, Government-sponsored projects that might provide guidance and precedent for an SPS program have included the Panama Canal, the Tennessee Valley Authority, and the Interstate Highway System. (See ch. 9, Financing, Ownership, and Control.) What is important is the flexibility available to U.S. planners, a flexibility not found in the Soviet Union, which, if a multinational effort is preferred, makes it possible to accommodate international partners on various terms.

Both Western Europe and Japan have more urgent requirements for reliable energy supplies than the two current space powers. The impetus for SPS development would be similar to that for the United States, but the need is more imminent, and the costs of alternatives, in the absence of indigenous fossil fuels, are higher. Could an SPS be built in an acceptable period without extensive U.S. assistance (assuming Soviet assistance is improbable)?

“The price for Air Force support of Shuttle funding in Congress was substantial redesign of the original Shuttle model, lowering performance and increasing costs See Jerry G rey, Enterprise (New York: William Morrow & Co , 1979), pp. 66-68.

“See *Soviet Space Programs 1971-1975,* vol. 11, ch. 2, “Organization and Administration of the Soviet Space Program, ” August 1976, pp. 63-82.

'°For discussions of these issues, see Peter Vajk, *SPS Financial/Management Scenarios,* DOE/NASA contract No. EG-77-C-01 -4024, October 1978, Herbert Kierolff, *SPS Financial/Management Scenarios,* DOE/NASA contract No. EG-77-C-01 4024, October 1978.

The requisite technical and financial base is available; strong aerospace industries exist; national and multilateral space programs, such as the European Space Agency (ESA), are in place. However, both ESA and Japan lack the depth of U.S. industry's aerospace expertise, its worldwide tracking and relay networks, and above all experience in and development of manned space-vehicles. The most sophisticated non-American launch vehicle is ESA's Ariane, which is still being test-flown and is scheduled to begin commercial operations in 1982.[51] The Ariane is a high-quality three-stage expendable booster, but it is far smaller than the large U.S. Saturn rockets used for the Apollo program. And it is far behind the U.S. Space Shuttle in capabilities, payloads, and cost effectiveness (at least to LEO). Since the Shuttle itself is too small and expensive for full-scale SPS construction, ESA is at least two generations of vehicles away from being able to develop an SPS unilaterally. Producing the requisite lift capabilities in an independent program would be extremely costly and time-consuming.

It is clear that any unilateral SPS program depends on a dramatic and unpredictable increase in the sense of urgency about medium and long-term energy supplies. Even if such an increase were to occur, such efforts would be very expensive for any one country or region to undertake, especially since crash programs are necessarily more expensive than ordinary ones; money is traded for time.

Multilateral Interests

There are three reasons why interested parties may wish to abandon their preference for autonomy in favor of an international effort. These are: 1) to share the high costs and risks; 2) to expand the global market; 3) to forestall foreign opposition and/or promote international cooperation.

costs

The exact costs of developing, manufacturing, and operating a SPS are unknown; NASA estimates a 22-year, $102 billion program for the reference design.[52] (See ch. 5, Costs.) Although the R&D costs would be much lower than construction costs, they would be the hardest to finance, and the ones where international cooperation would be most valuable. The number of satellites needed for a global system would clearly be much larger than for a U.S. system alone. However, the R&D/prototype costs are essentially the same whether the system is unilateral or multilateral. Since the very long 30-year period of investment before payback is the project's weakest link, it would be desirable to spread these costs between a large number of possible investors. And by widening the available pool of capital and expertise, an international effort would have less of an inflationary impact on resources, thus keeping costs down.

However, it should be realized that an international consortium, whether involving private firms or government agencies, will tend generally to increase the overall costs. Under the best of circumstances there are costs associated with doing extensive business across borders, with coordinating efforts in different languages and geographic areas, and with balancing the divergent national interests of foreign partners. Without careful management and a high degree of cooperation from the states involved, these extra inefficiencies can eliminate any advantage gained from internationalizing the project. The experience of European collaborative efforts has been that costs rise as the large number of participants increases the managerial superstructure and project complexity .53

The Global Market

We have previously discussed the SPS's potential global market. An international venture may improve the marketing prospects of the system. First of all, potential users and buyers would be less concerned about becoming dependent on a particular country or corporation, which may infringe on national sov-

[51] Edward Bassett, "Europe Competes With U.S. Programs, " *Aviation* Week and Space Technology, Mar 3,1980, p. 89.

[52] Kierolff, op. cit., pp. 4-5

[53] Testimony of Dr. Wolfgang Fink, *International Space Activities,* 95th Cong., November 1978, U.S. Government Printing Office, p 12

ereignty. Many states, especially LDCs, are concerned about such a situation, particularly with regard to U.S. firms. Over the past 15 to 20 years, LDCs have made great efforts to gain indigenous control over local industries and resources, often resorting to nationalization and expropriation. The accumulation of financial and legal expertise by LDC governments means that future dealings with foreign firms will be more cautious and equitable than in the past. Also, it is often politically more feasible for a neutral or nonalined state to deal with an internationally controlled consortium than with a U.S. or Japanese or West European firm, especially when internal opposition to such relationships is strong.

A consortium that offered direct participation and ownership to a large number of states would improve its marketing position even more. Such participation/ownership, even if on a small scale, would help to familiarize members with the organization's operation and finances, and assure potential buyers that they were not being deceived. A financial stake would provide an incentive to see that the system worked efficiently and was suited for the needs of a variety of users.

Widespread participation by many countries with different financial stakes and energy requirements would also present a host of problems. Even small investors could be expected to lobby for a proportionate share of the benefits, including profits and contracts, and for a say in policy and management decisions. Investors with similar interests can be expected to band together. Often, small-stake participants with less to lose are willing to use any available forum to further ideological or economic interests unrelated to the business at hand. A balance must be struck between the advantage of open participation and the danger that such participation could undermine the organization's credibility and competence.

Forestalling Opposition, Promoting Cooperation

Because of the importance of the SPS and the size of the financial stake involved, major SPS participants could expect that nonparticipants would use their leverage for concessions in unrelated political or economic areas. However, mere participation would not forestall opposition. If member interests are not mutually compatible, opposition is only moved from without to within. The best check on internal obstructionism would be for the major participants to indicate their willingness to go it alone, if necessary, rather than allow internal obstacles to destroy the project. Since organizations quickly develop their own constituencies, within and without governments, which have an interest in maintaining the organization, a credible threat to go it alone must be backed up by national leaders and by investment in the requisite systems.

Possible Models

Intelsat, Inmarsat

How might such an organization be constructed, and what are the types of problems that might be faced? Here it is helpful to look at historical examples of international organizations in the space and energy fields. We will look briefly at Intelsat and Inmarsat; at cooperative efforts in nuclear power; and at the European Space Agency (ESA).

Of existing bodies, Intelsat and its near-relative, Inmarsat, have been mentioned most often as possible models for an international SPS project. Intelsat is attractive because it has been efficient and profitable, and because it has succeeded in including a large number of participating states.

Intelsat was founded in 1964, largely at the prompting of the United States, to provide international satellite telecommunication services. The initial agreement provided for joint ownership and investment in proportion to the use of the system by each participating country, and for renegotiation in 5 years to take account of experience and new developments.[54] At first, Intelsat was dominated by the United States through its semipublic participant, Comsat; LDC participation was minimal, and the

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"Jonathan Galloway, *The Politics and Technology of Satellite Communications* (Lexington, Mass.: Lexington Books, 1972), p 75

Soviet Union and East Bloc countries refused, to join, preferring to establish a separate organization, Intersputnik. The permanent agreements reached in 1971 reduced Comsat control and made it easier for low-use countries to participate. In 1979, Intelsat had 102 members, with the U.S. share being 24.8 percent.[55] (See app. E.)

Inmarsat is designed to provide positioning and maritime services between ships and ship-to-shore. Organized similarly to Intelsat, it is expected to begin operations in 1981, leasing its initial satellite services from Intelsat.[56] (See app. E.)

Though Intelsat has functioned relatively smoothly and has shown a good return on invested capital, serious disagreements between participants have arisen. Many of these disagreements have revolved around the allocation of procurement and R&D contracts, with member countries competing for prestigious and high-value shares. Given the predominant position of U.S. aerospace firms, much of the pressure has been for equitable shares for European and Japanese companies. However, some participants, especially LDCs and others without indigenous aerospace capabilities, have objected to distributing contracts on a geographical or political basis, charging that it drives up costs.[57] Non-U. S. contract shares have risen over time (23 percent of Intelsat 5, the latest model satellite, is foreign built),[58] and future use of ESA'S Ariane launcher and purchase of European communication satellites may raise this significantly. (See app. E.)

What do the Intelsat and Inmarsat model tell us about a possible "Intersunsat?" The relatively smooth functioning of Intelsat is largely a result of its initial organization, which had certain peculiarities not likely to be repeated in the future.

Above all, Intelsat came into being through the. dominant interest and investment of a single participant, the United States. U.S. determination to institute a global communication satellite system was due in large part to the Kennedy administration's desire, at a time when the Soviet Union seemed superior in manned and unmanned space capabilities, to achieve a space success before the Soviets that would pay off in terms of global prestige and the furtherance of U.S. national interests. The 1958 National Aeronautics and Space Act which established NASA proclaimed that space activities "should be devoted to peaceful purposes for the benefit of all mankind."[59] In addition to the scientific and commercial benefits, improved international communication was seen as a foreign policy plus for the United States, that would involve other states as participants under U.S. leadership. The technology for such activities was well advanced and judged to be superior to that of the Soviet Union.

The centralized management structure thus created, combined with U.S. technical leadership and its status as the largest single user of the system, gave Intelsat initial national support that was vital in allowing it to operate efficiently and with a minimum of delays. The promise of future renegotiations placated those, such as France, who objected to the initial phase of U.S. dominance. By contrast, the establishment of Inmarsat, despite its close adherence to the Intelsat model, took 4 years of negotiations and some 9 years before the start of actual operations.

At the outset of Intelsat negotiations in 1963, and even at the time of renegotiation in 1969-71, the U.S. position vis-a-vis Europe and the Third World was much stronger than it has been since or is likely to be again, not only in space technology but in general economic performance and military strength. This across-the-board preeminence made palatable-a U.S. position that would today probably not be tolerated.

[55] *Comsat Annual Report 1979*, p. 23.

[56] "Operating Agreement on Inmarsat," 1976; in *Space Law*, p. 445.

[57] Joseph N. Pelton, *Global communications Satellite Policy: Intelsat, Politics, and Functionalism* (Mt Airy, Md.: Lomond Books, 1974), p. 76.

[58] "Intelsat Being Readied for November Launch," Aviation Week *and Space Technology*, Oct. 27,1980, p 51.

[59] "National Aeronautics and Space Act," 1958; in *Space Law*, p 499

In the foreseeable future, U.S.-European equivalence in technical and economic capabilities and the increased self-confidence of the Third World countries, who were effectively excluded from the initial Intelsat arrangements, will make a repeat of the U.S. position impossible. With regard to an SPS, the United States would not necessarily be the largest user, nor would it have a monopoly on engineering expertise. And the political impetus provided by Soviet competition, which was vital to the formation of Comsat and Intelsat, is likely to be missing or muted.

The swift and effective establishment of Intelsat depended on several other factors. One was the prior existence of international and national entities dealing with global communications. Bodies such as the ITU provided technical background and legal precedents for dealing with communication satellites, and national telecommunications agencies had long experience with short-wave and cable transmissions. No such equivalent exists for the SPS.

The initial costs of Intelsat were comparatively low; as of 1980 (through 16 years of operation) a total of somewhat over $1 billion had been invested in R&D and procurement. In addition, the basic research had already been done, and paid for, by the United States; it was a proven technology with a predictable market. The SPS would be several orders of magnitude more expensive, would take decades to produce, and is far riskier. One consequence of communication satellites' low cost—and the existence of established communication entities—was that the basic decisions, both at the beginning and later on, were made by expert bodies with little public awareness.[60] This prevented sharp polarization and allowed negotiators to give and take without risking outcries at home. SPS negotiations would not take place in this atmosphere. As one observer notes, "An SPS is not likely to come into being through the nonpolitical activities of technical agencies . . . Decisions about SPS at the international level will be made . . . by the political leaders of major nation-states in the context of international political debate."[61] The large size and importance of SPS contracts would create strong pressures for geographical allocation; here the experience of the North Atlantic Treaty Organization (NATO) may be more relevant than that of Intelsat.

The above is not meant to dismiss Intelsat's experience. Valuable lessons from Intelsat are the importance of corporate-style independent management; weighted voting by investment share and usage; and interim arrangements that allow a project to begin work and gain experience before establishing a permanent structure. And the positive example of Intel sat and the experience gained in its operation will prove helpful in the future.

Other Models

Besides Intelsat, with its distinctive combination of state and designated-entity participation, there are other possible models for international cooperation, including: 1) joint-ventures by privately or Government-owned multinational corporations, on the model of Aramco, or the recently formed Satellite Business Systems, jointly owned by Comsat, IBM, and Aetna Insurance, 2) state-to-state agreements coordinating national space programs, such as ESA and its predecessors, ELDO and ESRO; 3) international agreements on the development and use of atomic power, such as Euratom; 4) U.S. bilateral arrangements between NASA and foreign agencies or companies.

PRIVATE CONSORTIUM

Agreements for joint financing and management by nationally based companies can provide extensive informal coordination across boundaries and facilitate the raising of capital on diverse financial markets. (See ch. 9, Financing, Ownership, and Control.) Two major difficulties would face such an attempt. From the company's viewpoint the very high initial investments and the uncertain legal and regulatory constraints would inhibit commitment without government guarantees. Many dis-

[60] Pelton, op. cit., p. 44

[61] John Logsdon, "International Dimensions of Solar Power Satellites Collaboration or Competition?" July 1980, p 3.

cussants have concluded that public sector financing would likely be essential for any SPS project. 'z From the state perspective, especially outside the United States, there would be reluctance to rely on private sector development and control of energy supplies, as well as potential antitrust problems (especially in the United States) caused by a concentration of companies.

ESA

Within Western Europe there have been ongoing efforts to coordinate national space programs so as to compete with the United States and the Soviet Union. In the early 1960's two organizations were founded: ELDO (the European Space Vehicle Launcher Development Organization), aimed at designing and building a European launch vehicle (the "Europa" rocket); and ESRO, (European Space Research Organization) to conduct basic research. Both groups, and especially ELDO, suffered from a lack of direction and from divergent national interests. '3 Allocation of contracts was based on the principle of "fair return;" contributions to the organization were in proportion to each state's GNP, and contracts were supposed to be let in similar ratios. This produced intense disagreements and delays, exacerbated by cost increases which had to be allocated evenly among the participants.

In the late 1960's Europe began to pay increased attention to the so-called "technology gap" between it and the United States. In 1967, J. Jacques Servan-Schreiber's book The Amer*icean challenge* "polemicized the U.S. economic invasion of Europe and aroused a popular interest in technology comparable to the Sputnik aftermath in the United States.''[64] Interest in joint space efforts increased; the failure of ELDO to produce a reliable Europa rocket was heavily criticized, with France and Germany claiming their willingness to produce it on their own.

The late 1960's also produced strong pressures, as in the United States, for projects with economic payoffs, rather than abstract research or prestige programs. After Apollo, the United States began to look for ways to reduce the costs of its proposed Space Transportation System. One way was increased cooperation with Europe. While France remained suspicious that such offers were designed to forestal I independent European programs, Germany welcomed NASA proposals for joint development as a way to gain access to U.S. technology and to use of the Space Shuttle. Hence, while France continued to emphasize launcher development, Germany turned to production of Spacelab for NASA.

In 1973, ESRO and ELDO were joined together as the 9-member European Space Agency. Its major projects to date have been: 1) the Ariane launcher, a $1 billion effort which is 64-percent French financed and flown from France's spaceport in Guiana, South America; [65] and 2) Spacelab, an $880 million project, 55-percent German financed, being built in West Germany. Other ESA projects have included regional remote sensing, meteorological, and maritime satellites, and a regional communications satellite (L-Sat) being developed under the guidance of Great Britain. [66]

The formation of ESA has not eliminated intra-European difficulties and the problem of coordinating national programs. A report in Interavia charges that "individual states are tiring of the paper-passing and consensus-seeking that is involved in getting programs started and keeping them alive within the framework of an international civil-service organization.''" One result may be a turn towards commercial alternatives. With the completion of Ariane a new firm called Arianespace has been formed, made up of European industries, banks, and the French National Space Agency, to market the launcher commercially and in competition

'*See Vajk and Kierolff for further discussion

'³ See Mihiel Schwarz, "European Policies on Space Science and Technology 1960-1978, " *Research Policy,* August 1979, pp. 205-242,

"Henry Nau, *National Politics and International Technology* (Baltimore: Johns Hopkins University Press, 1974), p. 55

"'The French Space Effort, " *Interavia,* June 1979, p, 508.

"Edward Bassett, "ESA Planning New Telecommunications Satellite," A *viation* Week and Space Technology, Dec 31, 1979, p 12

"'European Space Programs: An Industrial Plea for Integrated Effort,11*Interavia,* August 1979, p. 785, with the U.S. Space Shuttle.[68] If successful, Arianespace will provide an example of how an internationally financed and developed spacecraft can be turned over to a commercial operating group, which could be a model for similar development of the SPS. However, all-in-all the history of European collaboration provides more "dont's" than "do's" for a future SPS effort.

NUCLEAR POWER

International nuclear cooperation is the only model that compares with the SPS in its financial and political scope, though the security aspects of nuclear power are largely unique. Like SPS, nuclear power is a baseload electricity source requiring large investments and a high degree of technical competence, with widely perceived environmental dangers.

The overall picture of nuclear cooperation shows a field where development and operation, though expensive, is not prohibitively so, and where considerations of national prestige and security are extraordinarily high. "Have" countries have had little reason to promote the spread of nuclear technology, except as a profitable export or a form of foreign aid. The expense of initial development has been justified as a military necessity (as in the U.S. submarine reactor program). Cooperation is largely motivated by the need for agreed-on international standards and regulations to prevent accidents and inhibit proliferation. Strictly economic or energy-supply considerations have played a small role, except as window-dressing, while political and competitive needs have been the prime movers. Nuclear development in Third World countries, such as Brazil and India, has been especially motivated by noneconomic considerations.[69]

Development of an SPS should not suffer from the extreme obstacles to positive cooperation faced in the nuclear field: the military uses would be less important, the costs much higher, and the economic need greater. The intense politicization of nuclear development shows an extreme case of the forces that can come into play during the development of a major new technology.

U.S. BILATERAL ARRANGEMENTS

The United States has been very successful in establishing useful bilateral arrangements with foreign governmental agencies and organizations, such as ESA. NASA has been empowered to enter into exchanges of information and services, in coordination with other parts of Government, such as the State Department. NASA has provided launch services, technical assistance, and remote sensing (Landsat) imagery to a large number of foreign customers.'" The network of relationships built up over the years could be helpful in promoting a multilateral SPS. Direct bilateral cooperation with major potential partners in Europe and Japan might be the best way to initiate foreign cooperation and create a climate conducive to the expansion of the enterprise, especially in the initial less expensive R&D stages. Such agreements would take substantially less time to negotiate than regional or global ones. "

"''New Commercial Organization to Take Ariane Responsibility," *Aviation Week and Space Technology* Apr. 7,1980, p. 45.

"June Sabato and Jairam Ramesh, "Atoms for the Third World," *Bulletin of Atomic Scientists,* March 1980, p. 39.

'"Stephen M. Shaffer and Lisa R. Shaffer, "The Politics of International Cooperation: A Comparison of U.S. Experience in Space and Security," *Monograph Series in World Affairs, vol. 17, book 4,* University of Denver, 1980, pp. 15-26.

"Go rove, op. cit., p. 50,

NATIONAL SECURITY IMPLICATIONS OF SOLAR POWER SATELLITES

The potential military aspects of an SPS will be of major concern to the international community and to the general public. There are fears that the satellite will be vulnerable to attack, or that it may be used for offensive weapons (see ch. 9, Public Opinion). Such concerns may be decisive in determining the pace and scope of SPS development, and the mode of financing and ownership that is used. There are three basic aspects to consider: 1) SPS vulnerability and defensibility; 2) the military uses of SPS launch vehicles and construction facilities; and 3) direct and indirect use of SPS as a weapons system or in support of military operations. Of these it is the second, the extensive capability of new launchers and large space platforms, that will constitute the most likely and immediate impact.

Vulnerability and Defensibility

There are two main segments of any SPS, the ground receiver and the satellite proper. Since reference-system rectennas or mirror-system energy parks would be very large and composed of numerous identical and redundant components, they would be unattractive targets; the smaller antennas of other designs would be slightly more vulnerable. The satellite segment would be vulnerable in the ways outlined below, but in general no more so than other major installations. Its size and distance would be its best defenses.

Would SPS Be Attacked?

The reasons for attacking a civilian SPS would be that it is expensive and prestigious, not easily replaceable, and that it supplies an essential commodity, baseload electricity. In determining whether to target an SPS in the event of hostilities, the crucial consideration would be how much of a nation's or region's electricity is supplied by SPS. In most developed countries, utilities maintain a reserve of approximately 20 percent of their total capacity, in order to guard against breakdowns and maintenance outages. If SPS supplied no more than the reserve margin, its loss could be made up; however, given an SPS system consisting of many satellites particular regions or industries would be likely to receive more than 20 percent. Making up for losses would require an efficient national grid to transfer power to highly affected areas. Increased use of high voltage transmission lines and other measures should increase U.S. ability to transfer power. However, in many countries, especially LDCs, SPS losses might not be easily replaceable since SPSs, if used, would be likely to provide more than 20 percent of total capacity on a national basis.

An attack on SPS would also depend on other factors. If the attacker relies on its own SPSs, it may fear a response in kind. If the satellites were owned by a multinational consortium the attacker might be hesitant to offend neutral or friendly states involved. If they were manned— it is unclear whether permanent personnel would be required for SPS — the attacker might be reluctant to escalate a conflict by attacking manned bases.

The unprecedented position of the SPS, located in orbit outside of national territory, gives rise to uncertainties as to how an attack would be perceived and responded to. If the SPS is seen as analogous to a merchant ship on the high seas, attacks would be proscribed unless war were declared and outer space were proclaimed a war zone. Otherwise, any attack would be tantamount to a declaration of war. In practice, however, experience has shown that attacks on merchant vessels have not caused an automatic state-of-war, though they have often played a crucial part in bringing one about.

It is more likely that the SPS, because of its function and/or its stationary position (for certain designs), would be perceived as similar to a fixed overseas base or port rather than a ship. An attack would then be taken more seriously, especially if lives were lost. It will be important for national leaders to clarify what status an SPS would have, particularly in times of crisis. A low priority assigned to SPS could encourage enemy states to attack it as a way of demonstrating resolve or as part of an escalator response short of all-out war.

How Could SPS Be Attacked?

There are essentially five ways the satellite portion of an SPS could be destroyed or damaged: 1) ground-launched missiles; 2) satellites or space-launched missiles; 3) ground or space-based directed-energy weapons; 4) orbital debris; 5) disruption or diversion of the energy transmission beam.

A missile attack from the ground on a geosynchronous SPS would have the disadvantage of lack of surprise, due to the distances involved and the satellite's position at the top of a 35,000 km gravity well; missiles would take up to an hour or more to reach, geosynchronous orbit. An attack from prepositioned geosynchronous satellites would be faster and less detectable. However, a laser or mirror SPS in low orbit could be reached from the ground in a matter of minutes. Lasers or particle beams, which might be used to rapidly deface the solar cells or mirrors rather than to cause structural demage, would have virtually instantaneous effect.

Placing debris in SPS's orbital path, but moving in the opposite direction —such as sand designed to degrade PV cells or mirrors– would have the disadvantage of damaging other satellites in similar orbits, and of making the orbit permanently unusable in the absence of methods to 'sweep' the contaminated areas clean. The relative ease and simplicity of this method, however, could make it attractive to terrorists or other technically unsophisticated groups. Any explosive attack could have similar drawbacks, although since the resultant debris would be traveling in the same direction as most other satellites (which move with the Earth's rotation) the ensuing damage would be Slight.

If technically feasible, disrupting SPS's microwave or laser transmission beam, either by interfering directly with the beam or its pilot signals, or by changing its position so that it misses its receiving antenna, would be a highly effective way to attack the SPS. Since the effects would be temporary and reversible, such an attack might be favored in crisis situations short of all-out war. Disruption using metallic chaff would be ineffective against a microwave beam, due to its very large area. Laser beams could be temporarily deflected by clouds of small particles or by organic compounds that absorb energy at the appropriate frequency. Electronic interference possibilities for lasers or microwaves cannot be presently predicted.

A missile attack with a conventional warhead might be difficult due to SPS's very large size and redundancy. The most vulnerable spot on the reference and other photovoltaic designs would be the rotary joint connecting the antenna to the solar cell array. Laser transmitters would be more vulnerable due to their smaller size, though they would also be easier to harden. Attackers would be tempted to use nuclear weapons, either directly on the satellite, or at a distance. In space a large (one megaton or more) nuclear blast at up to 1,000 km-distance could cause an electrical surge in SPS circuitry (the electromagnetic pulse (EMP) effect) sufficient to damage a photovoltaic SPS[72] (though it would have no effect on a mirror-system). Such an attack would be particularly effective against a large SPS system, as it could destroy a number of satellites simultaneously. However, like an orbital debris attack, it has the problem of damaging all unhardened satellites indiscriminately within the EMP radius. Furthermore, any use of nuclear weapons would constitute a serious escalation of a crisis and might not be considered except in the context of a full-scale war.

Could the SPS Be Defended?

Defense of orbital platforms can be accomplished in three ways: 1) evasion; 2) hardening against explosive or electronic attack; 3) antimissile weaponry.

All of the SPS designs being considered would be too large and fragile to evade an incoming attack. SPSs may be equipped with small station-keeping propulsion units but not with large engines for rapid sustained movement.

Hardening against explosive or debris attack would require rigid and heavy plating. Such efforts would be prohibitively costly, except perhaps for a few highly vulnerable areas.

[72] Peter Vajk, "On the Military Implications of Satellite Power Systems," Lincoln Proceedings, April 1980, pp. 506-507

Hardening against EMP bursts or electronic warfare would require heavier and redundant circuitry as well as devices to detect and block jamming attacks. If incorporated in SPS designs from the beginning, these might be sufficiently inexpensive to justify inclusion. Different designs may differ in their vulnerability to such attacks —the photoklystron variation, for instance, would be less susceptible to EMP than the reference design.

Antimissile weaponry, whether in the form of missiles or directed-energy devices, could be placed on the SPS to defend against missile and satellite attack. Though potentially highly effective against incoming missiles, such weapons would be useless against long-distance nuclear bursts or remote lasers. Furthermore, they would have unavoidable offensive strategic uses against other satellites and intercontinental ballistic missiles (ICBMs), and would hence invite attack. For these reasons major defensive systems are unlikely to be placed on civilian SPSs. Attacks would be more effectively deterred by political arrangements and by the use of separate military forces.

Who Would Attack?

In most instances an attack could only be carried out by a technically sophisticated nation with its own launchers and tracking systems. Threats by such a space-capable power against other space-capable powers —say by the U.S.S.R. against the United States—are possible in the context of a major crisis or actual war where the attacker is willing to risk the consequences of its actions. Threats against inferior or nonspace-capable states, such as SPS-using LDCs, might be made at a much lower crisis threshold.

It is unclear which states will be capable of projecting military power into space over SPS'S lifetime. It is possible that technical advances will allow even small countries to purchase off-the-shelf equipment enabling them to attack an SPS, in the way that sophisticated surface-to-air missiles (SAMs) are now widely available to attack airplanes. However, it is more probable that, over the next 50 years, such capabilities will remain in the hands of the larger developed nations (including a number of countries that can be expected to enter this category in the future).

The state of technology obviously bears on the question of whether terrorists or criminals could attack an SPS. Politically motivated terrorists are generally strong on dedicated manpower, not technical expertise. The SPS would be a symbolic high-visibility target, but terrorists would be more likely to attack SPS launch-vehicles, which would be vulnerable to simple heat-seeking missiles, than to threaten the SPS directly.

However, a believable threat of direct attack by terrorists or small powers could be a spur to defensive measures such as hardening or antimissile devices, which would not stop an attack by a major power but might be effective against lesser threats.

Sabotage of the SPS through the construction force, either for political purposes and/or for ransom, could not be ruled out. Careful screening of construction workers — who would be few in number— can be expected, along with supervision while in orbit. The unavoidable conditions of life and construction in space would make it difficult, especially at first, to smuggle explosives or sabotage-devices into orbit. However, a major expansion into space involving large numbers of personnel would, in the long run, provide opportunities for sabotage that probably cannot now be foreseen.

Under current conditions any installation, in space or on the ground, is vulnerable to long-range missiles, or to dedicated terrorist groups. Reasonable measures to mitigate threats to SPS should be undertaken, but the dangers themselves cannot be eliminated.

Current Military Programs in Space

At present a number of nations use space for military purposes. The United States and Soviet Union operate the bulk of military satellites, but China, France, and a few other countries also have military capabilities. The prevalent uses involve satellites in low and high orbits for communications and data transmission, weather reporting, remote surveillance of foreign territory and the high seas, and interception of foreign communications. The crucial character of these satellites, especially in providing information on strategic missile placements and launches, is such that any future war between superpowers will undoubtedly include actions in space to destroy or damage enemy satellites. [73]

For these reasons both the United States and the U.S.S.R. are working to develop antisatellite (A-sat) weapons. The Soviets have in the past tested "killer satellites" capable of rendezvousing with objects in orbit and exploding on command. " 75 The United States has not yet tested A-sat weapons in space but is developing a sophisticated orbital interceptor designed to be launched from an F-15 fighter. " Neither system is capable of reaching geosynchronous satellites without being placed on larger boosters, but such development is probably only a matter of time.

The United States and U.S.S.R. have held informal talks in the past on limiting or banning A-sat weapons; the most recent such discussion took place in June 1979. These talks have been complicated by Soviet claims that the Space Shuttle is an A-sat system. The talks are currently "on hold. "

An outgrowth of A-sat concern has been the rapidly increasing interest, on both sides, in laser and particle-beam weapons. " Although some have predicted that such weapons could be deployed within a few years (especially lasers, whose technology is more advanced than particle beams), most experts say that, if at all feasible, they will not be available until the end of the decade.

High-energy lasers and particle beams are desirable because of their speed and accuracy–light speed for lasers, an appreciable fraction of that for particle beams–making them ideal for attacking fast-moving targets such as satellites and incoming missiles. They may be deployed on naval vessels, antiaircraft positions, and in space. Space-based directed-energy weapons 'could theoretically attack satellites at great distances — up to a thousand miles — since their beams would not be attenuated and dispersed by the atmosphere. Most importantly, they could also be used to engage attacking ICBMs, providing an effective ABM capability that would radically change the strategic nuclear balance. Such uses depend on attaining very accurate aiming and tracking, and extremely high peak-power capabilities.

Use of SPS Launchers and Construction Facilities

The most important military impact of SPS development would likely be military use of SPS launchers and construction facilities. In order to build an SPS it would be necessary to develop a new generation of high-capacity reusable lift vehicles to carry men and materials from the ground to low orbit. A second vehicle, such as an EOTV, would probably be used for transportation to geosynchronous orbit.

In addition, techniques and devices for constructing large platforms and working effectively in space would have to be developed, along with life support systems and living quarters for extended stays in orbit.

Improved and cheaper transportation would allow the military to fly many more missions, orbiting more and larger satellites and servicing these already in place. New construction techniques would enable large platforms for communications, surveillance, and/or directed-energy uses to be rapidly deployed. The

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[73]Clarence Robinson, "Space-Based Systems Stressed," *Aviation Week and Space Technology,* Mar. 3, 1980, p. 25.

[74]*Soviet Space Programs 1971-1975,* VOI 1, staff report for Committee on Aeronautical and Space Sciences, 1976, pp. 424-429.

[75]Craig Covault, "New Soviet Antisatellite Mission, " *Aviation Week and Space Technology,* Apr. 28,1980, p. 20.

"Craig Covault, "Antisatellite Weapon Design Advances, " *Aviation Week and Space Technology,* June 16, 1980, pp. 243-247

[77] See articles in *Aviation Week and Space Technology* of July 28, 1980; also Richard Burt, "Experts Believe Laser Weapons Could Transform Warfare in 80's, " New York *Times,* Feb. 10, 1980, p. 1.

military would have the further option of flying manned or unmanned missions.

Without SPS, advanced launch-vehicles and construction devices may not be built or, at best, be done so much less quickly. The military may hence have a strong interest in participating in their development, as they have with the Space Shuttle. Whether the military would actively support the SPS in order to benefit from such developments might depend on whether they think SPS funding would direct resources away from other military programs.

An ongoing SPS construction project with a high volume of traffic into space could provide opportunities for the military to disguise operations or incorporate them in normal SPS activities. Such a possibility would likely cause any unilateral SPS project to be closely monitored by foreign observers.

The most significant use of a fleet of military-capable SPS launchers and crews would be in providing a "break-out" capability whereby, in time of crisis, large numbers of communications and surveillance satellites, antisatellite weapons, or directed-energy platforms could be placed in orbit on short notice. This would be similar to the way a national merchant shipping or air cargo fleet is viewed as a military asset, and often supported in peacetime because of its strategic significance. Fear of such uses might be a spur to the development of antilauncher weapons, analogous to attack submarines or merchant raiders.

Military Uses of SPS

Direct Use of SPS

The energy transmission beams of the SPS could have direct military uses. A microwave system in geosynchronous orbit would not generate a beam intense enough to cause direct damage to people or installations; it might be enough to cause minor irritation or panic if used against populated areas. An intense microwave beam might be used to interfere with short-wave communications over a broad area (see ch. 5, Electromagnetic Com*patibility).*

Certain laser designs would be sufficiently powerful and focused to cause some immediate damage to people and structures, but would not be optimally designed for weapons-use. An SPS would use a continuous laser rather than the high peak-power pulsed lasers needed for military missions. For such uses, increased focusing of the beam would be required, as well as appropriate tracking mechanisms. If so equipped, a laser SPS could be used directly against satellites and ICBMs, and also against targets on the ground such as ships, planes, and oil refineries. Such uses would be greatly facilitated if a laser SPS were placed in low orbit, with energy relayed to the ground via geosynchronous mirrors. Since a sun-synchronous SPS in low-Earth orbit would of necessity pass directly over many different countries (including the Soviet Union), it could be seen as potentially more threatening than a geosynchronous satellite that remains fixed above one spot. A geosynchronous laser might have difficulty tracking low-flying ICBMs and satellites, due to its position 35,800 km from the target.

Since the key requirement for directed-energy weapons is a large power supply, any SPS that generates electricity directly [i.e., any design except the mirror-system) can be used to power such weapons. These weapons could be built into the SPS platform or placed at a distance in lower orbits and supplied by lasers from the SPS. The question is whether relatively small directed-energy weapons can be designed with autonomous power supplies, perhaps from nuclear reactors. Since weapons used against ICBMs must be capable of firing a large number of very rapid bursts in order to engage a fleet of 1,000 or more missiles, it may be that SPS power, if available, would be the most efficient and economical way to supply future laser or particle-beam platforms.

Direct use of the SPS in this way would of course make attack in time of war inevitable. Extensive defensive armament would have to be built in; the offensive weaponry could also be used to defend against missile attacks.

Any testing, deployment, or use of directed-energy weapons in space is presently prohibited by the 1972 ABM Treaty and other space treaties. A proposed SPS would probably be a topic of future arms control negotiations to clarify and limit its military implications (see discussion on pp. 156-157).

Indirect Military Uses

In addition to these direct uses, a laser SPS could be used to supply power to military units, providing increased mobility to ground forces that could dispense with bulky fuel supplies in remote and roadless areas. Given adequate tracking capability it might even be possible to supply mobile units such as ships, planes, or other satellites equipped with thermoelectric converters, increasing their range and allowing them to carry more armaments or cargo.[78]

A geosynchronous SPS is at an advantageous position for numerous communications and positioning uses, military as well as civilian. Its large size would make it easy to attach equipment to it; the military's need for redundancy makes it convenient to use all available platforms, as does future crowding of geosynchronous positions. Operation of a microwave SPS, however, could interfere with communications uses unless switched off.

SPS's power and position might make it suitable for electronic warfare uses, such as jamming enemy command-and-control links. This would require the addition of specialized equipment.

The mirror designs use reflected sunlight rather than energy transmission beams. However, it has been suggested that the reflected light could be used for weather modification or for nighttime battlefield illumination. The energy levels are not high enough, in current designs, to change weather patterns significantly (see ch. 8, Environment). Such use would be prohibited by the 1980 "Convention on the Prohibition of Military or any Other Hostile Use of Environmental Techniques."

Nighttime illumination could be significant, especially in cases of guerrilla warfare or urban terrorism where attacking forces rely on darkness and surprise as equalizers. However, fragile Solares mirrors could probably not be adjusted quickly enough to deal with sudden military developments; rapid deployment of mirrors by the military for specific uses would probably be more effective.

Ownership and Control

Any of the military uses discussed clearly depend on who owns, operates, and builds the SPS system. If SPSs are unilaterally owned by national governments, their military use is far more likely than if run by private enterprise or by a multilateral consortium. Fears of military involvement could be an incentive to establishing a multinational regime to operate or regulate SPSs, and to prohibiting militarily effective SPS designs.

A key question would be who has effective control over SPSs in a time of crisis. If a private SPS consortium, having its own launchers and crews, has a monopoly on SPS control and expertise, then governments might be hard-pressed to take over SPSs on their own. A limited defensive capability would help to deter any national takeovers. However, governments might stipulate that in an emergency they be allowed to commandeer SPSs for defense purposes.

A nongovernmental owner can be expected to resist any attempts to use SPSs for military functions rather than supplying electricity to commercial users. The threat of lawsuits or diplomatic protests at electricity interruptions caused by military preemption might help to deter such actions.

[78]See Michael Ozeroff, *SPS Military Implications,* DOE/NASA report, October 1978, pp. 13-16; also A Hertz berg, K Sun, and W. Jones, "Laser Aircraft," *Astronautics and Aeronautics,* March 1979, p. 41,

FOREIGN INTEREST

Interest in SPS has been expressed outside of the United States, especially in Europe but also in Japan, the Soviet Union, and some developing countries.

Europe

- The first significant European study of SPS was done in 1975 by a German firm under contract from West Germany's space research organization.
- In England, the Department of Industry funded a study, completed in early 1979, that led to a further effort by British Aerospace to investigate the implications of SPS for British industry. "
- In France, the work of Claverie and Dupas on global demand for SPS has already been mentioned.
- The ESA began SPS assessments in 1977, publishing a-number of papers in the ESA Journal of 1978. Ruth and Westphal performed a study in 1979,[80] which examined offshore sites for rectenna placement, and in 1980 a major report on ground receiving stations was published by Hydronamic B.V. of the Netherlands.[81] In 1978, Roy Gibson, then director of ESA, said ESA was "intensely interested" in SPS,[82] and ESA has supported a group within the IAF for SPS investigation. In June 1980, an International Symposium on SPS was held at Toulouse, France, with representatives from many European countries and agencies.[83]

In general, the European studies have focused on the European requirements for possible contributions to an SPS system. Little detailed work on the system proper has been done outside of designs to reduce the size of rectennas; European participants have relied on U.S. projects for technical information. Suspension of NASA/ DOE research efforts due to lack of fiscal year 1982 funding will have an adverse effect on foreign studies and has led to great disappointment among foreign SPS experts.[84] A major difference between U.S. and European efforts is that while in the United States SPS has attracted interest from energy experts and the DOE, European studies have been the exclusive province of organizations involved in space research .85

Soviet Union

The Soviets have initiated no major known studies of SPS, though there have been unverified claims of a Soviet SPS project. It is impossible to tell with certainty what the degree of interest or expertise is; U.S. experts feel the Soviets are relying on Western reports and are far from developing the launchers, microwave transmission expertise, and advanced solar cells necessary to consider an SPS.[86] Recent signs of interest include a paper entitled "Satellite Power Stations" published by scientists from M.V. Lomonosov State University, Moscow in December 1977.[87]88 At the 30th Congress of the IAF in Munich, September 1979, the Solar Power Bulletin reported that: "Although the Soviets were reluctant to disclose their level of commitment to a solar power satellite program, Chief Cosmonaut Beregovoy commented 'that if the United States puts up an SPS first, we will congratulate you, and if ours goes up first, we will expect congratulations from you'. "[89]

"K. K. Reinhartz, "An Overview of European SPS Activities," in *Final Proceedings of the SPS Program Review,* U.S. Department of Energy, July 1980, pp. 78-88.

[80] J. Ruth and W. Westphal, "Study on European Aspects of SPS,"ESA report No CP(P) 1266.

[81] A. R. Bresters, "Study on Infrastructure Considerations for Microwave Energy G round Receiving Station," Hydronamic Project, p. 495, November 1980

'*In Jerry Grey, "The Internationalization of Space, " *Astronautics and Aeronautics,* February 1979, p 76

[83] See Peter Glaser, "Highlights of the International Symposium on Solar Power Satellites," July 1980,

"Conversation with Jerry Grey, of the AI AA, Oct. 15,1980.

[85] K K Reinhartz, op cit., p 80

""Conversations with James Oberg, Johnson Space Center, and Charles Sheldon I I, Congressional Research Service, September 1980

" *Soviet Space Programs 1971-/975, VOI 1,* staff report, Library of (ongress, 1976, p 529

[88] See statement of Peter Glaser in House *Hearings on SPS,* 96th Cong , March 1979, p 218

[89] *Space Solar Power Bulletin,* Sunsat Energy Council, February 1980, p 3

Japan

The Japanese have expressed interest and funded studies within the National Space 'Development Agency, though no permanent office for SPS exists. Japanese interest in space exploration and industrialization is strong and includes plans for several new series of Launchers.[90]

Third World

Information about SPS has been spread to the Third World by discussions at COPUOS and by sessions on SPS at international conferences such as those of the IAF. Reaction has generally been cautiously optimistic. At the International Symposium in Toulouse, Dr. Mayur of India's Futurology Commission claimed: "There is no conflict between small scale technologies and the SPS." Dr. Chatel, former Chief of the UN's Office of Science & Technology, proposed an international working party to coordinate national programs and perform assessments. " The SPS has been placed on the agenda of the upcoming U.N. energy conference in Nairobi in the summer of 1981.

[90] James Harford, "Japan Showcases Crowing Space Prowess," *Astronautics and Aeronautics,* December 1980, pp. 120-125.

[91] Glaser, op cit

STUDY RECOMMENDATIONS

It is crucial to continue updating long-term projections as new information becomes available about developments in the space and energy fields. Close attention should be paid to: 1) future global electricity demand under various scenarios and on a detailed regional basis; 2) evaluation of the impact that possible external events —wars, oil embargoes, widespread famine— could have on U.S. and European energy needs; 3) the feasibility of a unilateral SPS System given a global market, including estimates of profitability; 4) monitoring of Law of the Sea negotiations and the resulting international regime with special attention to the implications for the Moon Treaty and other space agreements; and 5) weapons development and foreign military space programs, and arms-control negotiations.

U.S. energy and space experts often tend to pay little attention to the foreign implications of their programs. Since SPS is a system that may make sense globally but not domestically, neglect of the international dimension could lead to an unjustified foregoing of SPS development. In making plans for future R&D programs, attention should be paid to involving and informing potential partners as well as to considering the ways in which a global system might differ, technologically and institutionally, from a domestic one.