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SATELLITE POWER SYSTEM (SPS) ENVIRONMENTAL IMPACTS

PRELIMINARY ASSESSMENT

April 1, 1978

Floyd R. Livingston

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FOREWORD

The National Aeronautics and Space Administration (NASA) Office of Energy Programs is presently conducting a study of the potential utility of using large satellite power stations as energy sources for terrestrial needs. As part of this study, JPL has been requested to perform an analysis of the Potential Impacts and Benefits arising from the implementation of a Satellite Power System (SPS) network. This analysis is part of the data base being developed by NASA and the Department of Energy (DOE) for use in making a decision on whether to proceed with the next program phase of SPS. This work is being performed under the technical direction and guidance of Mr. Simon Manson of the Solar Energy Division of the NASA Office of Energy Programs (OEP).

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SECTION I

INTRODUCTION

In the assessment of any new electrical generating capacity, the environmental impacts must be addressed. If a Satellite Power System (SPS) is deployed after AD 2000, present laws regarding power plant siting, air quality control and other impacts may not apply at that time. Also new processes for materials may change air, water and solid waste emissions from those presently reported. Present day power plant siting requires assessment of electric energy needs, land use impacts, water resources impacts, air quality impacts, solid wastes impacts, radiation impacts, and noise impacts. The present assessment of SPS encironmental impacts follows these present power plant assessment factors.

The SPS could provide 25% of the new electrical generating capacity by AD 2015. Using the SPS to fill the void in power generation resulting from the depletion of natural gas, oil, and uranium resources may provide an environmentally clean alternative. In contrast to oil, gas, nuclear and coal fueled power plants (Refs. 1, 2), the SPS and hydroelectric power plants produce air, water, and solid waste emissions only during the construction phase. After the construction phase, only those pollutants resulting from operations and maintenance activities would be generated.

Land use impacts result from the placement of rectennas used for microwave receiving and rectifying. SPS land area requirements are expected to be less than those of coal power plants when the fuel cycle is taken into account and also much less than those of terrestrial solar power plants. Possibly the least SPS land use impact would occur if large desert dry lakes were used to site the rectennas. Minimum soil erosion, ground water, and construction impacts would occur with the desert sites. SPS water pollution impacts would result from the component manufacturing processes. Based upon the power that would be generated, the water pollutants from SPS would be 0.200 metric tons (MT) per megawatt-year (MW-yr). A coal-fired steam electrical power plant pollutes water with from 6.7 to 630 metric tons of wastes for each megawatt-year of power. Since coal will be the principal fossil fuel in the SPS operations period, the advantage of solar generated electrical power is apparent. SPS water pollution via waste heat discharge is negligible compared to that due to light water reactor power plants which discard their waste heat to local streams or ocean water.

Air quality impacts of the SPS resulting from the construction phase amount to 0.405 metric tons per megawatt year. Over half of these pollutants are particulates emitted from plants manufacturing cement for rectennas and launch sites. A coal-fired steam power plant would produce air releases of from 5.5 to 110 metric tons per megawatt-year of operation. Solid wastes impacts of the SPS are 0.108 metric tons per megawatt-year of operation compared to 890 to 2100 metric tons per megawatt-year for the coal-fired plant.

Heavy Lift Lanuch Vehicle (HLLV) sites could experience overall sound pressure levels of up to 129 dB during HLLV launch. Cities as far away as 14 km (9 miles) would be impacted with sound levels of 120 dB. These overall sound pressure levels are about 6.7 dB stronger than those occurring with a Saturn V launch. Catastrophic explosion of the HLLV on the launch pad could result in doors and windows being blown out in a city 6 km (3.5 miles) away.

Recommendations for further study are given in Section IX of this report.

SECTION II

EVALUATIVE CRITERIA

The Power Plant Siting Act of 1971 provided federal requirements for certifying new electrical power plants. The certifying agency would require a detailed statement from the electric entity covering the following items:

1. The environmental impact of the proposed facility.

2. Any adverse environmental effect which cannot be avoided if the facility is constructed and operated as proposed.

3. Alternative locations, measures, or other actions.

4. The relationship between the short-term environmental impact of the proposed facility and the maintenance and enhancement of long-term productivity.

5. Any irreversible and irretrievable commitments of resources if the proposed facility is constructed.

If the Satellite Power System (SPS) Scenario-A* program were initiated by an electric entity and certification were required, then certain evaluative criteria would be examined. Even in evaluating long-range plans for certification of bulk power supply facilities, the certifying agency would consider the electric energy needs, land use impacts, water resources impacts, air quality impacts, solid wastes impacts, radiation impacts, and noise impacts. The objective of this report is to make a preliminary examination of the SPS Scenario-A program in terms of these evaluative criteria regarding environmental impacts.

The electric energy needs of the country were examined as this need is the major purpose for creating the SPS concept. The growth in demand and projection of need indicate a definite void that could be filled by the SPS. In a general way, the area of land required for the SPS rectenna sites, and the impacts of land use have been examined. Water resources impacts occur during the construction phases of the SPS. Also, air quality impacts occur during the construction phase of the SPS, but very little during the operations phase. Solid wastes impacts were examined, but disposal of these wastes was not considered. Ionizing radiation environmental impacts of the SPS program would be non-existent for ground construction and operations. Noise impacts at the launch were assessed as well as possible explosion hazards on the launch pad. Ionizing radiation hazards to space crews have been examined in an occupational health impacts paper. Microwave radiation hazards and solar ultraviolet radiation hazards have been assessed in separate reports.

*Assumes 48 SPS 10-GW stations brought on line and operated in the calendar period 2000 to 2055 AD (Ref. 3).

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SECTION III

ELECTRIC ENERGY NEEDS

Before new electrical generating capacity is built, a need must be demonstrated. The use of electrical energy in the United States has steadily become a larger percentage of the total energy usage in this country. In 1947, only 13% of the fuel was used to produce electrical power, but by 1970 this use had increased to 25%. By the year 2000, the U.S. Department of Interior (Ref. 2) predicts that between 40 and 50% of the fuel will be consumed producing electrical power. Actual and projected use of energy in 1971, 1980, and 2000 (Table 1) indicates this trend of shifting emphasis to electrical power generation. Total energy in each category is increasing even though some categories show a decreasing percentage of total energy.

Table 1. Use of Energy in U.S.A.

Use	1971, %	1980, %	2000, %
Household and commercial	21	18	11
Industrial	29	26	21
Transportation	25	24	22
Electrical Generation	25	31	42
Synthetic Gas	-	1	4

Greater use of coal and uranium-235 in future years, which are the two fuels most suited to the production of electricity, is the primary reason for the shift to electrical generation. Also, the combustion of fossil fuels at a few large electrical generating plants should result in less air quality impacts than combustion in millions of homes, factories, and cars consuming gas and oil for heat, cooling or power. The widespread use of electric automobiles and public transportation also leads to more central power plant generation of electricity. Significant amounts of electricity will also be required in the recycling of wastes and sewage treatment.

Sources of the electricity in the country at the present time and in future years may change significantly for many reasons. The makeup of power consumed in this country as projected by the Federal Power Commission is shown in Table 2. These projections are subject to much controversy, and hence should be regarded as uncertain for detail planning.

Table 2. Sources of Electricity (10^6 GW-hr)

Source	1972	1980	1990
Hydro	273 (15.6%)	317 (10.2)	318 (6.4%)
Coal	771 (44.2%)	1211 (38.9%)	1651 (27.8%)
Oil	272 (15.6%)	421 (13.2%)	512 (8.7%)
Gas	375 (21.4%)	410 (13.2%)	445 (7.5%)
Nuclear	54 (3.1%)	750 (24.1%)	2913 (49.3%)
Other	2 (0.1%)	4 (0.1%)	20 (0.3%)
Total	1747	3113	5922

According to Table 2, the generation of hydroelectric power may increase in future years, but the total fraction of hydroelectric power may decrease to 6.4% in 1990. The use of coal to generate electricity may more than double by 1990, but the percentage of total power derived by combustion of coal may decrease from the 1972 level of 44% to less than 28% in 1990. Also, the use of oil and natural gas combustion may increase in the future; however, these resources may make up only a total of 16% of electrical power generation by 1990. The expansion of the use of uranium-235 to generate electrical power would result in 2913 x 10^6 GW-hr by 1990, thus representing almost one-half of the electrical power generated. The United States nuclear electrical generating capacity was predicted by the Atomic Energy Commission to expand to 475 GW by 1990 and on to 1090 GW by the year 2000. Based on favorable geologic indications, the uranium reserves are expected to meet the requirements up to 1990. Continuing vigorous exploration would be needed to meet uranium requirements after 1990.

The Satellite Power System (SPS) could be implemented in such a manner as to provide 25% of the new electrical energy demand by AD 2015 (Ref. 3). A significant portion of the future electrical power program demand could be met by the development of the SPS to produce 25% of the Federal Power Commission extrapolated growth as seen in Figure 1. In this figure, the maximum electrical energy generated by the SPS system would be about 4.2 x 10^6 GW-hr/yr in 2025, or 14.5 % of the NASA Johnson Space Center extrapolation of the Federal Power Commission projection. If the SPS Scenario A is accomplished successfully by the year 2025, then expansion of more than these 48 proposed Space Power Stations could be expected in following years.

On the basis of Figure 1, there would appear to be a need for new electrical energy generation capacity beyond 1990 from sources other than hydro, coal, oil, gas, and uranium-235. Additional energy sources are

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uranium-238 and thorium-232 breeders, fusion, and solar. If the fusion breakthrough occurs, there will be no need for satellite-based solar power generation. Yet if it does not occur, there is no viable alternative to the SPS. Fusion is the only other nondepletable energy source, and therefore the only competitor to SPS. The solar alternative presents environment impacts differing in kind and degree from those of other electrical power plants as seen in Table 3. The environmental impacts of the Satellite Power System could be a decisive factor in the implementation of this solar power plant.

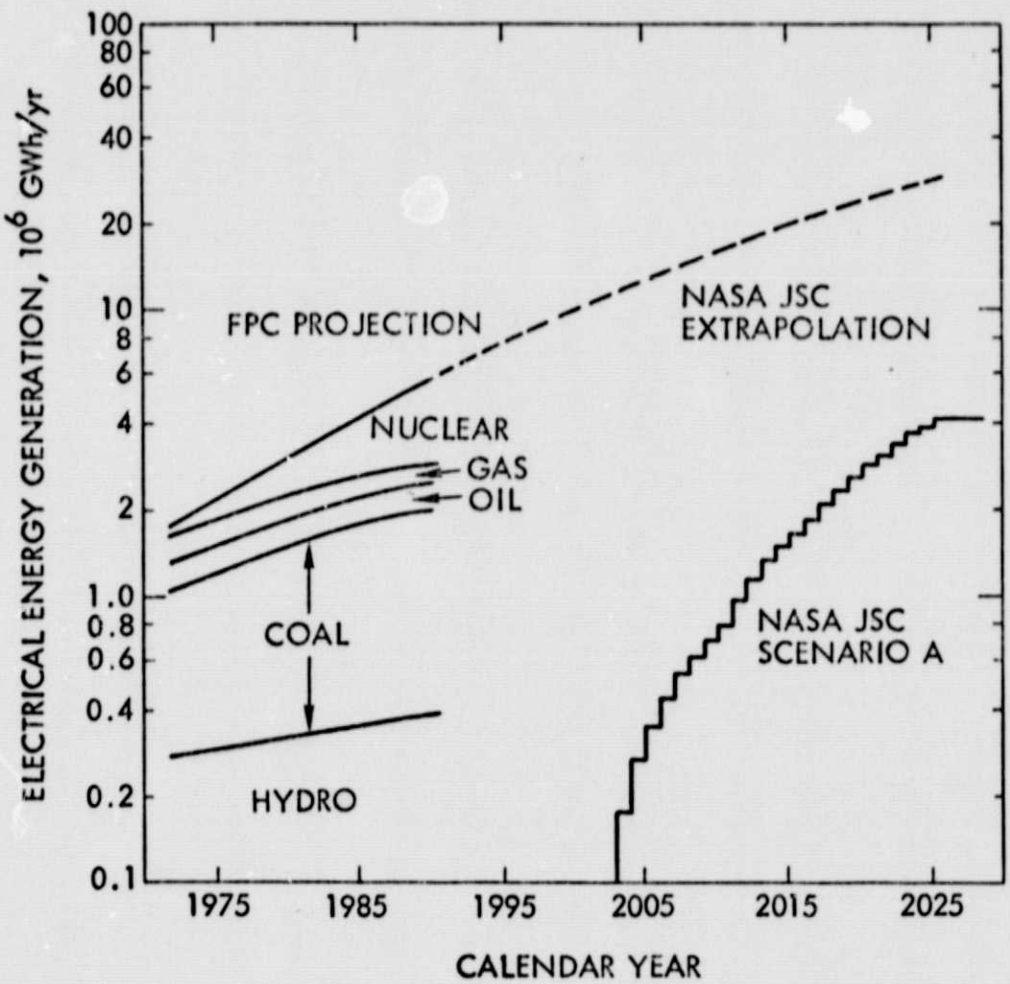

Figure 1. Electrical Energy Generation Trends

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Table 3. Environmental Effects of Electrical Power Generation

Energy Source	Effects on Land	Effects on Water	Effects on Air	Biological Effects	Supply
Coal	Disturbed land; large amounts of solid waste; mine tailings	Chemical mine drainage; increased water temperature	Sulfur oxides; nitrogen oxides; particulates; some radioactive gases	Respiratory problems from air pollutants	Large reserves
Oil	Wastes in the form of brine; pipeline construction	Increased water temperature; oil spills	Nitrogen oxides; some sulfur oxides	Respiratory problems from air pollutants	Limited domestic reserves
Gas	Pipeline construction	Increased water temperature	Some oxides of nitrogen	None detectable	Extremely limited domentic reserves
Uranium	Disposal of radioactive wastes; mine tailings	Increased water temperature	Some release of radioactive gases	None detectable in normal operation	Large reserves if breeders are developed
Sun (SPS)	Rectenna construction and land area utilization	Some pollution in fabrication	Some pollution in fabrication	Possible microwave, solar UV problems	Undepletable
Fusion	Characteristics of fusion systems remain to be determined.				

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SECTION IV

LAND USE IMPACTS

For an allowable microwave exposure intensity of 1 mW/cm^2, approximately 90 square kilometers of land may be required for each 5-GW rectenna site. The 96 rectenna sites planned for use with 48 10-GW satellites of the SPS Scenario-A program would then require a total of 8640 square kilometers of land if individually sited. Additional land (440 km^2) would be required for 21 launch sites. The land use requirement would be 673 m^2/MWe-yr which is less than the land use of 3600 m^2/MWe-yr requirements for a coal-fired steam electrical power plant, including fuel cycle, and less than ground Solar Thermal Electric and Solar Photovoltaic land use requirements of 3600 m^2/MWe-yr and 5400 m^2/MWe-yr. The light-water reactor power plant requires 800 m^2/MWe-yr including the fuel cycle. Alternatively, if a buffer zone were provided to reduce the microwave intensity to 0.1 mW/cm^2, about 136 km^2 would be required per rectenna site, and 96 rectennas at a load factor of 0.92 would require about 985 m^2/MWe-yr if individually sited.

Values presented in this section are based on a microwave beam having a 17 dB taper, an elliptical rectenna of dimensions 9.5 km E-W and 11.8 km N-S, a microwave intensity of 1 mW/cm^2 at the edge of the rectenna, and a microwave intensity of 0.1 mW/cm^2 at a distance of 1.29 km from the rectenna edge.

As in all power plant siting requirements, the rectenna sites would have to consider the consistency with any state and regional land use plans, and also the consistency with existing and projected area land use. There would be alternative uses of the sites which would be compared to SPS rectenna use. Shore sites considered by system contractors may also be possible.

Population residing on the proposed rectenna sites would be impacted directly by being displaced to other locations. Remote locations for rectenna siting would be sought to minimize these adverse impacts. The construction of one 5-GW rectenna site would require construction industries labor. The construction personnel plus families and other persons engaged in services would be attracted to the plant site and possibly overload the existing business and residential communities adjacent to the site. After construction, operation of the plant itself would result in residual land use impacts of surrounding communities. Impact of availability of power from the rectenna site could cause population growth in the region and/or may result in general population dispersal if remote siting is adopted.

Geologic requirements to siting a rectenna may include a need for relatively level land capable of transversal by construction equipment and installation of rectenna units. Since large structures that are sensitive to seismic activity are not proposed for the plant site, seismological characteristics of the region would not be of major significance.

Construction practices would be chosen to minimize dust, smoke, cement and other aerosol emissions to the atmosphere. In dry desert regions, fine materials are prevalent; however, they form a thin crust on the surface which retards erosion of the underlying material. The crust can be up to 6-mm thick (Ref. 4), but it is fragile and easily damaged by construction vehicles and workers. When damaged, wind will quickly erode the underlying fine material and increase atmospheric particulates. Also, the loss of fine material retards the growth of plants and animals in desert regions. In other parts of desert regions, the surface is covered by a pavement consisting of packed pebbles and stones cemented together. These remain after fine particles are carried away by wind and water erosion. The pavement inhibits further erosion by wind and water and retards water runoff. The pavement can be broken by construction vehicles with a resulting erosion of underlying material. Other climatic regions of the country would have similar land use impacts.

Transmission lines from remote rectenna sites to urban areas will require a corridor to minimize the adverse effects of erosion, scouring and wasting of land.

The rectenna site would spoil the scenic beauty of the natural terrain in the same manner as a conventional power plant, factories, roads and cities. Since the porposed 96 rectenna sites each conscitute a large land use area, the scenic impact of each one would have to be considered. In the more remote areas available for siting rectennas, a conflict with scenic beauty associated with wilderness exists.

In the intense construction phase, burrowing animals and their habitats would be destroyed. Other animals and birds would be displaced by the construction and by the rectenna itself. When in operation, the ground animals may be shielded from microwave radiation; however, birds may be exposed to hazardous levels of microwave radiation. Plant and animal life inhabiting the rectenna site during operation would likely differ from the prior flora and fauna due to shading and human activity.

Impacts on important historic, architectural, archaeological and cultural areas and features would be considered for any proposed rectenna site. The southwestern deserts are rich in archaeological sites which could be adversely impacted by construction and/or operation of a 5-GW rectenna. Each proposed site must be evaluated on its own merits.

The large dry lakes in desert regions would offer the best sites to minimize the land use impacts since they are relatively free of wildlife, plants, or possible erosion impacts. In addition, these large, dry lakes offer the flat terrain necessary for the construction of the proposed rectennas. The lakes are usually dry and are seldom flooded, so obstacles to construction and operation are minimal. Consideration of operating difficulties in flooded dry lakes would have to be addressed in any design study.

Weather effects due to the solar satellites' rectenna operations would be negligible because it is not a source of substantial heat (Ref. 5). Presence of the rectenna would result in a local air temperature rise of less than the $1^{o}C$ at most conditions.

SECTION V

WATER RESOURCES IMPACTS

A major use of water in the SPS Scenario-A program might be for the construction of concrete foundations for the rectenna array. Approximately 1,676,000 metric tons of concrete would be used in the foundation; of this, approximately 14% or 225,000 metric tons would be water. The water supply at the rectenna site would have to be adequate to supply this water over the construction phase. If the rectenna site included stream flow, estuarine and coastal waters, lakes and reservoirs, the impact of the facility on these water resources would be assessed. Alternate treated wood pole and timber versions of the rectenna support could reduce water requirements and use a renewable resource.

As mentioned earlier, construction operations can damage the terrain in such a manner as to increase the water runoff during storms and thus decrease the local water supply required for plant and animal life. In desert regions, the local ecosystem can be affected by any modification of the water cycle. Here rains usually occur in mountains or over alluvial fans and percolate into the ground water system of the high grounds. The ground water then flows to basins or plains and is eventually evaporated in the desert playas. Minimum impact to water resources and wildlife would occur with rectenna siting in these dry lakes.

Total non-recoverable water use at the SPS launch complex over the life-cycle of the SPS Scenario A would be about 80,000,000 metric tons, or about 6 metric tons/MW-yr compared to 500 to 9200 metric tons/MW-yr for a coal-fired plant. Most of this would be required to form hydrogen and oxygen rocket propellant, the remainder being used for rocket exhaust cooling. At Merritt Island Launch Complex 39, three wells capable of pumping 350 gallons per minute to a 1,000,000 gallon reservoir now exist (Ref. 6). Operating continuously at full capacity, one well comparable to the existing ones would be required to supply water use for each SPS launch complex. Hydrologic studies of the adequacy of the local water supply and the influence on the ground water table would be considered in any plan to obtain all of the required water from local sources.

In the fabrication and construction of the SPS units, the Space Transportation System, the rectennas, and the launch sites, there are indirect water use impacts. These result from processes in the primary metals industry, the fabricated metal products industry, the cement industry, coke production and chemicals industry. The water pollutants resulting from the manufacturing industries include acids, bases, dissolved solids, suspended solids, organics, and a measure of the biological oxygen demand (BOD) and chemical oxygen demand (COD). The amount of these water pollutants would be directly proportional to the amount of steel, aluminum, copper, glass, cement, etc. used in the manufacture of all subsystems. These water pollutants, as given in Ref. 7, are listed in Table 4.

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Table 4. Water Pollutants Resulting from Manufacture (Ref. 7)

Water Pollutant, kg/MT	Material Manufactured			
	Steel	Aluminum	Copper	Cement
Acids	-	-	-	-
Bases	-	-	-	0.0157
Biological Oxygen Demand	-	0.162	-	0.00065
Chemical Oxygen Demand	-	13.7	2.18	0.00012
Dissolved Solids	0.0713	5.05	-	0.00706
Suspended Solids	1.21	-	17.4	0.0281
Organics	0.55	2.5		

The total materials required for the SPS Scenario-A program have been assessed to be 249 million metric tons of solid material resources for the 48 SPS systems and the 55-year calendar period involved. These materials are required to fabricate and construct the flight systems, the rectenna systems, and the launch sites. In the manufacture of the components, water is polluted through the discharge of these acids, bases, dissolved solids, suspended solids, and organics in stream, flow, estuarine and coastal waters, lakes, and reservoirs. The total amount of these water pollutants (Ref. 7) and the amount normalized on the basis of generated electricity is illustrated in Table 5.

These total water pollutants are small compared to conventional electrical power plants. A coal-fired steam electrical power plant pollutes water with from 6.7 to 630 metric tons of waste for each megawatt-year of energy delivered. A light water reactor power plant of 35% cycle efficiency would discharge about 1.8 MW_{th} to its cooling water for each MWe generated. This waste heat would be transferred to the surrounding local water (or to the atmosphere).

Table 5. SPS Scenario A, Total Water Pollutants from Manufacture

Water Pollutant, 1000 MT	Material Manufactured					
	Steel	Alum.	Copper	Cement	Total	MT/MWe-yr
Bases	-	-	-	365.0	365.0	0.028
BOD	-	10.8	-	15.0	25.8	0.002
COD	-	910.0	0.59	2.8	913.0	0.069
Dissolved Solids	0.16	336.0	-	164.0	500.0	0.038
Suspended Solids	2.8	-	4.8	653.0	661.0	0.050
Organics	1.2	166.0	-	-	167.0	0.013
Total						0.200

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SECTION VI

AIR QUALITY IMPACTS

In the Satellite Power System, no air emissions result directly from the generation of electrical power. There are air pollutants resulting in air quality impacts during the mining, processing, fabrication assembling, and constructing steps in the production of the SPS units, the rectenna units, the launch sites, and the Space Transportation System units. Additional air pollutants are formed during the launch and boost of SPS material to low-Earth orbit and again at transfer to geosynchronous-Earth orbit. Also, dust particulate matter pollutes the near-Earth atmosphere during construction of the launch sites and the construction of the rectenna sites.

Air quality impacts of the Satellite Power System resulting from mining, processing and fabrication have been analyzed in the present report. These total environmental releases to the air have been found to be small compared to fossil fuel electrical power plants and comparable to the non-radioactive air emissions resulting from light-water reactor power plant construction. Source for the present air quality assessment has been the "Compilation of Air Pollutant Emission Factors" published by the U.S. Environmental Protection Agency (Ref. 8).

The resources that would be used for the SPS have been assessed in a companion report (Ref. 9). The material resources required in Scenario A for the construction and maintenance of the 48 SPS units, the Space Transportation System, the 96 rectenna systems and the 21 launch sites are illustrated in Table 6. The rectenna systems represent the major material resource impact and consequently the major air quality impact during the processing and fabricating of the structures. A rectenna utilizing steel structures is assumed for the purposes of this report.

Almost all of the air emissions occur from the metallurgical industries and the mineral products industries. The air pollutant emissions from mining, processing, and fabricating are illustrated in Table 6 for all of the production materials and the rocket propellant hydrocarbons. The largest amount of particulates occur from the cement industry; out of a total of 3.32 million metric tons, over 3 million tons result from cement use. The largest source of emissions within the cement plant is the kiln operation which results in 114 kg of particulate release per metric ton (MT) of cement for the wet manufacturing process. Total particulate emissions from the cement manufacturing is 130 kg/MT. In all cases discussed in this report, the cleanest present operation was assumed for the manufacturing processes. Even this assumption may be conservative considering that the SPS will be constructed after 2000 AD when cleaner manufacturing processes would be in effect. However, gas and oil may not then be available for process heat.

The public health impacts of sulfur oxides are better known than for other air pollutants. Therefore, more care has been taken to compile air pollutatn emission factors for this environmental release than for

Table 6. SPS Air Pollutant Emissions from Mining, Processing, and Fabrication

Material	Mass (1000 MT)	Particulates (kg/MT)	Particulates (MT)	SO_2 (kg/MT)	SO_2 (MT)	CO (kg/MT)	CO (MT)	HC (kg/MT)	HC (MT)	NO_2 (kg/MT)	NO_2 (MT)	Ammonia (kg/MT)	Ammonia (MT)
Aluminum	6,926	3.6175	25,055	1.1055	7,657	0.349	2,417	1.155	8,000	.011	76.2	.0495	343.
Steel	134,765	1.86	250,663	1.1055	148,983	0.349	47,033	1.155	155,654	.011	1482.	.0495	6671.
Inconel (steel)	261	1.86	485	1.1055	289	0.349	91	1.155	301	.011	2.9	.0495	12.9
Copper	273	0.81	221	250	68,250	-	-	-	-	-	-	-	-
Mech System (steel)	98	1.86	182	1.1055	108	0.349	34	1.155	113	.011	1.1	.0495	4.9
Insulation (dacron)	34	-	-	-	-	-	-	3.5	119	6.5	221.	-	-
Mylar	537	3.75	2,014	-	-	-	-	-	-	-	-	-	-
Silver (steel)	1.2	1.86	2.2	1.1055	1.3	0.349	.4	1.155	1.4	.011	.01	.0495	.06
Graphite	389.	1.75	681	2.01	782	0.635	247	2.1	817	.020	7.8	.09	35.
Molybdenum (steel)	16.6	1.86	30.9	1.1055	18.4	0.349	5.8	1.155	19.1	.011	.18	.0495	.82
Electronics (steel)	2,433	1.86	4,526	1.1055	2,690	0.349	849	1.155	2,810	.011	26.8	.0495	120.
Silicon	698	1	698	-	-	-	-	-	-	-	-	-	-
Glass	698	1	698	-	-	-	-	-	-	-	-	-	-
Adhesive (plastics)	322	3.75	1,208	-	-	-	-	-	-	-	-	-	-
Gold Kovar (paint)	348	1	348	-	-	-	-	15	5,220	-	-	-	-
Black Paint (carbon black)	348	·6	2,088	-	-	2,250	783,000	215	74,820	-	-	-	-
Concrete	166,818	.005	834	-	-	-	-	-	-	-	-	-	-
Cement	(23,231)	130	3,020,030	7.82	181,666	-	-	-	-	1.3	30,200.	-	-
Sand & Gravel	(120,356)	.05	6,018	-	-	-	-	-	-	-	-	-	-
Aggregate	6,174	.05	309	-	-	-	-	-	-	-	-	-	-
RP-1	32,958	.146	4,802	.020	663	12.71	418,760	1.56	51,453	.0164	543.	.02	659.
Contingency (steel)	535	1.86	995	1.1055	591	.349	187	1.155	618	.011	5.9	.0495	26.4
TOTAL			3.32×10^6		4.04×10^5		1.25×10^6		2.99×10^5		32,567		7,873.

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CO, HC, NO_2, etc. where effects are not as well known. The Portland Cement industry would produce 181,666 MT of SO_2 if low (0.8%) sulfur western coal is used for process heat. The 148.983 MT of SO_2 released during steel manufacture actually occurs in the production of coke from the 0.8% sulfur coal. Copper smelters would also release 68,250 MT of SO_2 even when using a combination of sulfuric acid plants and lime slurry scrubbing to reduce sulfur oxides. The cumulative environmental release of sulfur oxides during the 55-year SPS Scenario-A program would be 404,000 MT.

Carbon monoxide is released primarily during the manufacture of carbon black for black paint, during the propulsion phase of booster flight, and in the production of coke for steel manufacture. Carbon black would be produced by the reaction of oil with a limited supply of air at temperatures of 2500 to 3000°F (1370 to 1650°C). In this process, 2.25 MT of CO are released for each metric ton of carbon black produced. Possibly other methods or materials are needed to produce the black paint required for SPS thermal control.

Large amounts of hydrocarbons (HC) are released in the production of coke for the steel refining processes. These emissions originate in the byproduct coking operations when charging coal into incandescent ovens, and quenching the hot coke. Hydrocarbons are released during the manufacture of carbon block from oil and also during the combustion of the rocket propellants (RP-1) upon launch into LEO. Total hydrocarbons released are 299,000 metric tons for the SPS Scenario-A program.

During production of Portland cement, nitrogen oxides are formed in the kiln process. Also 1482 MT would be released during the manufacture of coke. Total nitrogen oxide release would be 32,567 metric tons. Also, 6671 MT of ammonia are released in the coke production process. Other atmospheric releases assessed are FH (8624 MT), CaF_2 (1454 MT), H_2S (6612 MT), and aldehydes (1318 MT).

In terms of environmental releases normalized by the electrical power generation capacity of the SPS Scenario-A program, the air quality impacts are very small compared to coal-fired or fuel-oil-fired electrical power generating plants. The air pollutants for the SPS Scenario-A program in terms of metric tons per megawatt power per year of operation are shown in Table 7. These air releases of pollutants are insignificant compared to the coal-fired steam power plant air releases of from 5.5 to 110 metric tons per megawatt year of operation. Therefore effects on public health of SPS air pollutants are minimal. If nuclear power plants discharged their waste heat to the air, they would inject about 1.8 MW_{th} into the atmosphere for each MWe generated.

Table 7. SPS Scenario-A Air Pollutants

Pollutant	Amount, MT/MWe-yr
Particulates	0.251
Sulfur oxides	0.0093
Carbon monoxide	0.093
Hydrocarbons	0.0226
Nitrogen oxides	0.0274
Ammonia	0.0006
Hydrogen fluoride	0.00065
Calcium fluoride	0.00011
Hydrogen sulfide	0.0005
Aldehydes	0.00010
Total	0.405

SECTION VII

SOLID WASTES IMPACTS

In the production of electrical power, the SPS produces no solid wastes. Solid wastes are formed in the manufacturing industries leading up to construction of the SPS units, the Space Transportation Units, the rectennas, and the launch sites. For example, 4 metric tons of bauxite ore are required to produce one metric ton of primary aluminum. The iron oxide, silica, and other impurities in the bauxite ore are removed by settling, dilution, and filtration. The red mud removed by the process must then be considered a solid waste impact chargeable to the SPS (Ref. 8).

The production of 1 unit weight of pig iron requires an average charge of 1.55 unit weights of iron-bearing charge, 0.55 unit weight of coke, 0.20 unit weight of limestone, and 2.3 unit weights of air. Blast furnace by-products consist of 0.2 unit weight of slag, 0.02 unit weight of flue dust, and 2.5 unit weights of gas per unit of pig iron produced (Ref. 8). The slag produced during the production of iron must be disposed as a solid waste.

Since the SPS is composed mainly of aluminum and steel (95.6%) excluding the concrete and aggregate used in rectenna sites and launch sites, only these materials will be assessed for solid wastes impacts in this report. The solid wastes impacts of 0.108 MT/MWe-yr shown in Table 8 are negligible compared to the solid waste impacts of 890 to 2100 MT/MWe-yr of the coal-fired steam electrical plant.

Table 8. SPS Scenario-A Solid Wastes Impacts

Material	Product, 1000 MT	Solid Wastes, 1000 MT	Amount, MT/MWe-yr
Aluminum	6,926	20,778	0.0471
Steel	134,765	26,953	0.0610
		Total	0.108

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SECTION VIII

NOISE IMPACTS

Noise impacts will occur principally during the construction phase of the SPS program, during which frequent launches of the Heavy Lift Launch Vehicle (HLLV) and the Personnel Launch Vehicle (PLV) at the NASA Kennedy Spaceflight Center (KSC) will occur. Noise from HLLV launches will occur periodically as part of the SPS maintenance cycle. Minor noise impacts will occur at the construction sites of the rectenna units becuase these sites would likely be in remote regions of the country.

A preliminary analysis of the noise and explosion hazards resulting from HLLV launch operations at Launch Complex 39 (LC39) indicates an increase in overall sound pressure level (OASPL) of 6.7 dB over Saturn V values (Ref. 10). Sound pressure dB-level contours for the HLLV are more than twice those for the Saturn V. The 130-dB contour is 16,400 feet (5000 m) from the launch pad for the HLLV and 7300 feet (2225 m) for the Saturn V launch vehicle. Lift-off thrust for the HLLV is 4.65 times that for the Saturn V, thus accounting for this increase. The far-field sound pressure levels (SPL) illustrated in Figure 2 are derived by scaling the far-field SPL measurements made on a number of Saturn I flights. The Saturn I data were plotted at distances up to 89,000 feet (27.1 km) from the launch pad and a mean line drawn through all data points. The curves of Figure 2 were determined by assuming the total sound power is proportional to the mechanical power with the conversion efficiency constant. The SPL decay with distance is taken to be the same as determined from Saturn I flights. No SPL data has been obtained for this study from the Saturn V flights. Future work should include Saturn V SPL test results.

Far-field OASPL for the Saturn V and the HLLV are shown in Table 9 for several locations near LC39. The Mobile Service Structure Park (MSS Park) Station would incur a 137.1 dB OASPL, the Vehicle Assembly Building (VAB) 129.7 dB, and Kennedy Parkway 128.9 dB OASPL. The city of Titusville, Florida, is situated along the west side of Kennedy Parkway and would incur noise impacts up to 128.9 dB. Other communities such as Cape Canaveral and Cocoa Beach South of LC39 would incur OASPL between 125 dB and 130 dB. Cities as far away as 14 km (9 miles) would be impacted with 120 dB OASPL as illustrated in Figure 2.

Launch of the HLLV from LC39 introduces considerably more serious explosive hazards in the area than the Saturn V or the Space Shuttle. The explosive hazards of HLLV have been found to be twice as serious as the Saturn V (Ref. 1) shown in Figure 3. The peak side-on overpressure (PSOP) for a catastrophic explosion of HLLV was determined using a curve relating scaled distance Z, $(ft/lb\ TNT)^{1/3}$, to PSOP. Values of Z were found from the expression $Z = r/E^{1/3}$, where r is the distance from the explosion in feet, and E is the weight of equivalent TNT

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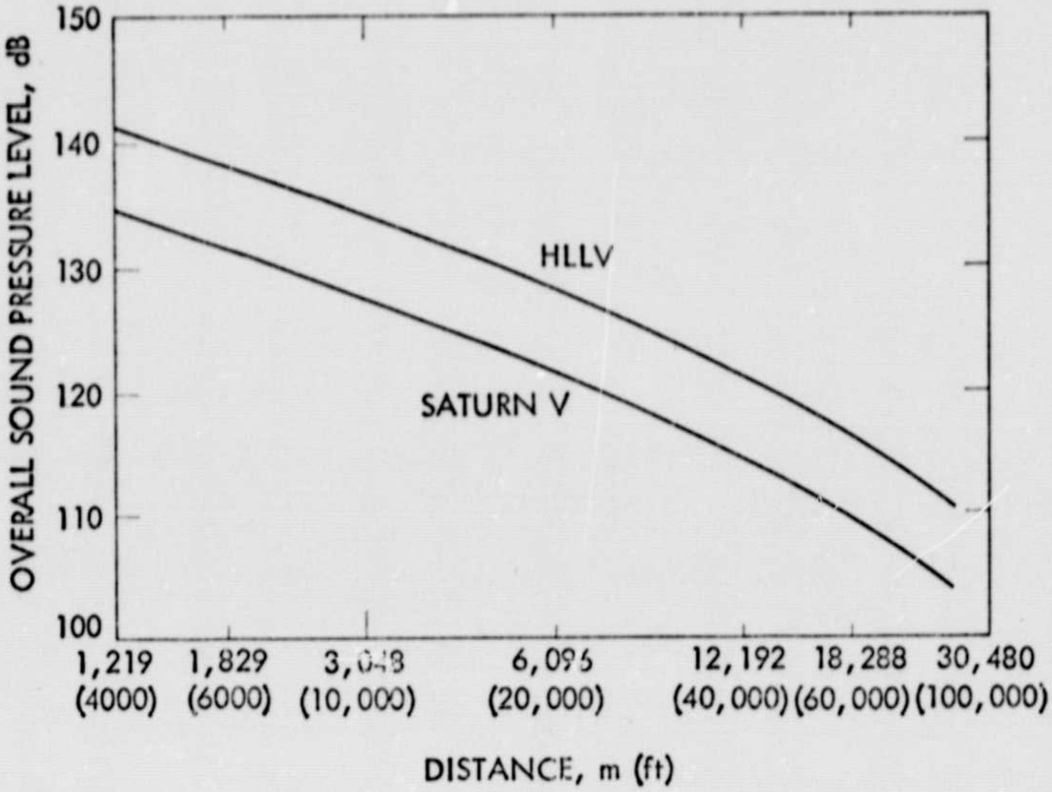

Figure 2. Variation of Overall Sound Pressure Level with Distance

Table 9. Far-Field Overall Sound Pressure Level at and Near LC39 with Vehicle at Pad A

Location	Distance, feet (m)	OASPL, dB	
		Saturn V	HLLV
MSS Park	6900 (2103)	130.4	137.1
Pad B	8650 (2637)	128.7	135.4
VAB	16700 (5090)	123.0	129.7
Kennedy Parkway	18500 (5939)	122.2	128.9

exploded at sea level (chemical explosion). The determination of explosive equivalency (E) values for the Saturn V, PLV, and HLLV was based upon the following criteria:

LOX/RP-1	20% of the weight of the first 500,000 lb, 10% of the weight of all additional LOX/RP-1
LOX/LH_2	60% of total weight
Solid Propellant	100% of the solid propellant when in the presence of liquid propellants

The application of these criteria to the Saturn V, the Personnel Launch Vehicle (PLV), and the HLLV is shown in Figure 3. The liquid fuel propelled PLV explosive hazard is about the same as the Saturn V. The all liquid-propelled ballistic HLLV would result in an explosive hazard greater than the Saturn V. The 0.4 psi PSOP contour would extend to 14,000 feet (4267 m) for the HLLV, where the Saturn V extends to 8500 ft (2590 m). Buildings inside the 0.4-psi contour cannot be occupied when danger of explosion exists. Peak side-on overpressures for several sites in LC39 are shown in Table 10.

Table 10. Explosive Hazards at LC39, Pad A

Location	Distance, feet (m)	PSOP, psi		
		SAT V	HLLV	PLV
MSS Park	6900 (2103)	0.54	1.1	0.51
Pad B	8650 (2637)	0.40	0.78	0.38
VAB	16700 (5090)	0.18	0.34	0.17
Kennedy Parkway	18500 (5639)	0.15	0.28	0.145

A catastrophic explosion of an HLLV on Pad A subjects the adjacent Pad B to an overpressure of 0.78 psi. A launch vehicle could accept this loading with proper and financially feasible protection. The VAB would be outside the 0.4-psi contour and could be occupied during hazardour periods. Other buildings closer to Pad A could not be occupied without structural reinforcement.

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At the Kennedy Parkway and in the City of Titusville, the PSOP for structures would not exceed 0.28 psi for a catastrophic explosion of the HLLV on Pad A of LC39. Therefore, there would be little danger of structural collapse at sites removed from the KSC; however, doors and windows could be blown out in populated areas with consequent danger of public injury. Further investigation into the energy release of HLLV propellants should be addressed in future work of catastrophic explosion hazards related to launch siting.

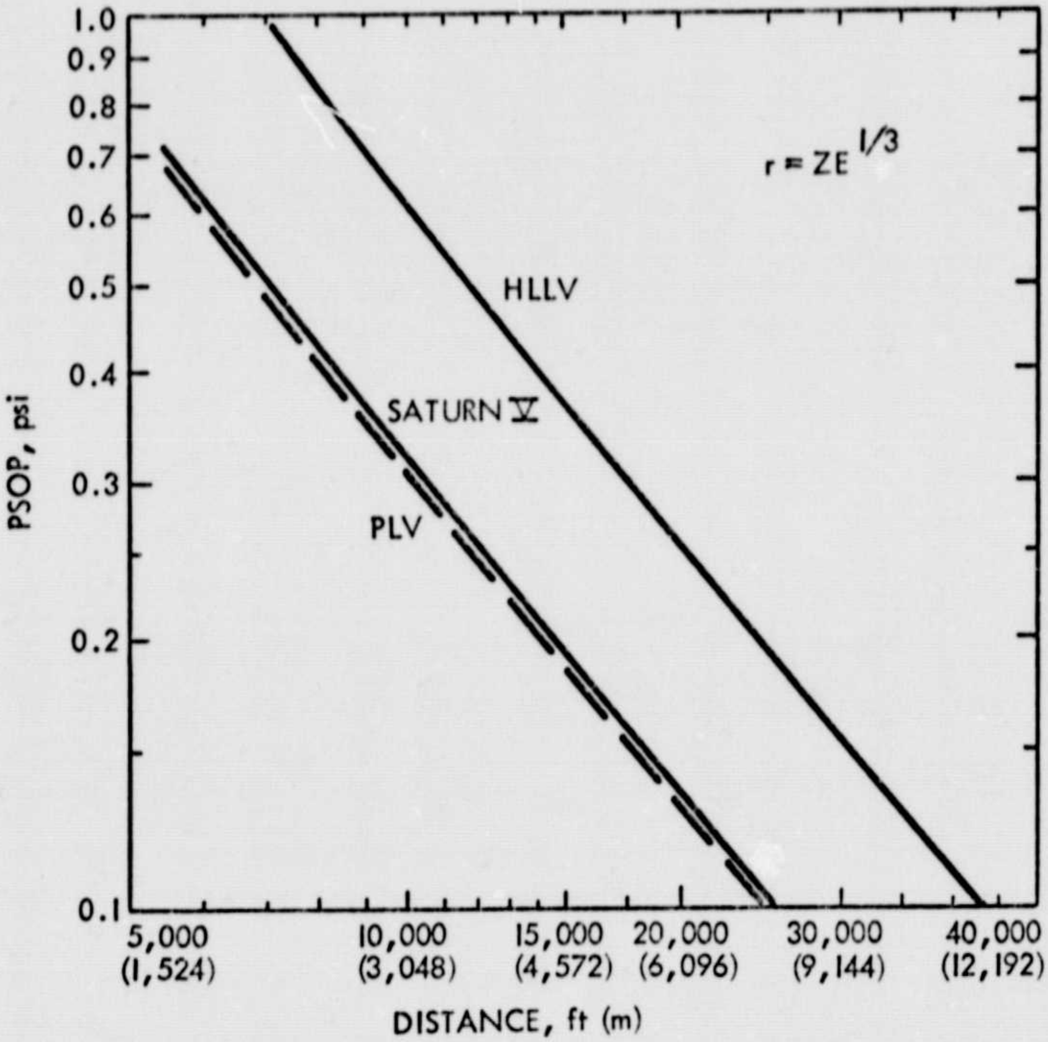

Figure 3. Variation of Peak Side-On Overpressure with Distance for Catastrophic Explosion

SECTION IX

RECOMMENDATIONS FOR FURTHER STUDY

Electric energy needs of the U.S. should be examined as conservation measures become more effective. The advent of cogeneration of heat and electricity at industrial sites and the incorporation of solar heating-cooling in residential areas may reduce the electric utility supplied electricity below the NASA/JSC extrapolated Federal Power Commission projection.

The preliminary examination of land use impacts should be extended to more detailed examination of the ecological disturbances in desert regions, and also consider the land use impacts occurring in midwestern plains, eastern topographic sites, and off-shore sites.

Increased use of water at the launch sites may adversely affect the ground water resources. A more detailed study of possible water resources impacts is warranted.

Air quality impacts resulting from launch vehicle emissions in the stratosphere and the resulting decrease in atmospheric ozone should be addressed by competent atmospheric chemical kineticists. Work here could result in a quantization of increased ultraviolet ray penetration to the surface. Particulate matter resulting from construction of the rectennas could pose a problem for surrounding regions. For each particular proposed rectenna site, this air quality impact should be assessed.

Noise impacts from launch vehicles could pose a serious environmental impact up to 14 km (9 miles) from the launch site. A better estimate of overall sound pressure level to be expected from the HLLV is required.

Due to the possibility of catastrophic explosion hazards of the HLLV propellants, investigation of the energy release of hydrocarbon fuels/LOX and LH_2/LOX should be conducted.

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