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COMPARATIVE ASSESSMENT OF ENVIRONMENTAL WELFARE ISSUES ASSOCIATED WITH THE SATELLITE POWER SYSTEM (SPS) AND ALTERNATIVE TECHNOLOGIES

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SATELLITE POWER SYSTEM
Concept Development
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DEFINITIONS OF UNIT SYMBOLS

°C:	degrees centigrade
Ci:	curie (unit of radioactivity: 3.7×10^{10} disintegrations per second)
cm:	centimeter
dBA:	decibel, adjusted
ft:	foot
GW:	gigawatt (10^9 watts)
hr:	hour
J:	joule
km:	kilometer
kV:	kilovolt
L:	liter
m:	meter
min:	minute
mg:	milligram
mW:	milliwatt
MW:	megawatt
MWe:	megawatt (electric)
ppm:	part per million
s:	second
t:	metric ton (1,000 kilograms)
w:	watt
yr:	year

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ABSTRACT

Environmental deterioration can affect an individual's health, safety, and welfare (examples of welfare effects include reduced crop yield, loss of property, and interference with other activities). This study identifies sources of environmental deterioration and associated welfare effects from two mature electric power generation systems (combustion of coal and light water nuclear reactors) and compares these with those expected from a conceptual satellite power system. Each activity within the energy pathway for each power system is examined to determine the potential welfare effects it imposes on a community. The severities of these effects are compared. On the basis of this comparison and the state of knowledge concerning specific environmental impacts and welfare effects, key environmental issues are identified for subsequent, in-depth analyses.

EXECUTIVE SUMMARY

Electric power generation systems produce a wide variety of negative environmental impacts. Some of these impacts affect an individual's well-being (rather than human health and safety or ecological quality). Examples of such "environmental welfare effects" include: reduced crop productivity, reduced commercial/recreational use of streams or land, climatic changes, interference with other activities, nuisance effects, and aesthetic losses.

This study identifies and compares the welfare effects of three energy-supply systems: coal combustion, nuclear power (light water reactors), and the conceptual satellite power system (SPS) with gallium aluminum arsenide solar cells. The evaluation covers the entire energy pathway, from resource extraction through delivery of electricity to a utility grid, including disposal of wastes. Twelve types of environmental impacts are examined as possible sources of welfare effects:

- Air pollution
- Atmospheric changes
- Thermal discharges
- Water pollution
- Water use
- Solid waste
- Land use disturbance
- Electromagnetic disturbance
- Microwave radiation
- Ionizing radiation
- Noise
- Aesthetic disturbance

After the environmental impacts and resulting welfare effects are identified for each activity within the energy pathway, the state of knowledge is reviewed concerning the extent and seriousness of, and the possibility of controlling, the welfare effects. The relative severities of the welfare effects are then determined and priority issues that warrant further study are identified.

This study is intended to be only a preliminary evaluation of the environmental welfare effects of power generation systems, aimed at providing insight into the most serious potential problems. In-depth analyses of key issues will be conducted in subsequent studies. Specifically excluded from this analysis are direct effects on human health and safety and natural biological systems, resource depletion (including direct use of land and water), and accident conditions. Some of these effects are considered in other analyses being conducted as part of the DOE/NASA Satellite Power System (SPS) Concept Development and Evaluation Program.

The table on page ix ranks the potential severity of welfare effects from the three power systems. The most serious potential welfare effects and their causes are summarized below. Section 4 of this report discusses all the environmental welfare effects identified in the assessment, the activities that cause these effects, and the state of knowledge concerning these issues.

In addition to identifying and comparing key environmental welfare effects, it is important to balance the severity against the level of understanding of these effects. For example, the lack of information regarding production levels and emission rates associated with solar cell manufacturing for the satellite power system elevates the level of concern over the severity of air and water pollutant emissions. Similarly, the certainty that the emissions will, in turn, produce the associated welfare effect is also considered. For SPS activities, the effects of microwave radiation upon beneficial insects (that influence crop production) and of microwave coupling with electronic systems are not fully understood. In the case of coal combustion, the effects of toxic air pollutant emissions and of climate changes linked to carbon dioxide emissions are also not clearly understood. Further investigation of these areas is warranted and would improve the quality of the assessment.

Potential Severity of and Status of Knowledge about Key Environmental Welfare Issues[a,b]

Environmental Impacts with Possible Welfare Effects	Coal		Nuclear		SPS		Activities Causing Potentially Severe Welfare Effects
	Potential Severity	State of Knowledge	Potential Severity	State of Knowledge	Potential Severity	State of Knowledge	
Air Pollution	1	B-C	2-3	B	1	C	Coal-fired power generation (toxic and secondary pollutants). SPS materials manufacture and rocket launch.
Atmospheric Changes	1	B-C	4	B	3	B	Coal-fired power generation (CO_2 emissions).
Thermal Discharges	2	B	2	B	2	B	--
Water Pollution	1	B	1	B	1	C	Coal mining (underground). Nuclear fuel fabrication. SPS materials manufacture.
Water Use	2	B	2	B	3	C	--
Solid Waste	2-3	A	3	B	2-3	C	--
Land-Use Disturbances	1-2	A	1	B	1	B-C	Coal mining (surface). Nuclear waste disposal. SPS materials mining, rocket launch, rectenna sites.
Electromagnetic Disturbances	3	B	3	B	1	B-C	SPS rectenna operation.
Microwave Radiation	4	B	4	B	1	C	SPS power transmission.
Ionizing Radiation	3	B	3	B	4	B	--
Noise	3	A	3	A	1	B	SPS rocket launch.
Aesthetic Disturbances	2	A	2	A	2	B	--

[a]Severity ranking is based on the most serious welfare effects of the activities within each fuel cycle. Potential severity is ranked according to the following criteria:

1 - Very significant contribution to welfare effects.
2 - Significant contribution to welfare effects.
3 - Minor but measurable contribution to welfare effects.
4 - Negligible contribution to welfare effects.

[b]State-of-knowledge ranking:

A - Issue thoroughly documented and understood.
B - Parts of issue understood, but gaps in knowledge exist.
C - Very little knowledge of issue exists.

Potentially Severe Environmental Welfare Effects

Air Pollution. Air pollution from coal-fired power generation and SPS materials manufacture and rocket launch could contribute to welfare effects such as lower crop yields, accelerated material deterioration, reduced visibility, and reduced commercial/recreational use of waters degraded by acid rainfall. Coal combustion releases trace amounts of toxic elements (not regulated by the National Ambient Air Quality Standards [NAAQS]), which have been found to accumulate in the soil near power plants, and emits sulfur dioxide and nitrogen oxides that can be transformed into particulate sulfates and nitrates, which have been strongly implicated in visibility degradation and acid rainfall. Toxic emissions would be expected from the manufacture of SPS solar cells and from SPS rocket launches.

Atmospheric Changes. Coal combustion contributes significantly to the total man-made input of carbon dioxide to the atmosphere and could augment the possible "greenhouse effect" of steadily-increasing carbon dioxide levels in the atmosphere. Global temperature increases may be capable of altering precipitation patterns, agricultural production, and ocean levels.

Water Pollution. Underground coal mining, nuclear fuel fabrication, and SPS solar cell manufacturing could produce welfare effects including reduced drinking water quality, reduced commercial/recreational use of streams and lakes, and lowered crop productivity because of irrigation with degraded water. While regulations have recently been promulgated to control acid mine drainage, the effectiveness of these laws has been seriously questioned. Fabrication of nuclear reactor fuel releases ammonia, nitrates, and fluorine at levels several orders of magnitude above those permitted by drinking water standards. Due to the proprietary nature of solar-cell manufacturing processes, it is not completely known what effluents would be discharged. Such manufacturing could have serious welfare effects if the raw materials involved are highly toxic.

Land Use Disturbance. Surface mining for coal disturbs large areas of land and the productivity of reclaimed mine sites is often less than that of the undisturbed land. Disposal of high-level, transuranic, and

low-level nuclear wastes and uranium milling residues (tailings) is likely to remove land from any future use. SPS materials mining, rectenna sites, and launch sites would remove large areas of land from other uses and require the relocation of roads and services.

Electromagnetic Disturbance. Microwave coupling with electronic systems as far as 100 km from an SPS rectenna site could have a significant welfare effect. The severity of the electromagnetic interference would depend on the type of electronic systems near a rectenna and their amenability to mitigating strategies that do not cause unacceptable operational compromises. Systems currently identified with performance degradation include: military radar, communications systems and computers. Radio and optical astronomy might also be affected by the SPS.

Microwave Radiation. Ecosystems within and near SPS rectenna sites would be exposed to chronic microwave radiation. While there is limited information on the effects of such exposure, the mortality, reproduction, and behavior of beneficial insects such as bees could be altered, possibly disturbing the pollination of food crops.

Noise. Noise levels from heavy-lift launch vehicles would be likely to exceed recommended EPA 24-hr average noise standards and elevate noise levels in communities as far away as 31 km. Launches would occur frequently, causing welfare effects such as annoyance and interference with other activities. Land-use changes and reduced property values would also be possible.

Welfare Effects of Moderate Concern

Impacts of a more moderate nature that are associated with the remaining impact areas are outlined below.

Water Use. Coal and nuclear power generation can consume large quantities of water through the use of evaporative cooling towers. Where water is scarce, dry cooling towers may be used. SPS activities would not use large quantities of water.

Solid Waste. SPS materials manufacturing and coal combustion generate considerable quantities of solid waste, which in most cases would remain on-site. Some SPS cell-manufacturing waste might have other commercial value. It is difficult to generalize as to whether these wastes could increase competition and costs for available waste disposal. Nuclear wastes are specialized wastes more appropriately considered in the context of land use.

Ionizing Radiation. Low levels of radiation will routinely be emitted during nuclear activities and coal combustion. Emissions from nuclear operations meet permissible Nuclear Regulatory Commission (NRC) standards for unrestricted areas. Large areas of land surrounding nuclear facilities are used as exclusion zones in order to meet these standards. However, it is not known whether there is a radiation threshold level below which an effect such as genetic alterations will not be observed. Standards limiting radioactive emissions from coal-fired generating plants do not exist but could be promulgated under the Federal Clean Air Act Amendments of 1977.

Aesthetic Disturbance. Some aesthetic disturbances could occur from all energy-system activities. The welfare effects of these impacts are for the most part site-specific and depend on personal orientation. Visual disturbances include unsightly large mines, energy facilities located in rural areas, transmission corridors, and solar power satellites visible in the night sky. The large quantity of land required for SPS rectenna and launch sites could infringe upon protected areas.

1 INTRODUCTION

Electric power generation systems produce a wide variety of negative environmental impacts, many of which affect human health and safety. However, some effects of environmental degradation are not directly related to health or safety, but rather concern an individual's well-being. Included within this latter category are both direct effects -- such as property damage, reduced crop yields, and removal of land or water from other intended uses -- and more subtle, less-direct effects -- such as interference with other activities (as from noise interfering with a conversation), nuisance and aesthetic effects, and climatic changes. For purposes of this report, these effects that concern human well-being will be referred to as "environmental welfare effects."

The definition of environmental welfare is important in establishing the framework and boundaries of the evaluation described in this report. Not all environmental impacts result in environmental welfare effects. For example, a chemical discharge into a river is not a welfare effect in and of itself. However, if the chemical discharge resulted in smaller catches by commercial fishermen or prevented recreational use of the river, the smaller catches and loss of recreational use would be welfare effects; the chemical discharge would be considered a welfare-related environmental impact. On the other hand, if a person became ill after swimming in the river polluted by the chemical discharge, the illness would be a health effect, not a welfare effect.

A parallel to this health-versus-welfare distinction is seen in the Clean Air Act, which provides for primary ambient air quality standards to protect human health and secondary standards to protect the public welfare from unknown or anticipated adverse effects. A comparative analysis of the health and safety effects of environmental degradation caused by the satellite power system (SPS) and other energy-supply systems is also being performed as part of the comparative assessment element of the DOE/NASA SPS Concept Development and Evaluation Program.

1.1 OBJECTIVES

The objectives of this study are to:

- Identify the potential environmental welfare effects of three systems for supplying electricity (coal combustion, nuclear power, and the satellite power system).
- Review the state of knowledge concerning the extent and seriousness of, and possibility of controlling, these effects.
- Compare, on a preliminary basis, the welfare effects of the three power systems.
- Identify priority welfare effects that warrant further, more-careful investigation.

This study is intended to be only a preliminary evaluation of the environmental welfare effects of three power generation systems, aimed at providing insight into the most severe problems. The comparative assessment is not intended to be exhaustively detailed. In-depth analyses will be reserved for welfare effects that are determined to be of highest priority and will be conducted in subsequent studies.

1.2 SCOPE

This evaluation of the environmental welfare effects of coal combustion, nuclear power (light water reactors), and the satellite power system (with gallium arsenide solar cells) covers the entire fuel cycle, from resource extraction through delivery of electricity to a utility grid, including disposal of waste products. The sources of the welfare effects included in this study are those environmental impacts that correspond to a deterioration of the physical environment. These impacts include: air, water, and noise pollution; water-use and atmospheric changes; thermal discharges; solid waste generation; land-use, electromagnetic, and aesthetic disturbances; and microwave and ionizing radiation.

Specifically excluded from this analysis are effects on human health and safety, effects on natural biological systems, resource depletion (including direct use of land and water), and accident conditions. Some of these issues are considered in other analyses being conducted as part of the DOE/NASA SPS Concept Development and Evaluation Program.

2 METHODOLOGY

2.1 ASSESSMENT APPROACH

The comparative assessment of the environmental welfare effects of the energy supply systems begins with an examination of the various activities involved in each fuel cycle or energy pathway. The complete energy pathway is considered. These activities result in environmental impacts such as noise and emissions of air and water pollutants. These environmental impacts in turn result in welfare effects, such as property damage, climatic change, or interference with other activities. This activity-impact-effect chain, illustrated in Fig. 1, is used in structuring the environmental impacts and welfare effects of each energy-pathway activity.

Some of the environmental impacts in Fig. 1 elicit more than one one type of welfare effect. For example, some air pollutants damage crops or materials, while others augment potential climate changes. Such impacts are divided into distinct groupings for greater clarity of discussion. For example, thermal impacts are discussed separately from air, water, or atmospheric disturbances. Other grouping crossovers are also necessary, as in cases where different environmental impacts lead to a similar welfare effect. This is noted for land disturbances (and other impacts), which could lead to both loss of land use and aesthetic damages. These situations are discussed in the category that provides the primary or most severe welfare loss.

The following steps are taken in evaluating the coal, nuclear, and SPS energy technologies.

- Identify the environmental impacts of the fuel cycle activities for each energy system. These impacts, shown in Fig. 1, are measured in such terms as air pollutant emissions, amount of land disturbed, and noise levels. The intent is to qualitatively identify all environmental impacts and to quantify as many as possible within the scope of this preliminary screening. The quantities of emissions from individual activities in the energy pathways are identified in Appendixes A, B, and C. It should be noted that much more detailed information on environmental impacts is available for coal and nuclear energy than for the SPS because the former are mature technologies while the latter is a conceptual design.

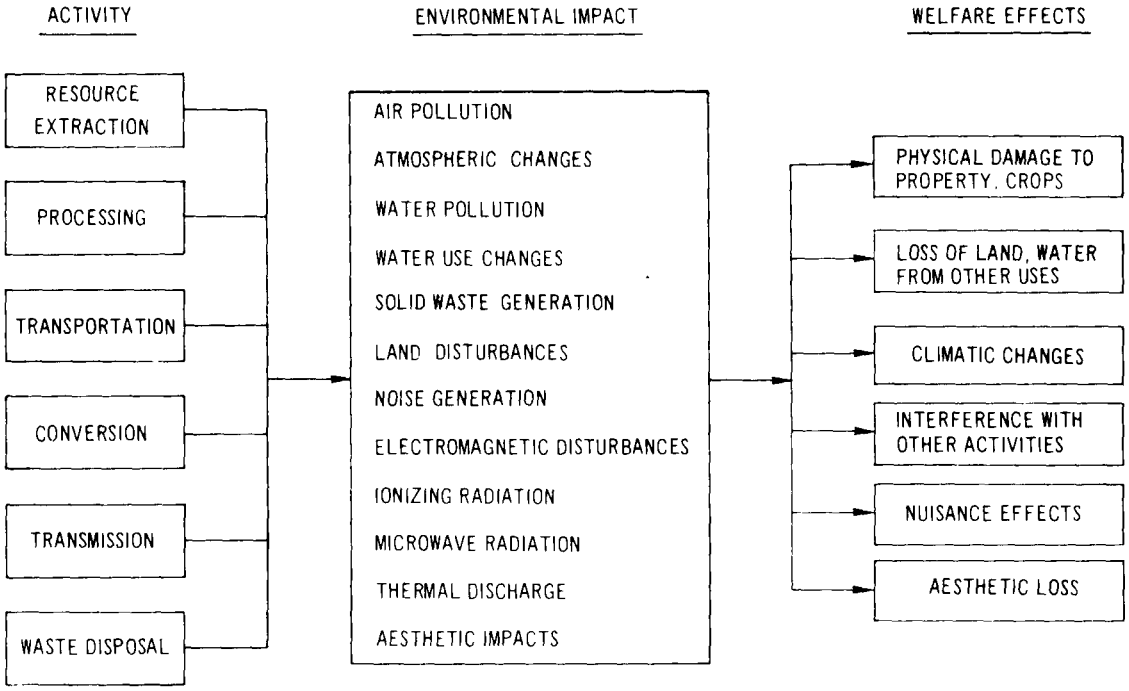

Fig. 1. Relationship of Fuel Cycle Activities, Environmental Impacts, and Welfare Effects

- Identify the welfare effects resulting from the environmental impacts. This step reviews and synthesizes available information on the welfare effects that are attributable to environmental deterioration. This information is used in the subsequent ranking and comparison of welfare effects.

- Determine the severity of the welfare effects. To judge the extent and relative severity of welfare effects, several criteria are used, including: (a) welfare effects related to specific types of environmental degradation presently occur; (b) relevant environmental quality standards are currently violated, and the violations could lead to welfare effects; (c) toxic pollutants are emitted in quantities that can perceptibly increase pollutant concentrations in the environment; (d) irreversible environmental degradation occurs; (e) the environmental degradation is near locations of human activities; and (f) the welfare effects are not amenable to mitigation strategies. In some cases, such as aesthetic loss, the only determinant is a qualitative value judgement. In practice, the impacts from any activity are rated as capable of producing a potentially severe welfare effect if one or more of the above criteria is met.

2.2 KEY ASSUMPTIONS

The welfare effect of each energy-related activity is examined in the context of the additional burden imposed on a community by that activity. Typical facility sizes -- for a mine, processing plant, or power plant, for example -- are used whenever possible as a basis for determining local welfare effects (the assumed facility sizes represent current opinion regarding the most likely unit sizes to be constructed in the near future). The welfare effects are not scaled to a common metric, such as cost or impact per 1000 MW of electrical capacity. Use of a common metric tends to obscure information because of the need to introduce various assumptions in converting impacts to a single unit of measure. The approach used in this assessment takes into account the fact that small, dispersed power plants often have smaller local welfare effects than a large, centralized facility, even though the quantity of emissions per megawatt of electricity generated may be less for the larger facility. At the same time, it is recognized that many minor impacts may have a cumulative impact that could equal or exceed a major impact from a single, large facility. Other assumptions that underlie this analysis are that all activities use advanced pollution control technology representative of newer facilities and that facilities operate routinely (that is, without accidents).

3 TECHNOLOGY DESCRIPTION

Brief descriptions of the three electrical power systems considered in this study are presented below. This discussion is intended only to broadly define the systems analyzed. Appendixes A, B, and C support this discussion by providing detailed environmental impact data for the coal, nuclear, and satellite power systems, respectively, and listing reference documents that furnish information on facility sizes (and associated environmental impacts) for the three systems.

3.1 COAL COMBUSTION

Coal combustion for electric power generation encompasses five principal activities: surface or underground mining, coal processing to reduce noncombustible material and sulfur, coal transportation by rail, combustion in a conventional boiler, and electricity transmission over high-voltage lines. Although other modes of coal transportation are available, they are not considered here.

3.2 NUCLEAR POWER

As indicated by Fig. 3, the nuclear fuel cycle is significantly more complex than the coal-combustion cycle. Nuclear fuel, which may be mined or reprocessed from old fuel, requires considerable refinement and conversion before it can be used in a power plant. When nuclear fuel is mined, the ore is milled, refined, and converted to uranium hexafluoride (UF_6). The UF_6 is enriched and then converted to uranium dioxide (UO_2). Uranium dioxide is fabricated into fuel pellets for power generation. Light water reactors use the heat generated by UO_2 nuclear interactions to produce steam, which powers an electrical generator. Fuel reprocessing, transportation of nuclear materials, and disposition and management of radioactive wastes are the remaining activities in the fuel cycle. The need for disposition of nuclear waste occurs throughout the energy pathway.

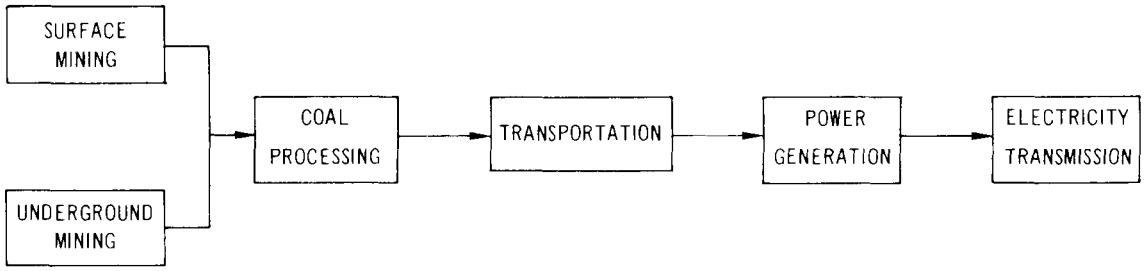

Fig. 2. Coal-Combustion Fuel Cycle Activities

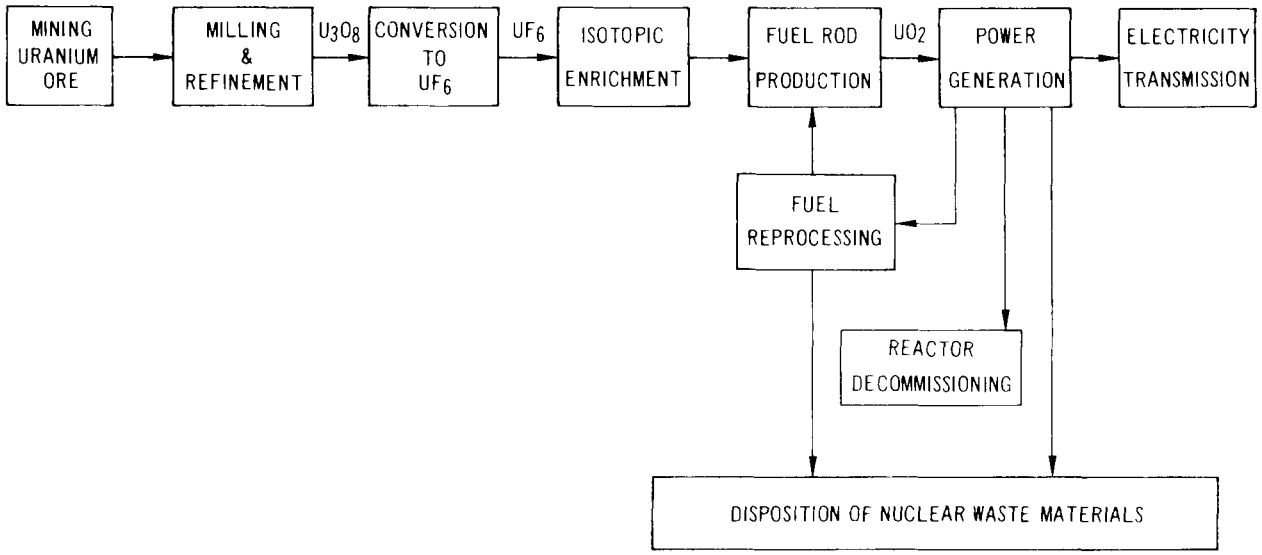

Fig. 3. Nuclear Fuel Cycle Activities (the transportation of nuclear materials occurs throughout the cycle)

3.3 SATELLITE POWER SYSTEM

The power generation components of the proposed satellite power system would include (1) a number of photovoltaic panels in geosynchronous earth orbit collecting solar energy and transforming that energy into a focused microwave beam for transmission to earth and (2) surface receiving antennas (called rectennas) collecting and converting the microwaves into electricity to be supplied to a utility grid. Figure 4 illustrates the system activities, which are described in detail in Ref. 1. As in the nuclear fuel cycle, many SPS activities precede actual power generation. Solar power satellites would be constructed in space, with materials and workers transported from earth in heavy-lift launch vehicles (HLLVs) and personnel launch

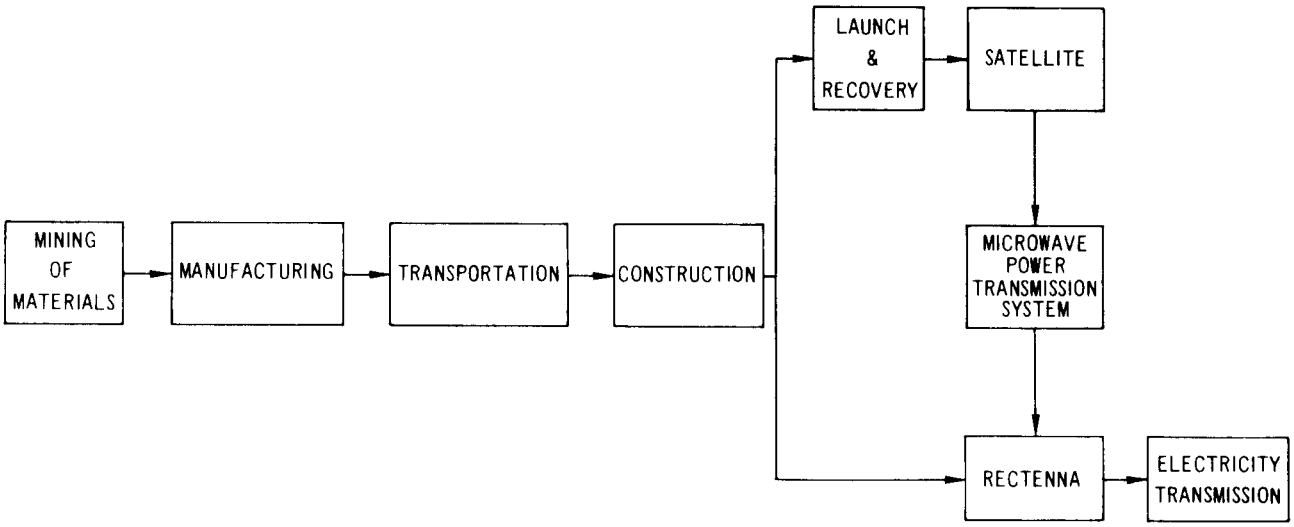

Fig. 4. Satellite Power System Activities

vehicles (PLVs). This construction transportation would involve a large number of rocket launches: 225 HLLV and 35 PLV launches per year to construct two 5-GW satellites with gallium aluminum arsenide solar cells.[2]

4 COMPARATIVE ASSESSMENT OF WELFARE EFFECTS

This section examines the potential welfare effects associated with the coal, nuclear, and SPS technologies presented in Section 3. In evaluating the welfare effects, only one activity pathway is considered for each energy cycle. For example, for coal transport, only train transportation is assessed -- coal movement by barge or slurry pipeline is not examined. Welfare effects are discussed for 12 types of environmental impacts:

- Air pollution
- Atmospheric changes
- Thermal emissions
- Water pollution
- Water use
- Solid waste
- Land-use disturbance
- Electromagnetic disturbance
- Microwave radiation
- Ionizing radiation
- Noise
- Aesthetic disturbance

For environmental impacts with complex welfare effects, tables are included to summarize the assessment process. A ranking of the relative severity of the welfare effects by technology is presented in Section 5.

4.1 AIR POLLUTION

Various welfare effects are attributed to emissions of air pollutants, including lower crop yield, accelerated material deterioration, reduced visibility (which can slow air traffic and obscure scenic vistas), increased household cleaning costs due to particulate soiling, and reduced commercial and recreational use of waters degraded by acid rainfall. The most significant welfare effects due to air pollution are expected from coal-fired power generation, SPS materials manufacture, and SPS rocket launches.

Coal

The major welfare effects of air pollution from the coal fuel cycle result from combustion, in particular from toxic emissions and from secondary particulates formed in the atmosphere (see Table 1). A 1000-MWe coal-fired power plant releases substantial quantities of particulates [250-700 metric tons per year (t/yr)], sulfur dioxide (3,000 t/yr to 28,000 t/yr depending on use of an SO_2 scrubber), and nitrogen oxides (8500 t/yr), as well as lesser amounts of carbon monoxide and hydrocarbons (see Appendix A). However,

Table 1. Welfare Effects of Air Pollution[a]

	COAL						NUCLEAR[b]										SPS				
	Surface Mining	Underground Mining	Processing	Transportation	Power Generation	Transmission	Surface Mining	Underground Mining	Milling	UF_6 Production	Enrichment	Fuel Fabrication	Power Generation	Transmission	Reprocessing	Waste Management	Resource Extraction	Materials Manufacture	Transportation	Rocket Launch	Transmission
Ability to Create Welfare Disturbance																					
Criteria Pollutants	M	L	L-M	L-M	M	L	L-M	L	M	L	L	L	L	L	L	L	L-M	M	L-M	M	L
Toxic Pollutants	-	-	-	-	H	-	-	-	-	L	L-M	L	M	-	L	-	-	H	-	H	-
Secondary Pollutants	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	M	-
Data Quality	H	H	M	H	M-H	L	H	H	H	H	H	H	M-H	L	M	M	H	L	H	L	L

[a]Legend: H = high M = moderate L = low U = unknown - = no impact or not applicable
Fuel-cycle activities with no impacts are not listed.

[b]Radiological effluents considered in Sec. 4.10.

these five pollutants are EPA-designated criteria pollutants, and welfare-related (secondary) air quality standards have been promulgated for them. If emissions of these pollutants from new facilities are restricted to levels sufficient for maintaining the National Ambient Air Quality Standards (NAAQS), as required by licensing procedures, the welfare effect from criteria pollutants should not be significant. In addition, the EPA has recently proposed more stringent performance standards for large combustion sources, which would further reduce emissions of particulates, sulfur dioxide, and nitrogen oxides (see Appendix A).

Other pollutants emitted during coal combustion are not restricted by welfare (or health) standards. These pollutants, trace and toxic elements that are present in coal, are released with the combustion gases and include elements such as arsenic, cadmium, mercury, and selenium (see Appendix A). The pollutant levels at which soils, vegetation, or livestock might be damaged are not established; however, pollutants may accumulate in nearby soils and vegetation during the operation of a power plant.

Transformation of sulfur dioxide and nitrogen oxides in the atmosphere into particulate sulfates and nitrates (secondary particulates) can cause

additional problems that the NAAQS are not designed to prevent. Transported over long distances, these pollutants have been strongly implicated with visibility degradation and acidic precipitation. For these reasons, and because both visibility degradation and some soil accumulation of trace elements have been observed near coal-fired power plants, coal combustion is a key welfare concern (see Appendix A).

Organics, acids, chromates, zinc and other potentially hazardous elements are present in cooling tower drift releases and could concentrate in soils surrounding a power plant. These chemicals are added to the tower make-up water as biocides and to inhibit corrosion. Available information suggests that this is not a major pathway for the transfer of toxic elements to the landscape,[3] since levels above background concentrations are only observed to distances of one mile from the tower and the vegetation ultimately attains an equilibrium concentration. Salt drifts also occur from cooling towers using seawater for condenser cooling and could decrease crop productivity at elevated concentrations. These effects are categorized as having a moderate welfare impact.

Windblown coal losses during transport are 1-2% of the total quantity shipped, or about 36,000 t/yr to meet the coal requirements of a single 1000-MWe plant. Dusting of crops could reduce photosynthetic activity and retard productivity. However, because these fugitive-particle releases are dispersed over a large area and could be reduced by covering rail cars, this is not a significant welfare problem.

Particulates and nitrogen and sulfur oxides are emitted during coal processing. However, data on emissions are not available in a form suitable for welfare assessment. Welfare effects are believed to be low to moderate.

Nuclear

Air pollutants generated in the nuclear fuel cycle are primarily from fuel preparation activities. Uranium ore must be leached, roasted, and treated with fluorine before isotopic enrichment. For certain activities it is not possible to distinguish from available data which sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon monoxide (CO) emissions are generated by the nuclear process and which are from the ancillary coal-fired power plants that are assumed to supply energy for these fuel

processing operations. Incorporating these emissions in the evaluation of welfare impacts would not be in keeping with the approach of this assessment, i.e., to examine the extent of impacts on the basis of a facility's emissions (unless such power plants are routinely located on the processing site). This is quite evident when examining the quantity of emissions noted in the literature for the enrichment process. Emissions from this supporting operation exceed the amount generated from a model 1000-MWe coal-fired boiler.

Fluorides are emitted during UF_6 production (3.6 t/yr), enrichment (52 t/yr), and reprocessing (0.1 t/yr). These emissions are of moderate welfare concern because a fluoride air quality standard appropriate for protecting livestock has been designated and is being met. Ambient levels of fluoride measured near a UF_6 facility and enrichment plant have been within acceptable and nondamaging levels.[4] Fluoride emissions, as well as sulfuric acid fumes emitted during milling, present the greatest potential for crop and livestock injury from nuclear activities.

Releases from cooling towers at nuclear power plants are similar to those discussed above for coal-fired plants. Emissions of sulfur oxides, nitrogen oxides, and gases throughout the nuclear fuel cycle can contribute to local air quality degradation.

SPS

Toxic emissions would be expected from the manufacture of SPS solar cells and from rocket launches. Potential emissions of gallium arsenide, hydrogen sulfide, ammonia, cyanides and other compounds have been identified for the solar cell manufacturing process;[5] these pollutants are not controlled under existing NAAQS. Information concerning detailed emission rates and the manufacturing process itself is extremely limited. SPS launch and recovery operations could present additional air pollution problems. While there is little information concerning the actual propellant that would be used in SPS rockets, hydrazine and hydrazine derivatives, ammonia, chlorine, hydrogen fluoride, and hydrogen chloride have been identified as effluents from other rocket propellants.[6] Due to the potentially hazardous nature of these emissions, these activities are categorized as a potential area of concern for welfare effects. The exacerbation of regional acid precipitation

or visibility degradation by rocket exhaust would likely be small in comparison to the effects of other regional emissions. This will be evaluated in subsequent studies.

Hydrocarbon rocket propellents and other toxic materials could be accidentally spilled during transport to the launch site. Such spills, and the subsequent evaporation, could occur often enough to aggravate local air quality along transport corridors. Insufficient information is available to determine the nature or extent of any welfare effect.

Air pollutants controlled under the NAAQS would be emitted by the conventional mining, manufacturing, and construction activities in the SPS energy pathway. The welfare effects of these emissions would not be expected to be significant.

All Technologies

Small amounts of sulfur dioxide, nitrogen oxides, and carbon monoxide are emitted by the diesel equipment used during all mining, construction, and transportation activities. The diesel exhaust and particulate emissions are of low impact. Particulates are usually generated in sizable quantities during surface mining and construction activity and following removal of vegetative cover (windblown dust). Windblown dust could remain a problem following surface mining and construction in the absence of appropriate surface restoration.

Emissions from power transmission are identical for all three technologies. Although emissions of ozone and nitrogen oxides have been noted from the corona discharge around transmission lines, ambient levels are unknown but are thought to be low. These levels may increase with the use of higher-voltage transmission lines.

4.2 ATMOSPHERIC CHANGES

The release of air pollutants may also alter atmospheric characteristics, possibly causing changes in weather or climate. This assessment defines potential climate perturbations as a welfare effect and treats them as distinct from other air pollution impacts. This distinction results in a "crossover," such that atmospheric particulate emissions, which are

examined in Section 4.1 for their effect upon standards violation and visibility, are treated here for their ability to cause temperature changes (a climatic change). Only impacts for which there is a reasonable understanding of the relationship between the atmospheric perturbation and potential welfare effect are assessed. Climate changes are treated in greater depth in a separate SPS study.[7]

Climate effects resulting from atmospheric changes caused by the selected energy technologies are not readily quantifiable at our present level of understanding. The levels at which an effect is observed and the time scale at which the effect may appear are not clearly established. Any weather or climate change could seriously upset delicate planetary balances. Rather than comparing the principal welfare effects of different atmospheric changes (e.g., the welfare effects of global carbon dioxide emissions from coal combustion versus those of the global atmospheric particulate increases), the welfare effects are treated separately.

Carbon Dioxide

Much attention is given to the question of global warming caused by steadily increasing carbon dioxide (CO_2) levels in the atmosphere and the resulting "greenhouse effect," although understanding of this issue is limited. Increases in atmospheric CO_2 levels have corresponded to increases in fossil-fuel use during the last few decades. It has been speculated that an extensive increase in fossil-fuel burning could furthur raise atmospheric CO_2 levels. Studies have predicted that a doubling of CO_2 concentrations above pre-industrial levels will produce a global average warming of 1-3°C (see Ref. 7 for further discussion). This change could occur as early as the year 2025, although noticeable warming would not be detectable before 2000. Such a temperature increase could significantly affect precipitation patterns, agricultural production, and ocean levels (through the melting of polar ice).

Coal combustion releases substantial amounts of CO_2 into the atmosphere (5×10^6 t annually from a 1000-MWe plant).[8] Although this in and of itself does not create a local problem, coal combustion contributes significantly to the total man-made input of CO_2 into the atmosphere. Coal-fired generating plants in the United States produce about 20% of the world-wide anthropogenic CO_2 emissions.[7] Coal combustion releases other "greenhouse

gases" such as sulfur dioxide and water vapor, which have an unknown, though apparently less serious, potential effect on climate.

There are no significant CO_2 emissions from the nuclear fuel cycle.

A substantial portion of SPS air pollutant emissions would occur during launches of HLLVs for construction of the solar power satellites. Rocket effluent includes sizable amounts of CO_2, but these emissions would be two orders of magnitude lower than CO_2 emissions from coal combustion for producing an equivalent amount of electricity.[7]

Atmospheric Particulates

The increase in global atmospheric particulate levels and the percentage increase of anthropogenic contribution to global particle emissions are other areas of concern. Particles may change the radiative properties of the earth-atmospheric system by scattering and absorbing incoming solar radiation and, in so doing, cause a warming or cooling of the earth's surface. It has not been established whether the increase in atmospheric particle concentrations over the past century has produced a net warming or cooling effect. The direct coal-combustion emissions of particles (fly ash) and gaseous species (such as sulfur dioxide and nitrogen oxides), which are converted to secondary particles in the atmosphere, are large in terms of their regional contribution to atmospheric particulate loadings but small with respect to total global man-made contributions and total global (man-made and natural) atmospheric particulate contributions.[7] Their impacts are expected to cause minor but noticeable changes in atmospheric levels.

Atmospheric particulate emissions from the nuclear power cycle are relatively small.

Large quantities of SPS rocket exhaust products would be deposited in various layers of the atmosphere. It has been speculated that these emissions could alter the composition and density of the atmosphere (stratosphere), potentially resulting in long-term changes in climate and weather patterns. The impact of these emissions would likely be small on a regional level and negligible on the global level. These impacts are being further investigated in the environmental assessment of the SPS Concept Development and Evaluation Program.[5]

4.3 THERMAL EMISSIONS

All human activities release heat to the environment. Most of this heat is given off during production or consumption of electrical energy, transportation, space heating, and industrial use of heat. A nuclear electric power plant with an efficiency of 32% releases two units of waste heat for each unit of heat used to produce electricity. The environmental impacts of this waste heat are both local and regional and depend on the type of cooling technology used, amount of heat released, and local ambient meteorological conditions. Climatological impacts from thermal discharges are examined in more detail in another SPS study.[7]

Environmental impacts and welfare effects depend on whether the heat is discharged to the air or water. Alteration of local water temperature in streams, lakes, and oceans can result in outmigration of commercially or recreationally desirable fish or the death of species with little resistance to thermal fluctuations. State and federal laws require that indigenous populations be maintained and often restrict water temperature increases to less than 2°C above the ambient temperature, with absolute temperature limits for the receiving body of water ranging from 27°C to 38°C. These and other restrictions regarding water and land use for cooling purposes have resulted in a dominant trend toward the use of cooling towers. The effects of these cooling tower discharges to the atmosphere are considered here for the coal and nuclear technologies.

The welfare effects of thermal emissions are generally low to moderate for the three energy systems examined. Decreased visibility, traffic hazards, and general inconvenience caused by enhanced fogging and icing from cooling towers are the principal welfare effects. SPS activities would release heat into the atmosphere -- from rectenna operation, rocket launches, and microwave heating of the lower atmosphere. Only rocket launches appear to have the potential to alter weather and then only in the region surrounding the launch site.

Coal and Nuclear

A typical nuclear power plant releases about 40% more waste heat than a comparably sized coal-fired plant. This is primarily due to the higher

thermal efficiency of coal-fired plants (38% for coal, 32% for nuclear). Part of the waste heat from coal combustion is released with the stack gases (11×10^{15} J/yr discharged at the stack and 28×10^{15} J/yr discharged by the cooling towers for a 1000-MWe plant)[4]. A 1000-MWe nuclear plant releases 50×10^{15} J/yr.

Two principal types of cooling towers are used at coal-fired and nuclear plants: mechanical and natural draft. Of the two, mechanical draft towers appear to cause the more serious local impacts. Due to their lower height, they have the potential to augment fogging and icing during certain local weather conditions. For fogging to create a welfare effect, the towers must be in close proximity to a land use with which the fogging interferes. Examples of such interference include a potential visibility or icing hazard to ground or water transportation or a nuisance to nearby communities.

Increased fogging will occur in areas that are most susceptible to natural fog formation, have low atmospheric-mixing depths during cooler weather, and are subject to low-level temperature inversions. These conditions are most common to the northwestern and Appalachian regions of the country.[9] One estimate, considered to be conservative, indicates that less than 5% of the power plants with closed cooling systems will experience fogging problems.[9] Local icing may occur during freezing conditions when the moist thermal plume contacts a freezing surface. Icing can cause hazardous road conditions, but is unlikely to damage structures due to additional weight.[9]

For illustrative purposes, the predicted effects of the mechanical draft tower at the proposed (but later abandoned) Kaiparowits coal-fired plant were as follows:[10]

Fogging:	305 m downwind from tower - 8% of the time (30 days/yr)
	1.6 km downwind from tower - 0.2% of the time (1 day/yr)
Icing:	305 m downwind from tower - 5% of the time (15 days/yr)
	1.6 km downwind from tower - 0.06% of the time (1 day/yr)
Visible plume:	to 55 m - 50% of cold, humid days
	to 305 m - 10% of cold, humid days
	to 1.6 km - 0.3% of cold, humid days

Other effects attributed to cooling towers include: the production or enhancement of cloud formations, enhancement of precipitation, and

increases in relative humidity. Changes in precipitation are largely undetectable within the range of climatological variation. Induced changes in relative humidity from cooling towers are thought to be dwarfed in comparison to the amount of moisture that evaporates from natural sources.

Generally, in areas where cooling tower problems occur, technology is available at moderate incremental cost to eliminate adverse effects. The welfare effects of cooling towers are of moderate concern locally (1-10 km from tower) and low concern regionally (10-100 km from tower).

Efficiency considerations have encouraged the concept of clustering future nuclear power plants in "parks" containing 20,000-50,000 MW of generating capacity. The large waste heat release (72,000 MW over a land area of 20-100 km^2) would approach the magnitude of latent heat release of a thunderstorm and other meteorological phenomena such as hail storms. It has been suggested that this level of heat release could produce or enhance the occurrence of similarly severe regional weather events. The potential welfare effect of waste heat release from envisioned power parks would be of moderate to high concern. The effect of waste heat release from an individual power plant is of lesser concern.

Uranium enrichment has second-order waste heat impacts: the power plant supplying electricity to the enrichment plant would release heat, most likely through cooling towers at future facilities. This discharge would have a low welfare effect, except when the power plant was located very close to the enrichment plant; in this case, the welfare effects of waste heat from uranium enrichment would be considered moderate. For all fuel-cycle activities (coal, nuclear, and SPS) except uranium enrichment, second-order impacts are minor and are not assessed.

SPS

An SPS rectenna would release about 7.5 W/m^2 of waste heat over a 100 km^2 area. This energy density is equal to 10% of the net solar radiation at the ground and is equivalent to the heat release of an average suburban development.[5] With light winds, temperature increases of as much as 1°C and increased cloudiness could occur in the vicinity of the rectenna.[5] Changes in precipitation distribution would be unlikely. The atmospheric perturbations

from rectenna operation should be smaller than those of other man-made installations. They would also be dwarfed by the quantities of heat released by urban areas, which are referred to as heat islands due to appreciably warmer temperatures than adjacent rural areas. Weather-related welfare effects would be expected to be moderate.

Atmospheric absorption of energy along the microwave beam path (from satellite to rectenna) is being examined to determine its potential for causing local heating, enhancing turbulence, and altering the dynamics of atmospheric circulation. The extent of any heating or other weather effects would be expected to be negligible.

SPS rocket launches would release a bouyant "ground cloud" of hot exhaust effluents that would rise and disperse. Under certain meteorological conditions, this cloud could possibly modify local weather and would have a moderate welfare effect.

All other SPS activities would release negligible quantities of heat to the atmosphere.

4.4 WATER POLLUTION

Many of the water quality impacts historically associated with energy activities are expected to decrease dramatically as a result of recent regulatory programs. Various federal, state, and local water quality management programs significantly limit emissions, establish criteria for water and stream quality, and mandate reclamation requirements. It should be noted that there is disagreement over the efficacy of these laws -- particularly those relating to mining.

The direct water-quality-related welfare effects of the coal, nuclear, and SPS fuel cycles are site-specific in nature. The effects of effluent streams vary by location and flow rates in the receiving body of water; their nature will depend on background pollution levels and downstream water uses. Occasionally, small increases in pollutant loadings are sufficient to degrade a stream and limit its uses.

The most significant welfare effects are expected from underground coal mining, nuclear fuel fabrication, and SPS materials manufacture and space

vehicle launches. These effects could include degraded drinking water supplies and reduced commercial and recreational use of streams and lakes, including effects on fisheries. Acidified water may also lower crop productivity because of degraded irrigation water and reduced commercial and sport fishing opportunities.

Coal

Water pollutants are generated during coal mining and processing and power generation. Because coal mining operations and the associated receiving waters vary extensively, impacts and residuals ascribed to a typical mining operation are of limited value. The principal environmental problem associated with both operational and abandoned Eastern mines is contamination of surface water and groundwater by acidic mine drainage. The acid discharge from controlled mines is neutralized by lime treatment, but may contain dissolved solids such as sulfates, calcium, magnesium, and other minerals contributing to water hardness. Eastern streams that receive mining effluent show elevated ambient levels of suspended solids, iron, manganese, and trace metals, within EPA guidelines. A study examining impacts from mine drainage into a "model" stream indicates that the discharge of treated effluent into a stream with a flow rate of 2.83 m^3/s (100 ft^3/s) could substantially elevate levels of soluble ions (notably calcium, magnesium, sodium, chloride, and sulfate) and adversely affect sensitive aquatic species.[11] Because of this possibility, underground coal mining is rated as having a high welfare effect (see Table 2). When the same quantity of mine effluent was added to a model stream with a flow rate of 28.3 m^3/s (1000 ft^3/s), all chemical parameters of the stream were unchanged.[11]

Western coal mining results in discharges of alkaline mine effluents and suspended solids. However, this drainage and runoff can be collected in settling ponds. The study noted above showed only minor increases in sodium and sulfate, with pollutant levels remaining in compliance with EPA limitations.[11] Surface mining is therefore considered to have a moderate welfare effect.

Stringent pretreatment and effluent limitations on coal processing prevent surface or groundwater contamination from settling pond overflow and refuse pile runoff. High concentrations of iron, metals, sulfates, dissolved and suspended solids, and many trace elements are often associated

Table 2. Welfare Effects of Water Pollution[a]

	COAL				NUCLEAR									SPS				
	Surface Mining (Western)	Underground Mining (Eastern)	Processing	Power Generation	Surface Mining	Underground Mining	Milling	UF_6 Production	Enrichment	Fuel Fabrication	Power Generation	Reprocessing	Waste Management	Resource Extraction	Materials Manufacture	Transportation[b]	Rocket Launch[c]	Rectenna Operation
Exceed Drinking Water Criteria in Receiving Body of Water	M	H	H	V	M	M	M	L	L	H	V	L	L	U	U	L	L	U
Other Factors Influencing Welfare Effect																		
Mitigation Potential	M	V	H	H	H	H	H	M	M	L	H	U	U	U	U	M	M	U
Certainty of Effect	H	H	V	V	M	M	V	H	H	H	V	U	U	L	U	M	M	U
Overall Ranking of Welfare Effect	M	H	M	M	M	M	M	L	H	M	M	L	L	U	H[d]	L	L	U

[a]Legend: H = high M = moderate L = low V = variable U = unknown
Fuel-cycle activities with no impacts are not listed.

[b]Impact of rocket propellent spills has not been evaluated.

[c]Impact of launch aborts which could discharge propellents into water bodies has not been assessed.

[d]Although effect of manufacturing emissions is unknown, the toxicity of the raw materials makes this a high area of concern.

with this activity. However, there is a high potential for pollutant abatement, by such means as the use of clay liners beneath the refuse area and diversion ditches to prevent the water from reaching the pile. This potential makes the net welfare impact from processing moderate and short-term.

Power plants produce effluents from coal storage, combustion (bottom ash, fly ash, and sludge), and auxiliary waste (boiler and cooling tower). These cause slightly elevated levels of dissolved solids, ammonia, sulfates, phosphates, and trace elements in the receiving body of water. The degree of treatment available for this waste is very high. Good siting and management practices mitigate many water pollution problems. The extent of the potential environmental impact is considered high for power generation, but the mitigation options reduce the overall welfare effect to "moderate."

Nuclear

Fewer water pollution problems are associated with uranium mining than with coal mining. Water leaving settling ponds contains suspended solids,

silicates, and trace amounts of uranium ore, which make the water appear turbid.[12] The quality is nearly restored to the level of the local groundwater by settling pond treatment; mining has a moderate welfare effect.

Processing waste from uranium mills contains sulfuric acid leachate residue, sulfates, silica, trace metals, and organic solvents, which are discharged to a tailing retention pond. These tailing ponds are designed to prevent contamination of groundwater and surface water and do not significantly affect the off-site environment.[12] Their environmental and welfare impacts are moderate.

Two effluent streams are generated by uranium hexafluoride production. Treated scrubber and cooling-water solutions contain fluorides, sulfates, nitrates, sodium, ammonia, and other chemicals. Monitored receiving streams indicate that ample dilution occurs, reducing pollutant concentrations to levels that do not violate drinking-water criteria. Additional wastes generated by the solvent extraction operation are neutralized and held indefinitely in sealed ponds.[12]

Uranium enrichment by the gaseous diffusion process produces residual waste from cooling, cleanup, and auxiliary production operations. Major liquid effluents in the waste stream (including calcium, chloride, sodium, sulfate, iron, and nitrates) are emitted at concentrations less than current effluent standards.[4,12] Additional dilution within the receiving body of water reduces the levels to below the concentrations permitted by drinking-water quality standards.

Fabrication of the fuel for light water reactors releases liquid effluents in amounts several orders of magnitude above those permitted by drinking water standards; welfare effects are of high concern. The effluent concentrations leaving the holding ponds or lagoons are 420 mg/L of ammonia, 280 mg/L of nitrates, and 200 mg/L of fluorine; effluent enters receiving waters with flow rates ranging from 0.14 m^3/s (5 ft^3/s) to 198 m^3/s (7000 ft^3/s).[12] The welfare effect depends upon the activities and water quality requirements of the downstream users and the upstream water quality.

Power generation liquid effluents, primarily emitted from the condenser cooling system, include biochemical oxygen demand (BOD), chlorine, phosphate,

boron, chromates, acids, and organics. Stringent regulatory requirements and judicious site selection procedures minimize the potential for impact.

The major effluents from fuel reprocessing operations are sodium, chloride, sulfate, and nitrates. Dilution in the receiving body of water limits the increase in concentration above existing levels to less than 1.3 ppm for sodium and less than 0.1 ppm for the other effluents.[12] This is well below the levels permitted for drinking-water quality.

Off-site effluents are not expected from management of radioactive wastes that are not high-level wastes.

SPS

There is a paucity of applicable data by which to evaluate the impact of SPS activities. Mining of materials would produce known effluents, but the levels at which they would be discharged are unknown. Materials processing could discharge conventional and unconventional water pollutants; however, due to the proprietary nature of these processes, there are no data on potential production or effluent rates or suitable facility locations. The cell manufacturing activity is categorized as an area of potentially high welfare concern because of the toxicity of the raw manufacturing materials.

Discharges to bodies of water occurring during transportation of rocket fuel and during rocket launches would be expected to be minor during normal operating conditions and have been rated as having a low welfare effect. Contamination of the launch tower cooling water would be possible but the quantities involved would likely be small and on-site treatment would be possible. (The impact level from these activities would be higher in the event of an accidental spill or aborted rocket launch.) The water pollution potential of rectenna operation is unknown.

4.5 WATER USE

Water usage for energy-producing activities has several types of impacts, including: increasing competition for water supplies among municipal, industrial, and agricultural (irrigation) users; disrupting local water supplies; and changing stream character. These impacts can lead to reduced

water availability for irrigation or other uses or for dilution downstream (enhancing water quality problems - see Section 4.4). Changes in the base flows of streams may alter their stormwater-carrying capacity. No serious welfare effects appear likely from the coal, nuclear, or SPS technologies if proper water planning and management are exercised. Coal and uranium mining, uranium enrichment, and coal-fired and nuclear power generation are, however, of moderate concern.

Coal and Nuclear

Surface and underground mining for coal and uranium requires that large amounts of water be discharged from the mines, resulting in a temporary lowering of the groundwater table. One estimate indicates that 466 x 10^6 L of water are pumped from a uranium surface mine, affecting water users in the vicinity of the wells.[12] Because most of this water recycles through natural seepage and evaporation, eventually returning to the groundwater after pumping ceases, this is not a significant welfare concern.

Water diversion structures constructed near mines for runoff and erosion control may intercept overland flow and speed its delivery to surface water courses or divert water to a different aquifer. Sediment-control settling ponds will slow the water's return to groundwater. Because these effects can alter the character of a stream, reduce its stormwater-carrying capacity, or exacerbate low-flow/drought conditions, they can cause more serious welfare disturbances than mine pumping. This is a moderate welfare concern for coal mining, but is slightly less important for the nuclear fuel cycle due to smaller mining requirements.

The consumptive water use of coal-fired and nuclear power plants may be sizable, depending on the technology employed for condenser cooling. Using an evaporating (wet) cooling tower, a 32% efficient light water reactor (1000 MWe) would annually "consume" 23.9 x 10^9 L of water. A comparably sized coal plant would "consume" 14.4 x 10^9 L each year.[4] Although evaporative uses of water do not actually consume water, access to the water is lost to local downstream users. A recent study of the Ohio River Basin indicated that under a "high energy development" scenario, with all power plants employing wet cooling towers (including retrofitted wet towers on existing plants), there would be a serious impact on several tributaries and a moderately high impact

on the Ohio River itself when compared against the 7-day/10-year low-flow condition.[13] Water-use considerations and competing demands would also be of significant concern, particularly in the western United States. However, dry cooling towers, which consume only a small amount of water as make-up water for circulation, can be used in areas where water is scarce. Because water availability is a very important criterion in power plant siting and because of the availability of dry cooling, welfare effects related to water use are rated as moderate.

In the nuclear fuel cycle, water is also used during fuel processing. The largest consumptive water uses occur during milling and uranium enrichment: 100 x 10^6 L/yr and 320 x 10^6 L/yr, respectively, when normalized to a 1000-MWe light water reactor.[4] This is considered likely to have a moderate welfare effect. It is interesting to note that cooling water requirements at the power plant supplying the electrical energy to the enrichment plant (second-order impacts) are sizable and clearly exceed the process requirements when once-through cooling is used at the power station. (To support the fuel requirements of one 1000-MWe light water reactor, 41.6 x 10^9 L would be withdrawn annually.)[12] However, almost all this water is returned to surface water supplies. It is anticipated that new facilities would employ cooling towers.

Other activities in the coal and nuclear fuel cycles have low consumptive water use, although coal processing and reclamation water withdrawals could be substantial.

SPS

The impacts of water use by SPS activities would be similar to those from any large-scale industrial operation. Aquifers and bodies of water would, on occasion, be disrupted during mining and construction activity, and manufacturing water requirements would create a demand for water that would compete with other uses. The impact of these conditions is entirely dependent on the sites chosen for mining, manufacturing, and construction and cannot be generically assessed.

Cooling of the rocket launch tower would require a high water-volume-flow rate (704 m^3/min) for a period of about three minutes per launch. If this water were to be withdrawn from local aquifers, it could create a short-

term water pressure problem for surrounding communities. The use of dedicated water wells or on-site water storage facilities should alleviate any pressure fluctuation problems.

Water requirements for rectenna operation are not known.

4.6 SOLID WASTE

The generation of solid waste leads to welfare effects when the quantity of waste creates additional demand and higher costs for available waste disposal sites or when the nature of the waste reduces the potential uses, productivity, and value of the land into which it is placed. These effects are more appropriately treated as land-use issues. As shown in Table 3, the welfare effects of the solid waste generated by the selected technologies are evaluated on the basis of the amount of waste leaving each facility and the commercial use of the waste. Recognition is given to those activities that produce hazardous or toxic waste, although their impacts are considered in Section 4.7, which addresses land-use disturbance. Nearly all the fuel cycle activities evaluated have low welfare effects; SPS materials manufacture and rocket launches could be of moderate welfare concern.

Coal

Coal mining activities generate extremely large quantities of solid waste in the form of overburden and refuse. The amount varies by the method of extraction. It is estimated that in the process of converting coal into electric energy, 1.6 t and 0.8 t of solid waste are produced, respectively, for each ton of surface-mined and underground-mined coal burned.[13]

In area strip mining, solid wastes are produced only during the initial cut made to open the mine. This waste amounts to 450,000-900,000 t of overburden.[4] The rock and earth overburden constitutes a waste material only temporarily, since it is returned to the mine as backfill. The water treatment facility at an area mine with environmental controls will generate sludge: a mine producing 10,000 t of coal daily would produce 100 t of solid waste per day. Although this amount is about equivalent to the daily municipal refuse from a town of 40,000,[4] the amount of waste leaving the mine site is small.

Table 3. Welfare Effects of Solid Waste[a]

	COAL					NUCLEAR[b]										SPS			
	Surface Mining	Underground Mining	Processing	Power Generation	Transmission	Surface Mining	Underground Mining	Milling	UF_6 Production	Enrichment	Fuel Fabrication	Power Generation	Transmission	Reprocessing	Waste Management	Resource Extraction	Materials Manufacture	Rocket Launch	Transmission
Primary Impact (quantity of waste leaving facility)	L	L	L	V	L	L	L	L	L	L	L	L	L	L	L	L	M-H[d]	M	L
Other Factors Influencing Welfare Effects																			
Commercial Use of Waste	-	-	-	L	-	-	-	-	-	-	-	-	-	H	L	L	M	L	-
Hazard Potential[c]	L	L	L	M-H	M	L	L	M	M	M	L	H	M	H	L	L	M-H	L	M
Quality of Data	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	M	L	L	H
Overall Ranking of Welfare Effect	L	L	L	L-V	L	L	L	L	L	L	L	L	L	L	L	L	M	M	L

[a]Legend: H = high M = moderate L = low V = variable U = unknown - = no impact or not applicable

[b]Most wastes from nuclear activities are "specialized" and would not impact waste disposal sites in a conventional way.

[c]The hazardous nature of wastes is considered a land use impact (see Section 4.7) and does not influence the overall ranking.

[d]The quantity of waste could be high if all cells were manufactured at a single facility.

In underground mines, only a small amount of solid waste is produced in sinking the mine shaft. The sludge produced when mine water is treated amounts to 50,800 t/yr for a typical mine in northern Appalachia, 19,200 t/yr in central Appalachia, and 407 t/yr in the central United States;[4] this is not a significant welfare concern.

Coal processing generates varying amounts of waste, depending on the type of coal and the degree of treatment. Much of this waste consists of unwanted noncombustible materials and pyritic minerals (the removable sulfur content). The amount of refuse in raw coal varies from 22% to 36% and averages about 27%.[11] Production rates at processing plants are variable, and approximately 635,000 t/yr of coal refuse would be generated from Illinois or Pennsylvania coal for a typical 1000-MWe plant, reaching a maximum cumulative value of 19.1×10^6 t over a 30-yr plant life.[11] This amount can be disposed of at the processing site in an area of about 2 km^2; welfare effects are low.

The quantity of waste produced during power generation varies according to coal quality and the efficiency of the particulate and sulfur dioxide control devices utilized. Fly ash, bottom ash, and scrubber sludge are generated in the amounts listed in Appendix A, with the total wastes collected annually ranging from 104,000 t for a plant using low sulfur coal without sulfur scrubbing to 525,000 t for a plant using a flue gas scrubber. New source performance standards for electric power plants require flue gas scrubbing or equivalent controls. This waste is generally landfilled on the plant premises, but when this is not possible, it may be trucked off the site. Trace metals in the combustion ash may percolate beneath the landfill, potentially contaminating the soil and groundwater and impairing future productivity (considered as a land-use issue in Section 4.7). Resource Conservation and Reclamation Act regulations may require more extensive landfill preparation and monitoring for coal combustion wastes, if they are classified as hazardous or special wastes. On occasion, ash waste is used commercially as an additive to cement or as roadfill. The welfare effects of solid wastes from coal-fired power generation are rated as low.

Nuclear

Wastes are generated during all activities in the nuclear fuel cycle. Most of these activities generate radioactive waste that must either be sent off-site for commercial burial or buried on-site. As such, these are not conventional solid wastes, and, as previously noted, are treated as a land-use issue. The types of waste generated are noted here.

Mining and milling operations generate the largest amounts of solid waste. Annual mining wastes total 2.7×10^6 t of overburden and barren rock per 1000-MWe reactor(14×10^6 t/yr per facility); this material is returned to the mine as backfill.[12] The 482,000 t of mill tailings are composed chiefly of sandstone and clays and are impounded in an on-site tailings retention pond.[12]

Production of uranium hexafluoride generates 40 t of process effluents in meeting the annual fuel requirements of a 1000-MWe light water reactor.[12] These effluents consist of iron, calcium, magnesium, copper, and nonvolatile fluorides. The residue contains trace quantities of radionuclides and is shipped to a commercial burial site.

Effluents from uranium enrichment (gaseous diffusion process) are collected in holding ponds. Waste includes soil runoff, settleable solids, and precipitated metals. Less than 1 t of this waste is attributable to plant operations and is retained on-site.

The waste produced during fuel fabrication is a calcium fluoride precipitate from the liquid waste stream. About 680 t are produced annually from the facility and retained on-site.[12]

Nuclear power generation produces several different types of waste, including numerous liquid and solid radwastes that are activated during power generation through fission product leakage as well as activated chemical inhibitors that are solidified and sent to a commercial burial site. Reactor purification substances and spent reactor parts are shipped off-site. Spent reactor fuel is assumed to be shipped to a reprocessing center. The annual quantities and types of residual waste are listed in Appendix B.

Fuel reprocessing and waste management generate limited amounts of high-level and low-level radioactive wastes that are either buried on-site or sent to a commercial or federal disposal area. Reprocessing wastes consist of undissolved fuel hulls, other fuel element parts, discarded equipment, and laboratory wastes.

SPS

The principal solid waste problems associated with the SPS stem from rocket launch activities and residuals from the photovoltaic cell manufacturing process. As shown in Appendix C, the production of gallium aluminum arsenide cells for a 5-GW satellite would generate 23.2×10^6 t of solid waste, which could present a disposal problem if all solar cells were manufactured at a single facility. Most of the waste would be aluminum oxide, which has some other commercial value and might not present a disposal problem.

Rocket launch activities would generate waste from construction, operation, and facility sewage sources. Specific quantities are unavailable and could potentially have moderate welfare effects.

Solid waste would also result from mining and the manufacture of conventional materials required for SPS deployment, e.g., steel and concrete. However, these wastes are not expected to pose significant welfare problems.

All Technologies

Other wastes are generated routinely during all three of the fuel cycles considered. These wastes, which are of low welfare concern, include the rubble generated during construction and specialized wastes such as transformer fluids, which contain polychlorinated biphenyls (PCBs). The latter is considered of low concern because other, less toxic, compounds may be substituted for the PCBs.

4.7 LAND-USE DISTURBANCE

Several distinct types of welfare effects may occur from land-use and land disturbance. These effects may stem from:

- Alteration of land surfaces and soil characteristics, which may change existing or future land uses.
- Burial of hazardous waste, which could limit further use of the land.
- Fragmentation of a region due to excessive land requirements, which would necessitate relocation of people or roads and impose other inconveniences.

The use of land for energy-related activities is in some ways both a resource issue and a welfare issue. For example, the permanent withdrawal of land for burial of nuclear wastes is considered a resource issue; however, the inability to return this land to further productive (such as farming) use or to public use (such as trails, private roads, or right-of-ways) is also a welfare infringement. Land requirements for various energy systems are being compared as part of the SPS Concept Development and Evaluation Program. Other welfare considerations regarding land utilization -- such as altered economic value and alternative potential uses of the land -- are most accurately assessed on a site-specific basis and involve both beneficial and detrimental effects.

This analysis of land-use disturbance focuses on the nature and extent of disturbances that are related to land use but somewhat distinct from the issue of land occupation. Several parameters are considered in the qualitative determination of the severity of welfare effects. These considerations, noted in Table 4, include: quantity of land used, quantity of land disturbed, effect upon land beyond the site boundary, restrictions on future productive use of the land, and potential for multiple uses of the land. The most

Table 4. Welfare Effects of Land-Use Disturbance[a]

	COAL						NUCLEAR										SPS					
	Surface Mining	Underground Mining	Processing	Transportation	Power Generation	Transmission	Surface Mining	Underground Mining	Milling	UF_6 Production	Enrichment	Fuel Fabrication	Power Generation	Transmission	Reprocessing	Waste Management	Resource Extraction	Materials Manufacture	Transportation	Rocket Launch	Rectenna Operation	Transmission
Primary Impact (quantity of land used)	H	M	L	H	M	H	M	L	M	L	L	L	M	H	M	L	H	M[b]	U	H	H	H
Other Factors Influencing Welfare Effects																						
Quantity of Land Disturbed	H	M	L	M	M	M	M	L	L	L	L	L	M	M	M	L	H	U	M	M	M	M
Restrictions on Future Productive Use[c]	M	L	-	-	-	-	M	L	M	L	-	-	H	L	U	L	-	-	-	-	-	-
Contamination of Land Beyond Site Boundary	M	-	M	-	L	-	M	-	M	-	-	-	-	-	-	-	-	-	-	-	H[d]	-
Multiple Uses of Land	-	L	-	M	-	M	-	L	-	-	-	-	-	M	-	-	-	-	M	-	-	M
Overall Ranking of Welfare Effect	M-H	M	M	M	M	M	M-H	L-M	M-H	L-M	L	L	M(H)[e]	M	M	L-M	H	M[b]	M	H	H	M

[a]Legend: H= high M = moderate L = low U = unknown - = no impact
Fuel-cycle activities with no impacts are not listed.

[b]Ranking uncertain - will depend upon number and size of production facilities.

[c]After cessation of activity.

[d]Electromagnetic interference -- see Section 4.8.

[e]Capability of using land after power plant is decommissioned is unknown.

significant welfare effects of land-use disturbance -- restrictions on future productive land use or on public access to land -- are a result of mining for coal, uranium, and SPS materials and of disposal of nuclear waste, particularly from milling and power generation. The potential for land-fragmentation effects is of concern for SPS launch, recovery, and rectenna sites.

Coal

Land deterioration may be caused by various activities during the coal fuel cycle. Major disturbances that do not relate principally to land occupation occur from strip mining, subsidence of land covering underground mines, and contamination of land surfaces (particularly from coal refuse piles).

Surface mining disturbs 0.12-0.8 km^2 of land per year to provide the fuel to support a 1000-MWe coal-fired plant.[11] During a 40-yr power plant

lifetime this level of mining would disturb about 4.9 km^2 of Wyoming coal land or as much as 32.4 km^2 of Appalachian land.[11] Stripping of the land overlying coal seams removes vegetation and ground cover and alters soil permeability and land topography, often leading to erosion and accelerated surface water runoff. The productivity of post-mining vegetation will often be less than that of the original vegetation.[11] Other original land uses, such as recreation, ground cover, occasional forestry, and grazing, may be possible after reclamation. Recent reclamation requirements limit the acreage being disturbed and encourage the resumption of productive use as quickly as possible after mining. Return of coal-mined land to fully-productive agricultural use is estimated to require 10-30 yr in Illinois.[11] Surface mining therefore has a potentially high welfare effect.

The major environmental welfare impact of underground mining for coal results from subsidence (settling) of the overlying rock strata to fill the cavity remaining after extraction. The direct welfare effects include reduced land values, damaged overlying structures, injured livestock, and damaged crops. Underground pipes may be ruptured in urban areas and drainage patterns may be altered in rural areas. Because much smaller quantities of land are involved than for surface mining, subsidence is of only moderate welfare concern.

Coal processing may use 1.9 km^2 over a 30-yr facility lifetime. Contamination of land surfaces from coal refuse piles can slightly reduce the land values in the area surrounding a processing facility.[8]

Power generation usually requires a plant site of 2-4 km^2 and additional land for ash and scrubber-waste disposal. Trace metals in the combustion ash may percolate beneath the landfill, potentially contaminating the soil and groundwater and lowering subsequent productivity. This issue is currently of concern to regulatory agencies. Regulations may be proposed under the Resource Conservation and Recovery Act that designate this waste as hazardous and require more extensive landfill restrictions. Currently, there are no laws requiring the return of ash/sludge landfills to productive use, although procedures are available for such reclamation. If wastes are properly disposed of and land reclaimed, this activity is projected to have moderate land-use-related welfare effects.

Coal transportation uses a significant quantity of land. Right-of-way requirements are approximately 15.2 m. It is estimated that the quantity of land required, when prorated to exclude non-coal tonnage, is 0.15 km^2 for each 500 km of hauling distance. Joint use of the right-of-ways is possible.

Nuclear

In comparison with the coal fuel cycle, the mining land-use requirements for a nuclear plant are moderate; 0.22 km^2/yr are disturbed to support a 1000-MWe nuclear facility. The typical nuclear mine supplies 5.3 light water reactors, disturbing approximately 1.2 km^2 annually. A typical surface mining operation is likely to encompass 12.1 km^2, although only one-third of this will be disturbed. The alternative use of this land is likely to be grazing.[12] Some land (0.05 km^2/mine/yr) is permanently committed to uranium mining waste dispoal and precluded from other use. In an expanded nuclear economy, the amount of land disturbed would increase due to the mining of lower-grade ores. Uranium has a smaller land-use impact than coal mining for producing an equivalent amount of fuel.

Storage of mining and milling residues (tailings), transuranic wastes (primarily from spent-fuel reprocessing), and low-level wastes (residuals from UF_6 production, fuel fabrication, reactor operation, and fuel reprocessing) require the largest land commitments. The largest annual commitment (0.05 km^2) is currently for milling waste disposal. Low-level wastes are now being buried at a few commercial sites across the United States with no intent to use the land for any future purpose.[4]

Methods for disposal of transuranic and high-level wastes are being investigated. Burial of these wastes in deep geological formations is estimated to require approximately 3.2 km^2.[14] Alternatives to burial include seabed, icesheet, and extraterrestrial disposal. The irretrievable use of land for storage of nuclear wastes is an area for considerable concern.

The limited future productive use of land is also important to other nuclear activities. Uranium hexafluoride production, power generation, and reprocessing all entail the withdrawal of small amounts of land from other uses (see Appendix B). Adequate information is not available to assess the potential for future activities at decommissioned nuclear generating stations. Conceivably, a large portion of the power plant site could be

restricted from other uses. The welfare impact of these permanent land withdrawals is an area for some concern.

Certain activities in the nuclear fuel cycle require large buffer or exclusion zones. Fuel enrichment and reprocessing plants require a buffer zone of 6.1-12.1 km^2 or more; smaller exclusion areas are needed for other nuclear activities. While these areas protect the general population against exposures to radiation, they also represent a loss of potentially productive pasture, forest, or farmland. (For example, the removal of 12.1 km^2 of productive farmland could translate into the loss of 4082 t of corn annually, or a similar loss of other crops, livestock, or pulpwood.[15]) In perspective, it should be noted that other activities -- such as the disposal of chemical manufacturing wastes or military weapons wastes -- also permanently remove land from other uses. The full contribution of nuclear power activities to such permanent land commitment is unknown.

SPS

The principal land-use impacts of the satellite power system stem from the large land requirements for mining, launch and recovery sites, and rectenna sites. The Kennedy Space Center, a typical launch facility, has an area of 570 km^2. A single rectenna site could occupy 92 km^2 (at 34°N latitude, as well as an exclusion zone beyond the site boundaries, for a total of 175 km^2.[16] In general, rectennas would be sited in sparsely populated areas to minimize competing land uses and displacement of large numbers of persons. Because of their size, rectenna sites would additionally require the relocation of roads, which would inconvenience persons having to drive around areas they formerly could drive through, and services (such as electricity and water). The extent of the impact of these land requirements would be highly dependent on the specific sites chosen.

The manufacture of gallium aluminum arsenide solar cells could generate waste containing potentially toxic substances (such as gallium and arsenic). Leaching of these materials from waste piles could possibly affect soil and groundwater unless waste disposal areas are properly designed and managed.

All Technologies

Land requirements for power transmission lines -- easements 45.7-122 m in width -- are common to all centralized energy technologies. The high impact

of this land use is offset by the dispersion of the land (0.08 km^2 per kilometer) and the possible joint use of the land for low-intensity farming and pasturing.[8]

4.8 ELECTROMAGNETIC DISTURBANCES

The most significant and extensive electromagnetic disturbances would result from the satellite power system. Welfare effects from rectenna operation would include, but not be limited to: discruption of, or interference with, military radar; public service communications systems; and computers. Reflected light and other electromagnetic disturbances from the orbiting power satellites could infere with optical and radio astronomy. Coal and nuclear effects are minor.

SPS

Microwave coupling with electronic systems would occur at distances of up to 100 km from an SPS rectenna site. The type and severity of the disturbance would depend upon the nature of the electronic systems near the rectenna and their amenability to mitigating strategies. The electronic systems that have been identified as likely to suffer functional degradation include:[5]

- Military systems, including radar and communications.
- Law enforcement, emergency, and other public service communication systems.
- Industrial computers and computer-controlled systems.
- Transportation support systems.
- Specialized services, such as satellite tracking systems.

Mitigation strategies may be possible for some types of equipment operating beyond 40-50 km from the rectenna, although in many instances operational compromises would result from the mitigation strategies. Military electromagnetic systems could not be modified because of an unacceptable probability of operational compromises. Microwave coupling is a potentially severe welfare effect.

Emissions from SPS launch vehicles could modify the electron density of the ionosphere for several thousand kilometers around the launch site. Limited experience with Skylab launches indicates a significant potential for

disruption of communications systems relying on ionospheric interactions. The extent of the disruption and the ability of the ionosphere to recover between rocket launches are unknown. This is expected to be of lesser welfare concern than the microwave coupling effect.

The solar power satellite itself would create electromagnetic disturbances in the form of reflected light, infrared radiation from waste heat rejection, noise in the radio portion of the spectrum, and the formation of dust clouds in geosynchronus earth orbit from debris, leaks, off-gasing of materials, and other deterioration processes. The extent of the disturbances are unknown, but radio and optical astronomical observations could be hindered due to an increase in the background level of existing interference and restrictions of the spectrum available for observations. An environmental assessment of SPS-related microwave disturbances is underway.[5]

All Technologies

Electromagnetic interference from high-voltage power transmission lines is associated with coal, nuclear and SPS technologies. The severity of any welfare effect is considered mild and could be limited to radio and TV disturbances in fringe reception areas. This effect may be intensified with the use of higher transmission-line voltages (greater than 745 kV).

4.9 MICROWAVE RADIATION

Of the three technologies assessed, only the satellite power system would emit microwave radiation. Microwave radiation levels at a rectenna would be as high as 23 mW/cm^2 within the exclusion zone; chronic levels below 1 mW/cm^2 would be experienced beyond this zone.

There is limited information on the direct effect of microwave radiation on biological systems, little of which relates to the chronic effects of low-level exposures. It has been speculated that microwave exposure could alter the mortality, reproduction, and behavior of beneficial insects such as bees; disturbances to the pollination process could adversely affect crop production,[5] a welfare effect. Direct microwave exposure could also increase the susceptibility of crops to environmental stresses such as drought, resulting in decreased yields. The likelihood and severity of potential welfare effects are unknown. Further study will be undertaken as part of the SPS Concept Development and Evaluation Program.

4.10 IONIZING RADIATION

Low levels of ionizing radiation are routinely emitted during the combustion of coal containing trace quantities of radioactive material and during all activities in the nuclear fuel cycle. The effects of radioactive releases during nuclear activities are minimized by restricting access to land surrounding the facilities; this land is termed an exclusion zone. Satellite power systems would not emit ionizing radiation.

Radiation emissions from nuclear activities are of low welfare concern, since they are in compliance with federal regulations established by the Nuclear Regulatory Commission (10 CFR 20) that limit permissible radiation doses in both restricted and unrestricted areas. While radioactive emissions from coal combustion are not regulated, they are relatively low and are not believed to have significant welfare effects. However, the effects on animals and plants of long-term exposure to low-level radiation are not known with certainty. While current regulatory standards assume the existence of a threshold level of radiation below which damage to living tissue does not occur, it may be that any exposure to ionizing radiation is biologically harmful.

If long-term, low-level radiation can harm animals or plants, genetic changes in livestock and crops would be possible. The welfare effects would be subtle, but could have an impact in areas where large amounts of money and time have been expended in attaining specific quality breeds of meat- and milk-producing livestock. Often the maintenance of these breeds depends on the successful propagation of a small number of animals. Radiation-induced genetic changes in such animals could interfere with breeding efforts.

Coal

Radioactive elements (primarily uranium, thorium, and radon) naturally present in coal are emitted with the stack gases during combustion. Coal combustion releases about 1.2 Ci annually, depending on the nuclide concentration in the coal seam.[17] Radioactive airborne releases from a 1000-MWe coal-fired power plant are considerably less than those from a comparably-sized nuclear plant; however, because of the lack of exclusion zones around coal-fired plants, the general off-site radiation dosage (exposure) from combustion of coal with certain characteristics may be higher

than that from a nuclear reactor.[17] While general-population doses are not a welfare concern according to the definitions adopted for this study, they are indicative of exposure levels for livestock and crops. Standards limiting radioactive emissions from fossil-fuel power plants have not been established, but could be promulgated under the federal Clean Air Act Amendments of 1977.

Nuclear

While uranium mining activities increase the amount of uranium dust and decay products (mainly radon and daughters) released to the atmosphere, they do not measurably increase environmental radioactivity outside the immediate vicinity of the mine.[12] During milling, radioactive emissions (primarily from Rn-222) escape to the atmosphere with gas and particulate emissions.[17] However, the exposure from these emissions in unrestricted areas cannot be distinguished from background levels.[18]

Radioactive airborne emissions from enrichment and fuel fabrication are also low. Estimated concentrations of uranium at the boundaries of both types of facilities are estimated to be less than 0.1% of applicable 10 CFR 20 standards for radiation release to an unrestricted area.[12]

Tritium and Kr-85 are the principal emissions from nuclear fuel reprocessing. These emissions represent the largest radioactive release in the nuclear fuel cycle (see Appendix B) and are within 10 CFR 20 limits. Routine operation of nuclear power plants releases measurable quantities of radioactive isotopes to the atmosphere in the form of noble gases, halogens, particulates, and tritium.[12] Radioactive waste management has the lowest level of radioactive emissions: 0.005 Ci/yr, which is near the lower limit of radiation detection.[12]

While it is not within the scope of this assessment to estimate the nature or extent of the welfare effects of nuclear accidents, a qualitative review of the effects surrounding an accident is illuminating. (However, the severity ranking is only influenced by emissions occurring during routine facility operations.) These welfare effects would result from both immediate and long-term actions needed to reduce excess risks to health and welfare and to ultimately return the affected area to a usable state.

Immediate welfare effects following an accident would stem from removal of radiation pathways to humans and would include loss of access to and use of large land areas and property; destruction of contaminated food supplies such as crops, livestock, and milk products; and loss of drinking water supplies.

Other direct welfare effects would include population evacuation costs, loss of commerce and productivity, and civil defense costs. Contamination of water supplies or extensive radiative releases could require relocation of an entire population center for an indefinite period of time and could reduce land values.

More subtle welfare effects of nuclear accidents would include the temporary disruption of power, costs of replacement power, reduction in the tax base if a power plant was prematurely decommissioned, and loss of home property and business in an evacuated area. Welfare effects would not always be limited to the locality of the accident. Nuclear insurance costs would be likely to increase for all subscribers. Discovery of a design weakness in one nuclear facility might require all similar facilities to be modified or temporarily shut down.

4.11 NOISE

The welfare effects of noise are primarily changes in land-use patterns, reduced property values, annoyance, and interference with other activities (for example, interference with work efficiency or speech). Hearing and other physiological effects related to public health are not considered here. More detailed information on the effects of noise exposure is provided in Refs. 5 and 19. SPS rocket launches would be the only activity likely to have a major welfare effect.

Coal and Nuclear

Coal and nuclear mining and power generation have moderate noise impacts. Power plant noise arises from cooling tower fans and plant support activities. Blasting and drilling during mining may also elevate noise levels in the immediate vicinity. Noise measurements assessed at the property line in most cases are not expected to be significant, and use of a buffer zone between the noise source and the property line frequently serves

as a mitigation technique. High noise levels may occur sporadically during coal transportation, but would not contribute significantly to 24-hr weighted noise exposures.

SPS

Noise from HLLVs (60-80 dBA, 24-hr weighted average) would be likely to exceed recommended EPA 24-hr average noise standards and elevate noise levels in surrounding communities as far away as 31 km. Instantaneous peak (or peak property-line) noise levels would similarly be high. Launches would occur frequently (225 HLLV launches per year to construct two 5-GW satellites with gallium arsenide cells).[2] This noise is a major welfare concern. The PLV would be expected to generate about one-fourth the noise of an HLLV since its thrust would be about one-fourth that of an HLLV and since it would be launched less often (35 times per year). Sonic booms occurring during SPS vehicle launch and reentry operations would elevate noise levels to a lesser degree.

All Technologies

Barely-audible noise from high voltage (> 345-kV AC) power transmission results from the corona created by the lines and can be heard several hundred feet away in inclement weather. Transmission lines carrying 745 kV have not been commonly used, but are being installed at an increasing rate. This noise is considered a minor welfare impact.

4.12 AESTHETIC DISTURBANCE

Fuel-cycle activities that reduce the perceived quality of daily living experiences can be said to have aesthetic welfare effects. An aesthetic deterioration can be either direct, such as an unsightly mine, or indirect, such as water pollution causing aesthetic degradation of lakes. Wherever possible, indirect aesthetic effects have been treated in the context of their primary environmental impact.

The direct aesthetic impacts of coal, nuclear, and SPS technologies are for the most part site-specific. The extent of these disturbances can be moderated by avoiding rare and endangered species and archaeological, cultural, historical, protected, scenic, and recreational areas during the

facility siting process. Because of the size of SPS launch and rectenna sites and operational constraints on siting, it could be relatively difficult to avoid infringing on such areas. Siting studies underway for the SPS will further clarify this issue, extending current understanding.[16]

Table 5 lists the visual aesthetic disturbances ascribed to the three energy systems. These include transmission corridors and energy facilities in rural areas, power plant plumes, and satellites visible in the night sky. In considering these impacts, it is useful to remember that all anthropogenic activities (such as shopping centers) can aesthetically degrade the environment and that evaluation of aesthetic disturbances is influenced by a wide variation in personal preferences and orientations.

Table 5. Visual Aesthetic Disturbances

Coal	Nuclear	SPS
Unsightly large surface mines and subsidence of deep mines	Unsightly mines (but smaller than coal mines)	Unsightly large mines to support high materials requirements
Refuse banks from coal processing		
Visible plumes from power plant cooling towers	Visible plumes from power plant cooling towers	
Tall power-plant stacks visible from long distances	Nuclear fuel processing facilities located in rural areas	Rectenna facilities located in rural areas
Transmission corridors through rural areas	Transmission corridors through rural areas	Transmission corridors through rural areas
		Bright satellites visible in night sky

5 CONCLUSIONS

This report has identified and compared the potential environmental welfare effects of the coal and nuclear fuel cycles and the satellite power system. These effects, discussed in Section 4, are summarized in Tables 6, 7, and 8 and ranked side by side according to potential severity in Table 9. The welfare-effect severity ranking assigned to a technology for a particular environmental impact area, such as air pollution, is based on the most serious effect of any activity within the energy pathway for the technology. Table 9 also indicates the state of knowledge concerning the welfare effects.

A primary objective of this assessment is to identify potentially severe welfare effects that warrant further investigation. The following environmental-impact/fuel-cycle-activity pairs have been linked with potentially serious welfare effects; the welfare effects are discussed briefly later in this section.

• Air pollution:	Coal-fired power generation SPS materials manufacture and rocket launch
• Atmospheric changes:	Coal-fired power generation
• Water pollution:	Coal mining (underground) Nuclear fuel fabrication SPS materials manufacture
• Land use disturbance:	Coal mining (surface) Nuclear waste disposal (high-level, transuranic, low-level waste) SPS materials mining, rocket launch, rectenna
• Electromagnetic disturbance:	SPS rectenna operation
• Microwave radiation:	SPS microwave beam transmission
• Noise:	SPS rocket launch

As Table 9 illustrates, there are several impact areas for which SPS activities might produce severe environmental welfare effects; however, understanding of these impacts is limited. Two types of limitations are noteworthy: (1) the certainty that a given environmental impact is capable of producing a welfare effect (for example, would microwave radiation affect bees to such a degree that crop production would be altered) and (2) knowledge of the processes and effluents involved in various SPS activities (for example, air and water pollutant emissions from manufacturing gallium

Table 6. Welfare Effects of Coal-Combustion Fuel Cycle

Environmental Impact	Activities Involved	Welfare Effects
Air Pollution	Mining Processing Transportation Power generation	Emissions of SO_2 and NO_x from power generation can lead to acid rainfall, which can reduce crop yield and remove lakes or rivers from commercial or recreational use. Emissions of SO_2 and particulates can cause or augment material damage and reduce crop yields. Secondary particulates can impair visibility.
Atmospheric Changes	Power generation	Injection of large amounts of CO_2 and other greenhouse gases into the atmosphere may promote global warming, with effects on precipitation, agricultural, and ocean levels. Particulate emissions may also play a minor role in climatic change.
Thermal Discharges	Power generation	Cooling tower operation can increase local fogging and icing, with effects on visibility, traffic, and convenience for nearby residents. Cloud and precipitation augmentation is possible, but should be minor, with little effect on crop productivity.
Water Pollution	Mining Processing Power generation	Discharges of acids, dissolved solids, suspended solids, and other chemicals can: degrade drinking water supplies, contaminate waterways, lower crop productivity because of acidified irrigation or groundwater, and reduce commercial and recreational use of streams and lakes.
Water Use	Mining Processing Power generation	Mining can disrupt water flow patterns. Cooling needs during power production require extensive amounts of water if evaporative systems are used. Both impacts can conflict with downstream and competing uses.
Solid Waste	Mining Processing Power generation	Demand for disposal sites can be increased. Land use, value, and productivity can be reduced by overburden and refuse from mining and processing, ash and scrubber wastes, and by hazardous trace metals from power generation.
Land Use Disturbance	Mining Processing Transportation Power generation Transmission	Surface mining and power generation (waste disposal) remove land from alternate uses; reclaimed land may be less productive agriculturally than before mining. Subsidence of land over underground mines can reduce land values; damage crops, buildings, and livestock; rupture pipes; and disrupt drainage. Coal processing can contaminate, and lower value of, surrounding land. Transportation and transmission land requirements are significant and limit other uses of the land.
Electromagnetic Disturbances	Transmission	High intensity magnetic fields around transmission lines can cause radio and TV interference in fringe reception areas.
Ionizing Radiation	Power generation	Small quantities of radioactive materials are emitted during coal combustion. Welfare effects of these emissions, which are uncertain, include effects of long-term exposure of crops and livestock to radiation.
Noise	Mining Transportation Power generation Transmission	Welfare impacts of noise generation from most coal-related activities are relatively minor due to the remote locations of the operations. Audible hum from high-voltage transmission lines may occur.
Aesthetic Disturbances	Mining Processing Transportation Power generation Transmission	Visual impacts will occur from mines, tailing piles, power plants, stack plumes, and transmission corridors.

Table 7. Welfare Effects of Nuclear Power Generation

Environmental Impact	Activities Involved	Welfare Effect
Air Pollution	Mining UF_6 production Enrichment Fuel fabrication Transportation Power generation Reprocessing	Fluorine and sulfuric acid emissions could damage livestock, grazing land, and crops. Other air pollutants are emitted from coal plants, which may be used to supply process power.
Thermal Discharges	Enrichment Power generation	Cooling tower operation can increase local fogging and icing with effects on visibility, traffic, and convenience for nearby residents. Cloud and precipitation augmentation is possible, but should be minor, with little effect on crop productivity. The same effects would be possible from power generation for uranium enrichment facilities. Nuclear power parks would release much more heat than single power plants, with increased welfare effects.
Water Pollution	Mining Milling UF_6 production Enrichment Fuel fabrication Power generation Reprocessing	Leaching of ore piles results in runoff threatening local fisheries. Process effluent can on occasion degrade drinking water supplies; degrade irrigation water, impairing crop growth; and reduce commercial and recreational use.
Water Use Changes	Mining Power generation Enrichment	Mining operations can disrupt water flow. Cooling needs during power production require extensive amounts of water if evaporative systems are used; uranium enrichment also has significant water requirements. All three impacts can conflict with downstream uses.
Solid Waste	Mining Milling UF_6 production Fuel fabrication	Release of trace elements into terrestrial ecosystems may locally reduce crop productivity. Lateral and upward movement of leachates may contaminate rooting zones of otherwise productive cropland.
Land Use Disturbance	Mining Enrichment Reprocessing Decommissioning	Agricultural use of reclaimed mines may be less productive. Exclusion zones around enrichment and reprocessing plants remove land from other uses, whereas burial of nuclear wastes may remove all further use of land involved.
Electromagnetic Disturbances	Transmission	High intensity magnetic fields around transmission lines can cause radio and TV interference in fringe-reception areas.
Ionizing Radiation	Mining Milling Conversion Enrichment Fuel fabrication Power generation Reprocessing	Low-level radiation emissions could act as an extremely low-level mutating agent for crops and livestock. Knowledge of a threshold level for adverse effects from ionizing radiation is uncertain.
Noise	Mining Power generation Transmission	No major effects. High-voltage transmission lines create a barely-audible hum.
Aesthetic Disturbances	Mining Power generation Transmission	Aesthetic degradation due to mines, cooling tower plumes, transmission corridors.

Table 8. Welfare Effects of Satellite Power System

Environmental Impact	Activities Involved	Welfare Effects
Air Pollution	Launch and recovery Mining Manufacturing Construction Transportation	Solar cell manufacturing and rocket launches may produce toxic emissions -- exact emissions and welfare effects are unknown. Environmental problems from fugitive dust from mining and construction and spills of rocket propellants could occur -- welfare effects are not expected to be as severe as those of toxic emissions.
Atmospheric Changes	Launch and recovery Rectenna	Rocket emissions of CO_2 and H_2O would augment the greenhouse warming effect to a small extent, with slight effects on precipitation, agriculture, and ocean levels.
Thermal Discharges	Launch and recovery Rectenna	Waste heat from the rectenna would raise local temperatures slightly, possibly produce slight changes in local cloudiness, and contribute to heat island effects. Heat from launch ground cloud could modify local weather. Welfare impacts would likely be minor.
Water Pollution	Mining Manufacturing Launch and recovery	Water pollutants generated by conventional mining and manufacturing activities could degrade drinking water supplies and cause reduced commercial and recreational yield in affected waters. (Transportation of propellants could result in accidental spills, with similar welfare effects.)
Water Use	Mining Manufacturing Construction Launch and recovery	Mining of materials could disrupt aquifers and bodies of water; impacts unknown. Local water shortages due to cooling needs of the launch tower would be possible, but should be avoidable.
Solid Waste	Mining Manufacturing Launch and recovery	Mine tailings, residuals from photovoltaic cell manufacturing, and wastes from launch-related activities could increase demand for disposal sites. Toxic manufacturing wastes could reduce productivity and usefulness of land to some degree.
Land Use Disturbance	Mining Launch and recovery Rectenna Transmission	Mining operations, launch and recovery sites, and rectenna sites remove large parcels of land from alternate uses. Post-mining agricultural use of reclaimed areas may be less productive. Large rectenna and launch complex sites could require relocation of homes, roads, and right-of-ways and inconvenience persons having to drive around an area that they formerly could drive through.
Electromagnetic Disturbance	Launch and recovery Satellite Microwave power transmission Transmission	Launch vehicle emissions could modify the electron density of the ionosphere and disrupt communications systems. Reflected light and waste heat from the satellite could create EM disturbances. SPS microwave coupling with electronic systems up to 100 km from the rectenna could occur. Power transmission can effect fringe TV and radio reception.
Microwave Radiation	Rectenna	Rectenna operation would emit low levels of microwave radiation beyond exclusion area. The effects of these emissions are unknown, but possibly could include indirect impacts on beneficial insects and invertebrates. Microwave radiation could also make crops more susceptible to other environmental stresses.
Noise	Launch and recovery Transmission	Noise from HLLV launches could exceed recommended EPA noise standards. Sonic booms would occur during launch and reentry. High voltage transmission lines produce a barely-audible hum. High noise levels near residential areas could reduce property values, cause annoyance, and interfere with other activities.
Aesthetic Disturbances	Mining Satellite Transmission	Mining activities and transmission lines would have visual impacts. The satellites would be visible as bright objects in the night sky.

Table 9. Potential Severity of and Status of Knowledge about Key Environmental Welfare Issues[a,b]

Environmental Impacts with Possible Welfare Effects	Coal		Nuclear		SPS		Activities Causing Potentially Severe Welfare Effects
	Potential Severity	State of Knowledge	Potential Severity	State of Knowledge	Potential Severity	State of Knowledge	
Air Pollution	1	B-C	2-3	B	1	C	Coal-fired power generation (toxic and secondary pollutants). SPS materials manufacture and rocket launch.
Atmospheric Changes	1	B-C	4	B	3	B	Coal-fired power generation (CO_2 emissions).
Thermal Discharges	2	B	2	B	2	B	--
Water Pollution	1	B	1	B	1	C	Coal mining (underground). Nuclear fuel fabrication. SPS materials manufacture.
Water Use	2	B	2	B	3	C	--
Solid Waste	2-3	A	3	B	2-3	C	--
Land-Use Disturbances	1-2	A	1	B	1	B-C	Coal mining (surface). Nuclear waste disposal. SPS materials mining, rocket launch, rectenna sites.
Electromagnetic Disturbances	3	B	3	B	1	B-C	SPS rectenna operation.
Microwave Radiation	4	B	4	B	1	C	SPS power transmission.
Ionizing Radiation	3	B	3	B	4	B	--
Noise	3	A	3	A	1	B	SPS rocket launch.
Aesthetic Disturbances	2	A	2	A	2	B	--

[a]Severity ranking is based on the most serious welfare effects of the activities within each fuel cycle. Potential severity is ranked according to the following criteria:

1 - Very significant contribution to welfare effects.
2 - Significant contribution to welfare effects.
3 - Minor but measurable contribution to welfare effects.
4 - Negligible contribution to welfare effects.

[b]State-of-knowledge ranking:

A - Issue thoroughly documented and understood.
B - Parts of issue understood, but gaps in knowledge exist.
C - Very little knowledge of issue exists.

aluminum arsenide solar cells). Although both of these categories -- for which the potential severity is high and the state of knowledge is limited -- are identified here as priority issues warranting further investigation, better understanding may reduce the severity of these rankings.

Experience with coal and nuclear systems has led in some ways to an increasing ability to make these power systems more compatible with the environment. Similar experience with the satellite power system might also allow us to moderate its negative impacts.

Air Pollution. Welfare effects attributed to air pollution include reduced crop yields, accelerated material deterioration, reduced visibility, and reduced commercial/recreational use of waters degraded by acid rainfall. Trace emissions of toxic elements from coal combustion are not regulated by the NAAQS; some accumulation of these elements has been observed near coal-fired power plants. Sulfur dioxide and nitrogen oxide emissions from coal combustion are transformed into particulate sulfates and nitrates, which have been strongly implicated in visibility degradation and acid rainfall. Toxic emissions such as ammonia, hydrogen sulfide, cyanides, and arsenic would be expected from the manufacture of SPS gallium aluminum arsenide solar cells and other emissions would be anticipated from SPS rocket launches. While the composition and quantities of these emissions are not known, the toxic nature of the expected pollutants and their ability to intensify in the environment make these activities important welfare concerns.

Atmospheric Changes. Although the climatic effects of atmospheric changes induced by air pollutants are not well understood, much attention has been given to steadily-increasing carbon dioxide levels in the atmosphere, because of the possible resulting rise in the earth's mean global temperature. Coal combustion contributes significantly to the total man-made input of CO_2 to the atmosphere. Global temperature increases are conjectured to be capable of altering precipitation patterns, agricultural production, and ocean levels.

Water Pollution. Welfare effects of water pollution include reduced drinking water quality, reduced commercial/recreational use of streams and lakes, and lowered crop productivity because of degraded quality of irrigation

water. Acid drainage has been a significant environmental problem for Eastern coal mines. While regulations have recently been promulgated to control acid drainage, the effectiveness of these laws has been seriously questioned. Fabrication of nuclear reactor fuel releases ammonia, nitrates, and fluorine in amounts several orders of magnitude above those permitted by drinking water standards. Welfare effects depend on the activities and water quality requirements of downstream users; some activities and water uses could be restricted because of water pollution. Because of the proprietary nature of processes for manufacturing SPS gallium aluminum arsenide solar cells, it is not known what types or amounts of effluents would be discharged. However, this activity could have serious welfare effects because of the toxicity of the raw materials involved.

Land-Use Disturbance. Surface mining for coal disturbs large areas of land and the productivity of reclaimed mine sites is often less than that of the undisturbed land. Return of coal-mined land to full agricultural productivity, when possible, is time-consuming (estimated to require 10-30 yr in Illinois). Disposal of high-level, tansuranic, and low-level nuclear wastes and uranium mill tailings is likely to indefinitely remove land from further productive use. Existing low-level waste disposal sites are not being considered for future use. SPS materials mining, rectenna sites, and launch sites would remove large areas of land from other uses. While the welfare effects would be highly dependent on the location of these facilities, they could be significant. For example, rectenna sites could require the relocation of homes, roads, and other services, which would inconvenience the users of these services.

Electromagnetic Disturbance. Microwave coupling with electronic systems as far as 100 km from an SPS rectenna site could have a significant welfare effect. The severity of the electromagnetic interference would depend on the type of electronic systems near a rectenna and their amenability to mitigating strategies that do not significantly degrade performance. Military communication and radar systems would be expected to be the most difficult to modify because modifications could introduce unacceptable operational compromises, but other systems, such as emergency communications and computers, might be similarly degraded. Military systems are located in the same type of sparsely-populated areas being considered for rectenna siting.

Microwave Radiation. Ecosystems within and near rectenna sites would be exposed to chronic microwave radiation. While there is limited information on the effects of such exposure, the mortality, reproduction, and behavior of beneficial insects such as bees could be altered, possibly disturbing the pollination of food crops.

Noise. Noise levels from heavy-lift launch vehicles would be likely to exceed recommended EPA 24-hr average noise standards and elevate noise levels in communities as far away as 31 km. Launches would occur frequently, possibly causing altered land-use patterns, reduced property values, annoyance, and interference with other activities. These impacts could be mitigated by choices of launch locations and flight patterns that would decrease the number of persons exposed to elevated noise levels.

Recommendations for Future Work. There are several areas in which additional study could improve the quality of the assessment. It is recommended that the following studies be undertaken.

1. Process-specific data should be developed for SPS activities, particularly for manufacturing (including production levels and emission types and quantities).
2. Since most environmental welfare effects vary considerably with the site location, the effects of facilities at hypothetical sites should be assessed. This analysis should be conducted for a series of hypothetical SPS sites and compared to coal and nuclear facilities in similarly scattered locations.
3. The welfare effects analysis should be extended to include other energy-supply systems expected to be viable after 2000, including terrestrial photovoltaic, fusion, coal-gasification/combined-cycle, breeder reactor, and distributed solar systems.
4. The welfare effects analysis of coal, nuclear, and SPS technology should be extended to include the effects of accident conditions. The initial emphasis should include SPS rocket propellent spills and rocket aborts, nuclear accidents, and coal emission-control-system malfunctions.

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APPENDIX A:

ENVIRONMENTAL IMPACT DATA FOR

COAL COMBUSTION FUEL CYCLE*

*All values have been adjusted from their original units to metric equivalents.

Table A.1. Air Pollutant Emissions from Coal Combustion Fuel Cycle

Activity	Units	Net Air Pollutant Emissions: TSP	SO_2	NO_x	HC	CO	Other	Comments
Mining								
Surface								
Eastern	t/yr per mine	0.38	0.80	10.98	1.10	6.67	Aldehydes = 0.18 Diesel exhaust emissions	See Ref. A.1. Mine yield: 136,077 t/yr (= 4.33×10^{15} J/yr).
Western	t/yr per mine	1.27-3.45	0.19	1.91	0.19	1.20	Aldehydes = 0.03 Diesel exhaust emissions	See Ref. A.1. Mine yield: 10^6 t/yr (= 1.74×10^{15} J/yr).
Underground		- - - - - - - - - - - - - - negligible - - - - - - - - - - - - - -						See Ref. A.1. Mine yield: 566,988 t/yr (= 18.0×10^{15} J/yr).
Processing	t/yr per facility	55.2	0.3	36	14.4	10.2	--	See Ref. A.1. Weighted national average. Producing 1.81×10^6 t/yr.
Transportation								
Train	t/yr per 1000-MWe power plant	29,937-38,102	--	--	--	--	--	See Ref. A.2. Does no: include diesel emissions (diesels are primary coal movers). Handling & windblown losses result in 1-2% loss of coal. 9,525 t of coal are carried on a unit train.
Power Generation								
Conventional Boiler	t/yr per 1000-MWe power plant	254-694	2,994-27,850	8981	--	--	Arsenic 0.04-0.50 Barium 0.48-2.32 Cadmium 0-0.01 Chromium 0.15-0.66 Cobalt 0.07-0.28 Lead 0.01-240 Manganese 0.10-0.79 Mercury 0.08-0.31 Selenium 0.24 Vanadium 0.19-0.71 Zinc 0.34-5.04	See Ref. A.2. Emissions listed are solely combustion related. Ranges reflect variation in coal quality. SO_2 values are with and without use of flue gas scrubers.
	$kg/10^9J$	0.043	0.516	0.301	--	--	--	See Ref. A.3. Maximum permitted by federal law for new facilities (NSPS).
	$kg/10^9J$	0.013	0.516 max.	0.258				
Transmission		- - - Some ozone and NO_x emissions; levels not established.- - -						Generated by the corona of lines (see Ref. A.1).

Table A.2. Atmospheric Changes Resulting from Coal Combustion Fuel Cycle

Activity	Disturbance	Comments
Power Generation	Carbon dioxide buildup in atmosphere resulting in potential mean ambient temperature increase	Level of effects currently are not well established.
	Emissions of 89 kg/10^9 J or 5.0×10^6 t CO_2/yr	See Ref. A.5.

Table A.3. Thermal Discharge from Coal Combustion Fuel Cycle

Activity	Unit	Thermal Effluent		Comments
		Discharge to Air	Discharge to Water	
Coal Processing	--	- - - - - Little or none - - - - - -		See Ref. A.1.
Power Generation	10^{15}J/yr for a 1000-MWe plant	10.55	27.96	Ref. A.6, adjusted according to Ref. A.1

Table A.4. Water Pollutant Emissions from Coal Combustion Fuel Cycle

	Water Pollution Effluents (net discharge)								
Activity	Units	Dissolved Solids	Suspended Solids	NH_3	Mn	Ni	SO_4	Others	Comments
Mining									
Surface	mg/L	2670-4015	48-73	2-5	0.61-12.36	0.1-0.2	1030-1630	Al 0.2-3.28 Total Iron 0.5-0.8 Zn 0.2-0.23	See Ref. A.7. Emissions reflect best available technology (BAT) level of control.
Underground	mg/L	2516-4700	20	1.1-3.9	0.1-2.0	0.1-2.0	393-2100	Chloride 152-272 Hardness 312-1650 Sr 1.4-2.8 Total Iron 1.5-3.0	See Ref. A.7. Emissions reflect BAT level of control.
Processing	t/yr per facility	1851	32.7	2.8	2.0	0.2	1017.9	Al 2.4 Total Metals (ferrous) 4.1 Zn 0.3	See Ref. A.1. Effluents are weighted national averages associated with elaborate beneficiation. Residuals from refuse piles and beneficiation process included. Effluents listed do not include groundwater contamination.
Transportation									
Train	- - - - - - - - - - - - - - - - - - No routine emissions - - - - - - - - - - - - - - - - - -								
Power Generation	t/yr per 1000-MWe plant	12,996	4.9	0.9	NA	53.9	611.54	Al 4.5 BOD 21.0 COD 2041.2 Cr 0.2 Nonferrous metals 1648.3 P 2.5 Zn 0.7	See Ref. A.1 (adjusted) and Ref. A.8. Impact varies by backgrounmd level, emission rate and flow rate of receiving water body, subject to water quality criteria and emission limitation guidelines.

NA = not available

Table A.5. Water Usage in Coal Combustion Fuel Cycle

Activity	Units	Consumptive Use	Nonconsumptive Use	Comments
Mining				
Underground	m^3-yr/10^{12} J	4.56-6.78	39.39-70.12	See Ref. A.9. Mining and preparation. Use of water not distinguished.
Surface	m^3-yr/10^{12} J	1.52-2.22	36.00-65.80	See Ref. A.9. Assumed to include some usage for dust control.
	10^3 m^3	--	465	See Ref. A.6.
Processing	m^3/t	--[a]	2.15[a]	See Ref. A.9. Water requirements dependent upon desired degree of cleaning.
	$m^3/10^{12}$ J	--[a]	7708	See Ref. A.1.
Power Generation	$m^3/10^{12}$ J	31.56 (1,2)[b] 94.67-112.20 (3,4,6)[b] 127.39-146.09 (5,7-10)[b]	-- -- --	See Ref. A.9. Varies by region.
	10^6 m^3/yr per 1000-MWe power plant	14.38	8.54	See Ref. A.6 (adjusted). Wet cooling tower.
		0	0.31	See Ref. A.6 (adjusted). Dry cooling tower; small amount of makeup water.
Revegetation	For areas with greater than 25.4 cm mean annual precipitation, no additional water is necessary (except during drought conditions in growing season).			See Ref. A.10.

[a]For wet cleaning; consumptive/nonconsumptive split not known.

[b]Water use breakdown by plant activity not indicated; numbers in parentheses indicate federal region.

Table A.6. Solid Waste Generated in Coal Combustion Fuel Cycle

Activity	Units	Solid Waste Generated		Comments
Mining				
Surface	$t/10^{15}$ J	550-1,295		See Ref. A.1. Value includes extraction, cleaning processes, and reclamation.
	10^6 t/yr per mine	0.45-0.91		See Ref. A.6. Amount of overburden in initial cut.
Underground	t/yr	407-50,802		See Ref. A.6. Production of treated mine sludge.
Processing	$t/10^{15}$ J	23,381		See Ref. A.1. For closed-cycle coal preparation with treatment of all refuse.
	t/1000 MWe per year	635,026		See Ref. A.2. Coal refuse.
Power Generation		Without Scrubbers	With Nonregenerative Lime Scrubbers	See Ref. A.1. Quantity of emissions depends upon ash and sulfur content of coal, extent of coal pretreatment, and efficiency of particulate collection device.
Scrubber Sludge	$t/10^{15}$ J	0	2,693-13,110	System: 500-MWe plant; 10.55×10^6 J/kWh; 34% thermal efficiency; 55% capacity factor
Boiler Ash	$t/10^{15}$ J	1,892-2,107	1,892-2,106	
ESP Ash	$t/10^{15}$ J	7,481	7,481	
		With Nonregenerative Scrubbers	Without Scrubbers	See Ref. A.2. System: 1000-MWe plant; 70% capacity factor; Variable coal quality
Bottom Ash	10^3 t/yr per power plant	12.7-21.8	20.9-36.3	
Fly Ash	10^3 t/yr per power plant	49.0-86.2	83.5-138.8	
Sludge	10^3 t/yr per power plant	16.3-41.7	0	

Table A.7. Annual Quantities of Combustion Wastes Collected at a 1000-MWe Coal-Fired Power Plant

Coal Characteristics and Quantities of Waste	Coal Source				
	Northern Appalachia	Southern Appalachia	Eastern Interior (Illinois)	Western Interior (Wyoming)	Four Corners
Coal Quality					
Heat Content (10^6 J/kg)	32.1	33.0	26.5	19.1	26.5
Ash Content (%)	3.6	3.9	5.2	6.0	5.2
Sulfur Content (%)	1.26	0.9	2.45	0.45	0.6
Coal Requirements per Plant (10^6 t/yr)	1.73	1.67	2.08	2.89	2.04
Combustion Wastes (10^3 t/yr)					
Bottom Ash	12.7	12.7	21.8	36.3	20.9
Fly Ash	49.0	50.8	86.2	138.8	83.5
Limestone Scrubber Sludge	217.7	163.3	417.3	--[a]	--[a]
Total	279.4	226.8	525.3	175.1	104.4

[a]No scrubbing.

Source: Adapted from Ref. A.2.

Table A.2. Atmospheric Changes Resulting from Coal Combustion Fuel Cycle

Activity	Disturbance	Comments
Power Generation	Carbon dioxide buildup in atmosphere resulting in potential mean ambient temperature increase	Level of effects currently are not well established.
	Emissions of 89 kg/10^9 J or 5.0×10^6 t CO_2/yr	See Ref. A.5.

Table A.3. Thermal Discharge from Coal Combustion Fuel Cycle

Activity	Unit	Thermal Effluent		Comments
		Discharge to Air	Discharge to Water	
Coal Processing	--	- - - - - Little or none - - - - - -		See Ref. A.1.
Power Generation	10^{15}J/yr for a 1000-MWe plant	10.55	27.96	Ref. A.6, adjusted according to Ref. A.1

Table A.4. Water Pollutant Emissions from Coal Combustion Fuel Cycle

Activity	Units	Water Pollution Effluents (net discharge): Dissolved Solids	Suspended Solids	NH_3	Mn	Ni	SO_4	Others		Comments
Mining										
Surface	mg/L	2670-4015	48-73	2-5	0.61-12.36	0.1-0.2	1030-1630	Al Total Iron Zn	0.2-3.28 0.5-0.8 0.2-0.23	See Ref. A.7. Emissions reflect best available technology (BAT) level of control.
Underground	mg/L	2516-4700	20	1.1-3.9	0.1-2.0	0.1-2.0	393-2100	Chloride Hardness Sr Total Iron	152-272 312-1650 1.4-2.8 1.5-3.0	See Ref. A.7. Emissions reflect BAT level of control.
Processing	t/yr per facility	1851	32.7	2.8	2.0	0.2	1017.9	Al Total Metals (ferrous) Zn	2.4 4.1 0.3	See Ref. A.1. Effluents are weighted national averages associated with elaborate beneficiation. Residuals from refuse piles and beneficiation process included. Effluents listed do not include groundwater contamination.
Transportation										
Train	No routine emissions									
Power Generation	t/yr per 1000-MWe plant	12,996	4.9	0.9	NA	53.9	611.54	Al BOD COD Cr Nonferrous metals P Zn	4.5 21.0 2041.2 0.2 1648.3 2.5 0.7	See Ref. A.1 (adjusted) and Ref. A.8. Impact varies by backgrounmd level, emission rate and flow rate of receiving water body, subject to water quality criteria and emission limitation guidelines.

NA = not available

Table A.5. Water Usage in Coal Combustion Fuel Cycle

Activity	Units	Consumptive Use	Nonconsumptive Use	Comments
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Underground	m^3-yr/10^{12} J	4.56-6.78	39.39-70.12	See Ref. A.9. Mining and preparation. Use of water not distinguished.
Surface	m^3-yr/10^{12} J	1.52-2.22	36.00-65.80	See Ref. A.9. Assumed to include some usage for dust control.
	10^3 m^3	--	465	See Ref. A.6.
Processing	m^3/t	--[a]	2.15[a]	See Ref. A.9. Water requirements dependent upon desired degree of cleaning.
	$m^3/10^{12}$ J	--[a]	7708	See Ref. A.1.
Power Generation	$m^3/10^{12}$ J	31.56 (1,2)[b] 94.67-112.20 (3,4,6)[b] 127.39-146.09 (5,7-10)[b]	-- -- --	See Ref. A.9. Varies by region.
	10^6 m^3/yr per 1000-MWe power plant	14.38	8.54	See Ref. A.6 (adjusted). Wet cooling tower.
		0	0.31	See Ref. A.6 (adjusted). Dry cooling tower; small amount of makeup water.
Revegetation	For areas with greater than 25.4 cm mean annual precipitation, no additional water is necessary (except during drought conditions in growing season).			See Ref. A.10.

[a]For wet cleaning; consumptive/nonconsumptive split not known.

[b]Water use breakdown by plant activity not indicated; numbers in parentheses indicate federal region.

Table A.6. Solid Waste Generated in Coal Combustion Fuel Cycle

Activity	Units	Solid Waste Generated		Comments
Mining				
Surface	$t/10^{15}$ J	550-1,295		See Ref. A.1. Value includes extraction, cleaning processes, and reclamation.
	10^6 t/yr per mine	0.45-0.91		See Ref. A.6. Amount of overburden in initial cut.
Underground	t/yr	407-50,802		See Ref. A.6. Production of treated mine sludge.
Processing	$t/10^{15}$ J	23,381		See Ref. A.1. For closed-cycle coal preparation with treatment of all refuse.
	t/1000 MWe per year	635,026		See Ref. A.2. Coal refuse.
Power Generation		Without Scrubbers	With Nonregenerative Lime Scrubbers	See Ref. A.1. Quantity of emissions depends upon ash and sulfur content of coal, extent of coal pretreatment, and efficiency of particulate collection device.
Scrubber Sludge	$t/10^{15}$ J	0	2,693-13,110	System: 500-MWe plant; 10.55×10^6 J/kWh; 34% thermal efficiency; 55% capacity factor
Boiler Ash	$t/10^{15}$ J	1,892-2,107	1,892-2,106	
ESP Ash	$t/10^{15}$ J	7,481	7,481	
		With Nonregenerative Scrubbers	Without Scrubbers	See Ref. A.2. System: 1000-MWe plant; 70% capacity factor; Variable coal quality
Bottom Ash	10^3 t/yr per power plant	12.7-21.8	20.9-36.3	
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Sludge	10^3 t/yr per power plant	16.3-41.7	0	

Table A.7. Annual Quantities of Combustion Wastes Collected at a 1000-MWe Coal-Fired Power Plant

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	Northern Appalachia	Southern Appalachia	Eastern Interior (Illinois)	Western Interior (Wyoming)	Four Corners
Coal Quality					
Heat Content (10^6 J/kg)	32.1	33.0	26.5	19.1	26.5
Ash Content (%)	3.6	3.9	5.2	6.0	5.2
Sulfur Content (%)	1.26	0.9	2.45	0.45	0.6
Coal Requirements per Plant (10^6 t/yr)	1.73	1.67	2.08	2.89	2.04
Combustion Wastes (10^3 t/yr)					
Bottom Ash	12.7	12.7	21.8	36.3	20.9
Fly Ash	49.0	50.8	86.2	138.8	83.5
Limestone Scrubber Sludge	217.7	163.3	417.3	--[a]	--[a]
Total	279.4	226.8	525.3	175.1	104.4

[a]No scrubbing.

Source: Adapted from Ref. A.2.

Table A.8. Land Requirements for Coal Combustion Fuel Cycle

Activity	Units	Land Area	Comments
Mining			
Surface	10^3 m^2/yr per 1000-MWe plant	121-809	See Ref. A.2. 10^6 t/yr mined. Much of this land is eventually returned to use.
Underground	10^3 m^2/yr per 1000-MWe plant	Variable	Subsidence of land is major impact. Likelihood of occurrence is dependent on geology of site.
Processing	10^3 m^2 per facility	Washing Plant: 20 Loading Facility: 162 Settling Pond: 702 Total: 384	See Ref. A.11. Land also required for refuse disposal. Reclamation regulations require return of land to prior use or better use; thus, detrimental immpacts should be short-term.
	10^3 m^2 per plant (30 yr)	1942-4047	See Refs. A.2 and A.12.
Transportation			
Train	m^2	138	See Ref. A.1. 15.2-m right-of-way, for a 482.7-km trip; excludes non-coal tonnage.
Power Generation	10^3 m^2 per plant	1922-4047	Adjusted from Refs. A.2 and A.12.
	10^3 m^2/yr per 1000-MWe power plant	Waste Disposal Ash: 6.1-18.2 Sludge: 24.3-56.7	
Transmission Corridors			
345 kV	m^2/km	0.045	See Ref. A.1. 45.7-m right-of-way. Land may be simultaneously used for other purposes.
500 kV	m^2/km	0.053	See Ref. A.1. 53.3-m right-of-way.

Table A.9. Electromagnetic Disturbances from Coal Combustion Fuel Cycle

Activity	Type of Disturbance	Comments
Transmission	Corona discharge, which may result in radio and TV interference (especially in areas of fringe reception).	See Ref. A.1.

Table A.10. Radiological Impacts from Coal Combustion Fuel Cycle

Activity	Units	Effluent	Comments
Power Generation	kg/yr for a 1000-MW plant	Uranium: 23.2 Thorium: 46.4	See Ref. A.13. Radioactive effluents originate in coal, and are emitted with the stack gas.
	Ci/yr for a 1000-MW plant	U^{238} chain: 0.008 U^{235} chain: 0.0004 TH^{232} chain: 0.005 Rn^{220}: 0.4 Rn^{222}: 0.8	See Ref. A.13.

Table A.11. Noise Generation in Coal Combustion Fuel Cycle

Activity	Noise Source, Level	Comments
Mining	Blasting, equipment operations, haulage and loading activities.	The noise impacts are addressed qualitatively since perception of noise varies by distance, ambient background, frequency, intensity, and duration of the noise. Regulations are frequently differentiated by land use classes and measured from the property line of the source.
Processing	Little or no adverse impact on land near beneficiation plant.	See Ref. A.1.
Transportation		
Train	95 dBA at 30.5 m from train.	See Ref. A.1.
	75 dBA at 305 m	Federal design noise levels range from 55 dBA (maximum desirable for residences) to 75 dBA.
Power Generation	Coal handling, plant operations, cooling tower fans.	
Construction	All activities	
Transmission	Corona will not be loud enough to cause any hearing damage.	345-kV AC lines create only barely audible noise. 745-kV AC lines can create audible noise several hundred feet in foul weather. See Ref. A.14.

Table A.12. Aesthetic Impacts of Coal Combustion Fuel Cycle[a]

Activity	Type of Impacts
Mining	Loss of land access for duration, until reclaimed.
Processing	Unsightly refuse piles.
Power Generation	Visible plumes periodically from stack and cooling towers. Periodic siting in rural, "natural" areas.
Transmission	Unsightly transmission corridors, poles and lines.

[a]Aesthetic impacts may also be components of other impact areas (e.g., land use, air or water pollution, noise) and are addressed as such in this report.

REFERENCES FOR APPENDIX A

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APPENDIX B:

ENVIRONMENTAL IMPACT DATA FOR

NUCLEAR FUEL CYCLE

*All values have been adjusted from their original units to metric equivalents.

Table B.1. Typical Plant Sizes for Activities in the Nuclear Fuel Cycle

Activity	Annual Production	Number of Light Water Reactors Supplied Annually
Extraction		
Open Pit (ore at 0.2% U^{308})	528,000 t	5.3
Underground (ore at 0.2% U^{308})	150,000 t	1.5
Uranium Milling (U^{308})	1,060 t	5.3
Uranium Hexafluoride (UF_6) Conversion	5,500 t	27.5
Uranium Enrichment		
Gaseous Diffusion (UF_6)	12,000 t	91
Gas Centrifuge-UF_6 (planned)	10,000 t	75
Fuel Fabrication (fuel elements)	990 t	26
Fuel Reprocessing (spent fuel)	990 t	26
Transuranic Waste Treatment	1,500 m^3	39.5
High Level and Transuranic Geologic Repository	4,000 reference repository years	4,000
Transportation		
Truck	3,528 shipments	1.0
Train	15 shipments	1.0
Barge	5 shipments	1.0
Nuclear Power Plant	1,000 MWe	Electrical production 22×10^{15} J

Source: Ref. B.1.

Table B.2. Air Pollutant Emissions from Nuclear Fuel Cycle

Activity	Pollutant (t/yr for a typical facility)						Comments
	SO_x	NO_x	HC	CO	F^-	Particulates	
Fuel Extraction							
Open Pit Mining	45.0	26.5	1.6	0.1	--	--	
Underground Mining	- - - - - - - - - - - - - - - unavailable - - - - - - - - - - - - - - -						Rock dust from mine vents.
Milling	196.1	84.3	6.9	1.6	--	51.4	
UF_6 Production	797.50	275.0	22.0	5.5	3.0	209.0	
Enrichment	387.0×10^3	101.7×10^3	990	2.5×10^3	45.0	101.7×10^3	Gaseous emissions are primarily from coal-fired power plants required to generate process power.
Fuel Fabrication	598.0	156.0	1.6	3.9	0.13	156.0	
Power Generation	--	--	--	--	--	Acids: 68.67 Chlorides: 0.07 Chromates: 17.01 Organics: 55.02 Zinc: 3.15	
Reprocessing	161.2	184.6	0.52	1.04	2.86	41.6	Approximately 77% of NO_x comes from process emissions.
Transportation	--	2.6	--	--	--	--	To support one power plant.

Source: Ref. B.1 for power generation data and Ref. B.2 for all other data.

Table B.3. Thermal Discharge from Nuclear Fuel Cycle

Activity	10^{12} J/yr Discharged Per Facility	Comments
Milling	385	About 53 x 10^9 J/hr used for process heat is discharged to the air.
UF_6 Production	580	Heat is discharged to the air during calcination operations.
Enrichment	303,866	Half discharged to the air, half to water. 66% of waste heat comes from ancillary power plants.
Fuel Fabrication	2.47	Waste heat from process cooling discharged to atmosphere via cooling ponds.
Power Generation	50,222	Discharged either to air or water via towers and ponds.
Reprocessing	1,673	About 195 x 10^9 J/hr discharged to atmosphere from off-gas stack and cooling ponds and towers.
Waste Management	negligible	High-level radioactive waste generates 2-5 kW of heat discharged to the air.

Source: Ref. B.3 for power generation data and Ref. B.2 for all other data.

Table B.4. Water Pollutant Emissions from Nuclear Fuel Cycle

Activity	Pollutant (t/yr for a typical facility)				
	SO_4^-	NO_3^-	Cl^-	Na^+	Other
Fuel Extraction					
Underground Mining	- - - - - - - - - - - - - - - unavailable - - - - - - - - - - - - - - - - - -				
Milling	--	--	--	--	Tailing solution: 1.27×10^6
UF_6 Production	123.8	2.8	5.5	107.3[a]	F^-: 242.0. Tailing solution: 41.3
Enrichment	486.0	243.0	738.0	738.0	Ca^{++}: 486.0 Fe: 36.0
Fuel Fabrication	--	598.0	--	--	NH_3^+: 260.0 Fluoride: 106.6
Power Generation	--	--	--	--	BOD: 1.89 Boron: 275.10 Chlorine: 22.05 Chromates: 1.89 Phosphate: 34.65
Reprocessing	10.4	23.4	5.2	137.8	--

[a]Contains about 80% potassium.

Source: Ref. B.1 for power generation data and Ref. B.2 for all other data

Table B.5. Solid Waste Generated in Nuclear Fuel Cycle

Activity	Solid Waste (t/yr for a typical facility)			
	Overburden Moved	Tailings	Residual Pollutants	Comments
Fuel Extraction				
Open Pit Mining	14.0×10^6	--	--	During the life of the mine, 144×10^6 t of overburden is moved. Most is returned as backfill.
Milling	--	482.3×10^3	--	Approximately 1600 t/day of solid waste tailings slurried in 4300 t of waste milling solutions are generated by the mill. Tailings are primarily sandstone and clay.
UF_6 Production	--	--	1.1×10^3	Solid chemical effluents containing Fe, Ca, Mg, Cu, F. About 50% of this material is ash produced during hydrofluorination.
Fuel Fabrication	--	--	676.0	CaF_2. Solids remain on site.

Source: Ref. B.2.

Table B.6. Liquid Radwaste System Inputs for a Typical Pressurized Water Reactor

Source	Average Volume[a] (m^3/day)
Containment Building Sump	0.15
Auxiliary Building Floor Drains	0.76
Laboratory Drains and Waste Water	1.51
Sample Drains[b]	0.13
Turbine Building Floor Drains[c]	27.25
Miscellaneous Sources	2.65
Steam Generator Blowdown	0.06% of main steam flow
Detergent Waste (laundry, decontamination, showers)	1.70

[a]From Ref. B.4.

[b] For continuous purge recycle: 0.057 m^3/day.

[c]For once-through steam generator systems, equals 12.1 m^3/day.

Table B.7. Liquid Radwaste System Inputs for a Typical Boiling Water Reactor

Source	Average Volume[a] (m^3/day)
Reactor Building Equipment Drain	7.57
Drywell Equipment Drain Sump	21.96
Radwaste Building Equipment Drain Sump	3.79
Turbine Building Equipment Drains	21.58
Reactor Building Floor Sump	7.57
Drywell Floor Sump	10.98
Radwaste Building Floor Drain	3.79
Turbine Building Floor Drains	7.57
Laboratory Drains	1.89
Condensate Demineralizer Regeneration	6.81
Ultrasonic Resin Cleaning	56.78
Demineralizer Backwash Resin Transfer	15.90
Detergent Waste (laundry, decontamination, showers)	1.70

[a]From Ref. B.4.

Table B.8. Quantities of Solid Wastes Generated per Year by One Nuclear Reactor

Source	Waste Input to Solid Radwaste System	Solid Waste Volume Shipped from Station	Comments
Spent Bead Resins	17-m^3 gross displacement volume (includes 35% void space)	17 m^3	The 17-m^3 shipped volume includes 61.7 m^3 of evaporator bottoms and 4.25 m^3 of solidification agent.
Powdex Resins	17 m^3	22.65 m^3	Shipped volume based on a 3:1 volume ratio of waste to solidification agent.
Evaporator Bottoms	93.59 m^3	122.53 m^3	Shipped volume based on a 3:1 volume ratio of waste to solidification agent. 60 ft^3 of bottoms used to solidify resins was not taken into account.
Filter Cartridges	29 cartridges	29 drums 6.06 m^3	One cartridge per drum.
Miscellaneous Paper, Cloth, etc.	140.45 m^3	28.09 m^3	A volume compaction ratio of 5:1 in baler.

Source: Ref. B.5.

Table B.9. Land Requirements for Nuclear Fuel Cycle

Activity	Land Use (km^2 per facility)			Comments
	Temporarily Committed		Permanently Committed	
	Undisturbed	Disturbed		
Fuel Extraction				
Open Pit Mining	0.8/yr	0.4/yr	0.04/yr	During the life of the mine land disturbed totals 4 km^2. Land covered by overburden storage totals 1 km^2.
Milling	0.01	0.01	0.05	Major portion of undisturbed milling land use is included under fuel extraction.
UF_6 Production	0.25	0.02	<0.01	--
Enrichment	0.22	0.07	0	A total commitment of 6 km^2 can be necessary for a complete gas diffusion complex.
Fuel Fabrication	0.02	<0.01	0	--
Power Generation	--	1.4-4	0.33	Land requirement are 1.4-4 km^2 for a typical power plant.
Transmission	--	0.05 m^2/km	--	345 kV: 45.7-m right-of-way. 500 kV: 53.3-m right-of-way.
Reprocessing	0.38	0.02	<0.01	Exclusion area totals 12 km^2.
Waste Management	--	--	2.59	High-level and transuranic geologic repository.

Source: Refs. B.1 and B.6 for power generation data, Ref. B.7 for transmission data, and Ref. B.2 for all other data.

Table B.10. Electromagnetic Disturbances from Nuclear Fuel Cycle

Activity	Type of Disturbance	Comment
Transmission	Corona discharge, which may result in radio and TV interference, especially in fringe-reception areas.	See Ref. B.1.

Table B.11. Radiological Impacts from Nuclear Fuel Cycle

Activity	Radiation Emissions (curies per facility per year)			Comments
	Air	Liquid	Solid Waste	
Fuel Extraction				
Open Pit Mining	negligible	--	--	Radon and daughters.
Underground Mining	unknown	unknown	--	Contaminated mine drainage and vent releases.
Milling	395	--	3180	Solid waste is buried. Air emissions are primarily Rn-222.
UF_6 Production	0.04	0.27	4.6	Solid waste is buried. Air emissions are uranium. Liquid is primarily uranium and daughters.
Enrichment	0.18	1.8	--	Solid waste is buried. Air emissions are uranium. Liquid is primarily uranium and daughters.
Fuel Fabrication	0.005	0.78	--	Solid waste is buried. Air emissions are uranium. Liquid is primarily uranium and daughters. Liquid release also includes Th-230.
Power Generation	57.01×10^3	214.32	6.0	--
Reprocessing	95.34×10^5	65×10^3	--	Primarily tritium and Kr-85.

Source: Ref. B.1 for power generation data and Ref. B.2 for all other data.

Table B.12. Aesthetic Impacts of Nuclear Fuel Cycle[a]

Activity	Type of Impacts
Mining	Loss of land access until mine is reclaimed.
UF_6 Conversion Enrichment Fuel Fabrication Reprocessing Waste Management	Siting in rural areas.
Power Generation	Visible plumes periodically from stack and cooling towers. Periodic siting in rural, "natural" areas.
Transmission	Unsightly transmission corridors, poles, lines.

[a]Aesthetic impacts may also be components of other impact areas (e.g., land use or air pollution) and are addressed as such in this report.

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APPENDIX C:

ENVIRONMENTAL IMPACT DATA FOR

SATELLITE POWER SYSTEM

*All values have been adjusted from their original units to metric equivalents.

Table C.1. Air Pollutants Generated by SPS Activities

Activity	Units	Air Pollutant Emissions: TSP	SO_2	NO_x	HC	CO	Other		Comments
Mining of Materials									
Silicon process[a]	kg/t solar Si	12.57	--	--	--	--	--		See Ref. C.1.
Gallium aluminum arsenide process	- - - - - - - - - - - - - -	data not available	- - - - - - - - - - - - - -						Arsenic produced mainly as byproduct of metal smelting (copper, lead). All domestic arsenic produced at one mill. Gallium produced as byproduct of aluminum processing or from recycling mine tailings. See Ref. C.1.
Manufacture of Materials									
Silicon cell[b]	kg/t solar Si	113.9	351.8	380.0	5.8	1.0	H_2S	6.8	See Ref. C.1.
							NH_3	0.6	
							Cyanides	1.1	
							Phenols	0.6	
							Pyridine bases	0.004	
Gallium aluminum arsenide cell	- - - - - - -	data limited because of proprietary processes	- - - - - - -						Problems are primarily associated with arsenic handling. Gallium handling is "clean" as it is recycled material (see Ref. C.1).
Aluminum[c]	kg/t	3.62	1.11	0.01	1.16	0.35	Ammonia	0.05	See Ref. C.2.
Steel, silver, molybednum, mechanical systems, electronics[c]	kg/t	1.86	1.11	0.01	1.16	0.35	Ammonia	0.05	
Copper[c]	kg/t	0.81	250.0	--	--	--	--		
Insulation[c]	kg/t	--	--	6.5	3.5	--	--		
Mylar, adhesives[c]	kg/t	3.75	--	--	--	--	--		
Graphite[c]	kg/t	1.75	2.01	0.02	2.1	0.64	Ammonia	0.09	
Glass[c]	kg/t	1.0	--	--	--	--	--		
Gold Kovar[c]	kg/t	1.0	--	--	15.0	--	--		
Black paint[c]	kg/t	6.0	--	--	215	2250	--		
Concrete	kg/t	0.005	--	--	--	--	--		
Cement	kg/t	130	7.82	1.3	--	--	--		
Sand, gravel, aggregate	kg/t	0.05	--	--	--	--	--		
RP-1 fuel[c]	kg/t	0.15	0.02	0.02	1.56	12.71	Ammonia	0.02	
Construction	t/km^2/month of construction activity	269	--	--	--	--	--		Emission rates very poorly known. Very rough estimate. See Ref. C.3.

Table C.1. (Cont'd)

Activity	Units	Air Pollutant Emissions TSP	SO_2	NO_x	HC	CO	Other	Comments
Transportation								
Accidental spills		--	--	--	--	--	Propellants, liquid hydrogen	Emission rates from spills unknown.
Launch and Recovery								
HLLV-booster	t/launch	- - - not available - - -			--	1231	Trace metals (data not available)	TSP results from entrainment of sand and dust into plume. NO_x formation related to afterburning in hot exhaust plume. SO_2, trace metal emissions depend on fuel composition. See Ref. C.4 for CO, Ref. C.5 for NO_x, and Ref. C.6 for trace metals.
PLV		- - - - - - no emission estimates available - - - - - -						Similar to HLLV but smaller scale.
HLLV-orbiter reentry		- - - - - - no emission estimates available - - - - - -						Similar to conventional aircraft except for some NO formation due to aerodynamic heating.

[a]Includes quartzite and coking coal mining. The SPS configuration employing silicon solar cells is not evaluated in this study, but data are included here for use as crude estimates because of lack of information on the gallium aluminum arsenide manufacturing process.

[b]Includes coking coal and cell manufacture. The SPS configuration employing silicon solar cells is not evaluated in this study, but data are included here for use as crude estimates because of lack of information on the gallium aluminum arsenide manufacturing process.

[c]Includes mining, processing, fabrication

Table C.2. Atmospheric Changes Resulting from SPS Activities[a]

Activity	Type of Disturbance	Comments
Microwave Power Transmission	Microwave heating of the atmosphere.	Expected to be negligible (see Ref. C.7).
Launch and Recovery	Deposition of exhaust effluents.	Large quantities of H_2O, CO_2, H_2 deposited in various layers of the atmosphere (see Ref. C.7).

[a]Additional atmospheric changes result from other types of environmental impacts, as noted in Tables C.1 and C.3.

Table C.3. Thermal Discharge from SPS Activities

Activity	Thermal Discharge	Comments
Launch and Recovery		
Rocket exhaust heat	No estimates available.	Creates a buoyant cloud of exhaust effluents.
Satellite	Waste heat discharge.	See Table C.8.
Rectenna	Continuous release of 750 MW of waste heat from a 100 km^2 rectenna.	This rate is approximately equal to that of an average suburban development (see Ref. C.7).

Table C.4. Water Pollution Generation from SPS Activities

Activity	Water Pollutant Effluents							Comments
	Units	BOD	COD	Dissolved Solids	Suspended Solids	Organics	Other	
Mining of Materials	- - - - - - - - - - - known effluents but no numerical data available - - - - - - - - - -							See Ref. C.1.
Manufacture of Materials								
Silicon cell[a]	kg/t solar Si	--	--	--	--	--	Oils and lubricants: 8800 Aqueous Na_2SiO_3: 180	See Ref. C.1. See Ref. C.1.
Gallium aluminum arsenide cell	- - - - - - - - - - - details limited because of proprietary processes - - - - - - - - - -							See Ref. C.1.
Steel	kg/t	--	--	0.071	1.21	0.55	--	See Ref. C.2.
Aluminum	kg/t	0.162	13.7	5.05	--	2.5	--	See Ref. C.2.
Copper	kg/t	--	2.18	--	17.4	--	--	See Ref. C.2.
Cement	kg/t	0.00065	0.00012	0.00706	0.0281	--	Bases: 0.0157	See Ref. C.2.
Transportation								
Accidental spills		--	--	--	--	--	Propellants	Data not available.
Launch and Recovery								
Launch tower cooling water contamination	- - - - - - - - - - - - - - - nature of contaminants unknown - - - - - - - - - - - - - -							See Ref. C.6. Water flow rates estimated as 704 m^3/min for HLLV launch and 97 m^3/min for PLV launch, both sustained for about 30 sec.
Propellant spills	- - - - - - - - - - - - - - - nature of contaminants unknown - - - - - - - - - - - - - -							See Ref. C.4. HLLV carries 7192 t of LOX, 1714 t of CH_4 fuel, and 340 t of LH_2 per launch. PLV carries 1694 t of LOX, 347 t of CH_4 fuel, and 79 t of LH_2 per launch.

[a]The SPS configuration employing silicon solar cells is not evaluated in this study; data are included here for use as crude estimates because of lack of information on gallium arsenide cells.

Table C.5. Water Usage by SPS Activities

Activity	Comments
Mining of Materials	
All materials	Disruption of aquifers and bodies of water dependent on mine location.
Manufacturing	Water use requirements unknown.
Construction	Disruption of aquifers, bodies of water, drainage from large construction projects.
Launch and Recovery	
Cooling of launch tower	High volume flow rate (704 m^3/min for 3 min for HLLV launch) impact on water pressure.

Table C.6. Solid Waste Generated by SPS Activities

Activity	Type of Solid Waste	Comments
Mining of Materials	Mine tailings	Solid waste dependent on mine location.
Manufacture of Materials		
Silicon cells[a]	32 t waste/t solar Si	See Ref. C.1. A 5-GW satellite system would require 13,813 tons of silicon (see Ref. C.4).
Gallium aluminum arsenide cells	4644 t $Al_2O_3{:}3H_2O$/MW cell 32 t other material/MW cell	See Ref. C.1. Aluminum oxide has some other commercial value.

[a]The SPS configuration employing silicon solar cells is not evaluated in this study; data are included here for use as crude estimates because of lack of information on gallium aluminum arsenide cells.

Table C.7. Land Requirements for SPS Activities

Activity	Land Requirements	Comments
Mining of Materials		
Silicon, aluminum, concrete, steel	Significant quantities of land required for mining. Amount depends on location.	See Ref. C.4. One 5-GW satellite requires 14,000 t of silicon, 151,000 t of aluminum, 1.3×10^6 t of concrete, 1.5×10^6 t of steel.
Launch and Recovery	Large launch complex. Range safety buffer zones.	Impact of land use dependent on site location. Kennedy Space Center is 570 km^2 (see Ref. C.8).
Rectenna	79 km^2 for rectenna at equator, as much as an additional 35 km^2 at higher latitudes. Buffer zone for microwave safety dependent on exposure standard. Total land requirement expected to average 200 km^2.	See Refs. C.4 and C.9.
Transmission	Comparable to coal and nuclear. Use of higher-voltage transmission lines likely to have larger land requirements.	

Table C.8. Electromagnetic Disturbances from SPS Activities

Activity	Type of Disturbance	Comments
Launch and Recovery		
Vehicle effluents	Modification of ionosphere electron density. Several hour recovery period. Area of 1000-2000 km around launch site affected (see Ref. C.7).	Very limited data from Skylab launches indicate potentially significant problems (see Ref. C.10). Electron density change can affect communication systems relying on ionosphere.
Satellite	Reflected light	Satellite would be brightest object in the sky next to moon.
	Infrared radiation from rejected waste heat	Satellite would be largest source of far infrared next to moon, although even many satellites would be a small portion of the thermal radiation from the lower atmosphere (see Ref. C.7).
	Formation of clouds of dust, debris, gases in LEO and GEO due to leaks, weathering, construction.	Debris clouds can interfere with radio astronomy (see Ref. C.7).
Microwave Power Transmission	Atmospheric scattering of power beam and pilot beam energy. Coupling microwave energy through power beam sidelobes, harmonics, noise sidebands, and terrain reflections.	Microwave energy can cause interference with a number of electronic systems in the primary frequency (2.45 GHz) and harmonic frequencies. Worst case atmospheric scattering would disperse 38% of transmitted power. Formidable problems expected out to 100 km from rectenna site (see Ref. C.7).
Power Transmission	Corona and high intensity electromagnetic fields.	Interference with electromagnetic systems (see Ref. C.11).

Table C.9. Noise Generation from SPS Activities

Activity	Noise Levels	Comments
Launch and Recovery		
Acoustic launch noise		
HLLV	140 dB at 1.2 km, 109 dB at 30.5 km downrange.	Noise levels higher than those of Saturn V launch vehicle. For Cape Kennedy launch surrounding cities would receive 120-130 dB (see Ref. C.12). Conversion to 24-hr weighted dB(A) would reduce levels by 50-60 dB (see Ref. C.8).
PLV	No estimates available.	PLV is smaller than HLLV. It has approximately one-fourth of the thrust (see Ref. C.4). Noise levels scale approximately with thrust.
Sonic boom	No estimates available.	Space-shuttle data (see Ref. C.8) indicate ascent overpressures of 290 N/m^2 at 60 km downrange, 48 N/m^2 at 85 km downrange. Focal zone overpressures can reach 480-1440 N/m^2 in a narrow range. Booster reentry generates 96-144 N/m^2 at 280-370 km downrange. Orbiter reentry generates a maximum of 101 N/m^2 at 44 km downrange.
Rectenna Operation		
Audible noise from corona near high-voltage transmission lines	345-kV AC lines create only barely audible noise. 745-kV AC lines can create noise that is audible at a distance of several hundred feet in foul weather (see Ref. C.11).	SPS transmission system not yet defined. Early sites will probably be 345 kV or less. Later sites may require higher voltage (745 kV or 1100 kV) or use DC transmission (see Ref. C.13).

Table C.10. Aesthetic Impacts of SPS Activities

Activity	Type of Impact	Comments
Mining of Materials		
Silicon Steel Aluminum Concrete	Unsightly large mines	14,000 t of silicon, 151,000 t of aluminum, 1.3×10^6 t of concrete, 1.5×10^6 t of steel required per 5-GW satellite.
Launch and Recovery	Large launch complex required	
Rectenna	Large facility located in remote areas impacting wilderness or national park areas	
Satellite	Visible in night sky	Other than the moon, satellite would be the brightest object in the night sky (see Ref. C.7).

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