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SATELLITE POWER SYSTEM (SPS) CONCEPT DEVELOPMENT AND EVALUATION PROGRAM PLAN

July 1977-August 1980

February 1978

Prepared By

National Aeronautics and Space Administration
and
U.S. Department of Energy

Assistant Secretary for Energy Technology
Division of Solar Technology
and
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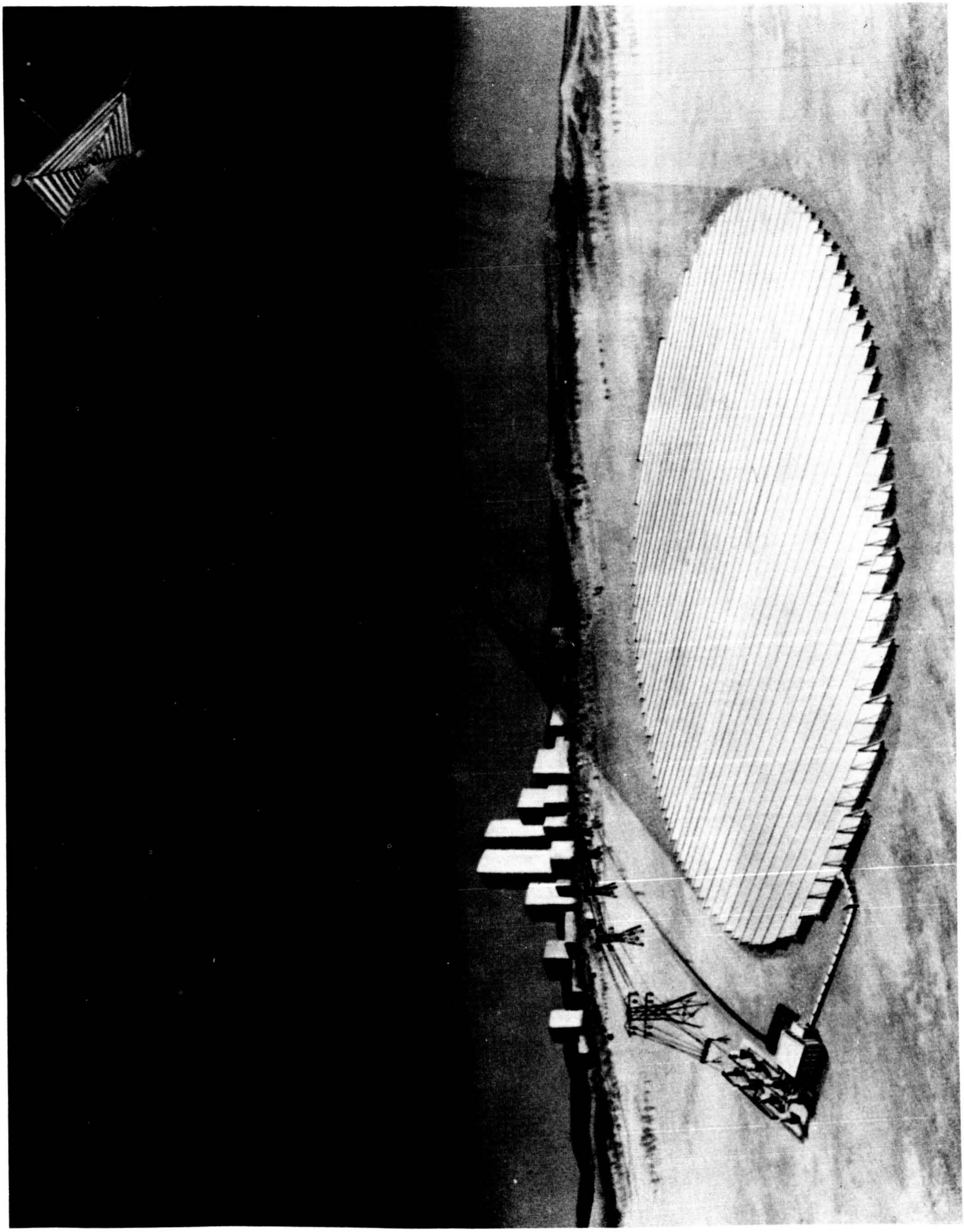

PREFACE

The possibility of generating large quantities of electrical power in space and transmitting it to earth using satellites was first suggested in 1968. Over the next several years, the National Aeronautics and Space Administration devoted several advanced studies to the concept. The energy shortages of 1973 spurred interest in the concept and in early 1976 the Department of Energy (the then Energy Research and Development Administration) established a Task Group on Satellite Power Stations to review past work and to suggest future options.

The Task Group recommended that ". . . an effective program plan be developed which focuses on well-defined objectives, criteria for assessing progress, and relationships among activities and decision points." This document implements that recommendation and, furthermore, rather closely follows a particular option favored by the Task Group in terms of budget, schedule, and major activities.

This is a joint DOE/NASA plan, in both its preparation and implementation. Studies are to be conducted over a three-year period leading to firm recommendations regarding the viability of the concept and the advisability and scope of its continued development. The $15.6 million budget is divided about 60/40 between DOE and NASA although the early part of the program emphasizes NASA activities.

NASA will conduct the systems definition of the SPS; the plan provides for parallel studies at the Johnson Space Center and the Marshall Space Flight Center. DOE will work on environmental, health and safety factors through the Assistant Secretary for Environment (ASEV) and will study SPS economic, international and institutional issues and make comparative assessments of the concept through the Assistant Secretary for Energy Technology (ASET).

This document is a summary and an overview of the program to evaluate the satellite power system concept. It is a revision of the plan issued in May 1977. The scope of this plan has been reduced somewhat compared to the May version; this plan has also been streamlined to emphasize the highlights of the projected work. Detailed implementing plans and statements of work will be prepared as necessary to achieve the objectives and milestones defined herein.

LIST OF ABBREVIATIONS

ASET	Assistant Secretary for Energy Technology/DOE
ASEV	Assistant Secretary for Environment/DOE
COE	Cost of Electricity
DBER	Division of Biomedical and Environmental Research/ASEV
DDT&E	Design, Development, Test and Evaluation
DECT	Division of Environmental Control Technology/ASEV
DOE	Department of Energy
DOES	Division of Operational and Environmental Safety/ASEV
DTO	Division of Technology Overview/ASEV
EIA	Environmental Impact Assessment
EH&S	Environment, Health and Safety
EMI	Electromagnetic Interference
EPRI	Electric Power Research Institute
ERAB	Environmental and Resource Assessment Branch/ASET
ERDA	Energy Research and Development Administration
FCC	Federal Communications Commission
GEO	Geostationary Orbit
GHz	Gigahertz (10^9 cycles per second)
GW	Gigawatt (10^9 watts)
HLLV	Heavy Lift Launch Vehicle
IPTASE	Interagency Panel on the Terrestrial Applications of Solar Energy
JSC	Johnson Space Center

MHD	Magnetohydrodynamics
MPTS	Microwave Power Transmission System
MSFC	Marshall Space Flight Center
MT	Metric Ton (1000 kilograms)
NAE	National Academy of Engineering
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NRC	National Research Council
OAST	Office of Aeronautics and Space Technology/NASA
OEP	Office of Energy Programs/NASA
RD&D	Research, Development and Demonstration
RFI	Radio Frequency Interference
SEB	Source Evaluation Board
SED	Solar Energy Division/OEP
SPS	Satellite Power System

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CHAPTER I

SPS CONCEPT DEVELOPMENT AND EVALUATION PROGRAM

I.1.0 INTRODUCTION

The purpose of this document is to present a program plan to guide the studies necessary to generate the information from which a rational decision can be made regarding the direction of the Satellite Power System (SPS) program after fiscal year 1980. A period of intensified study is proposed to synthesize and extend previous results, to obtain resolutions insofar as possible to several key issues, and to provide an adequate information base from which recommendations for future SPS efforts can be made.

The purposes of this chapter are: (1) to give an overview of the SPS Program Plan, (2) to briefly describe the SPS concept, (3) to outline the management of the program, (4) to list and discuss the key issues to be studied, and (5) to present the approach to be used in the program.

The following sections, taken together, provide an overview of the program plan. Section 2.0 gives the program objectives. Section 3.0 discusses the need for the program and its background including recently completed work. It also gives a thumbnail sketch of the SPS concept as it has been developed so far. Section 4.0 outlines the program management and approach to the planned studies. It lists and discusses the key SPS issues and relates them to the objectives to be accomplished. Specification of the required reports and reviews, the program schedule and the necessary resources conclude the section and the chapter.

Four functional activities are to be undertaken in the conduct of this program: (1) systems definition, (2) evaluation of environmental, health, and safety factors, (3) study of related socioeconomic issues, and (4) comparative assessment of alternative energy systems. The methodology is shown in a highly abstract form in Figure 1. A more detailed program profile is presented in the appendix.

The initial period of study will attempt to synthesize past results particularly with respect to system requirements, technology goals, the status of key issues (especially in the environmental and socioeconomic areas) and systems definition. These activities will be drawn together and integrated to make the baseline concept(s) selection in October 1978 and to propose an experimental research plan to support the selected concept(s). Using the baseline concept(s) as a reference, further systems definition and trade studies will be conducted. Environmental and socioeconomic issues will be evaluated and a comparative assessment of the SPS with alternative energy systems will be made. The results of these studies will be integrated to produce preliminary program recommendations in May 1979 for internal guidance and general publication.

The next study period will further pursue systems definition, environmental/socioeconomic studies, and comparative assessments. The results of these activities will be combined with an updated baseline concept to arrive at program recommendations by each study area in January 1980. These recommendations will be the subject of intensive integration by the SPS Coordinator, working with representatives of all the functional areas, to arrive at final recommendations for submission to the Administration in June, 1980.

On the basis of these recommendations, supported by the integrated results of the study, and considering other pertinent factors, it will be possible for the Administration to either recommend termination of the program or its continuation in accordance with a defined option. This decision is anticipated to occur within three months of the final program recommendations.

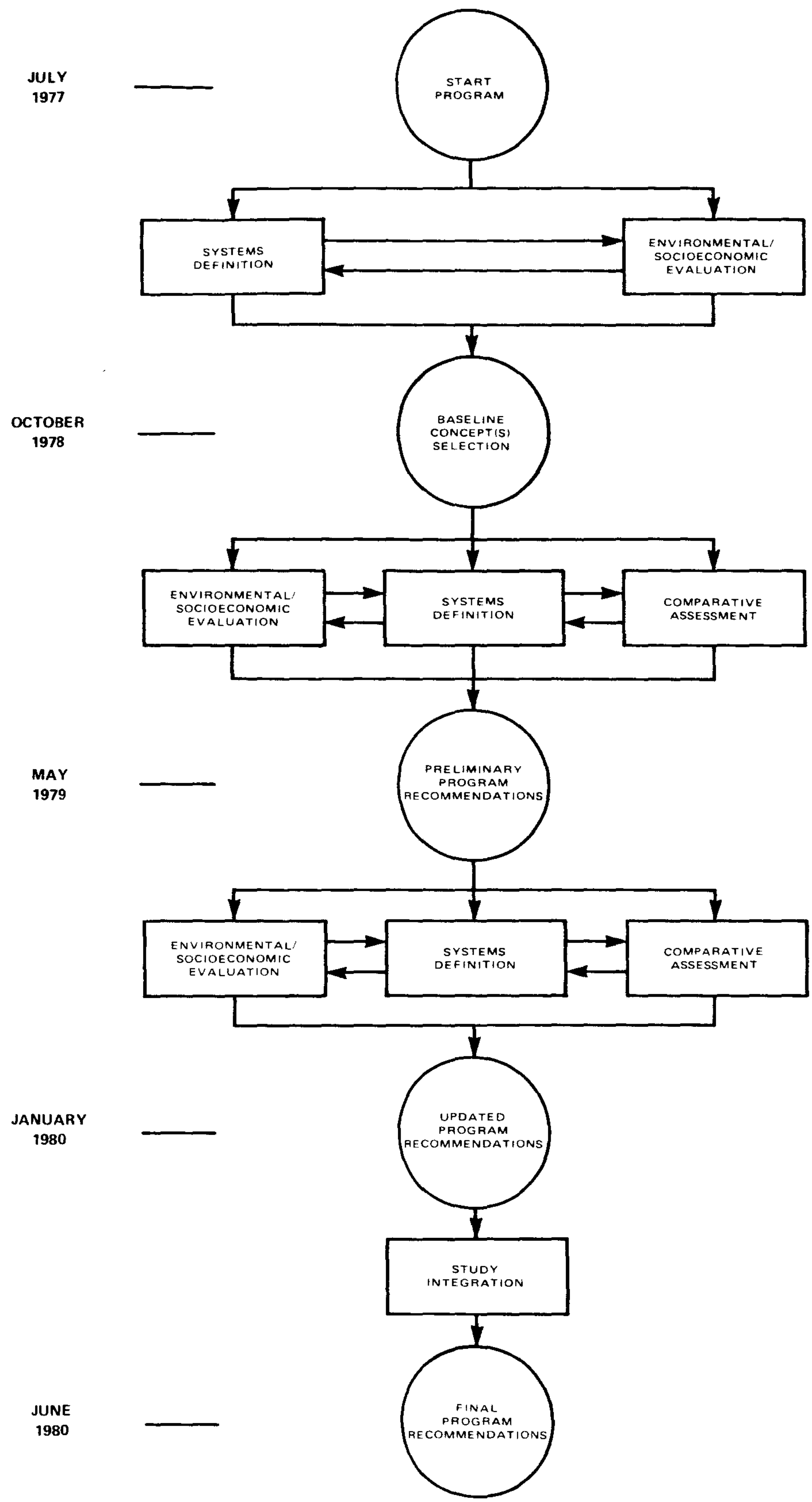

FIGURE 1. SIMPLIFIED DIAGRAM OF SPS CONCEPT DEVELOPMENT AND EVALUATION METHODOLOGY

I.2.0 OBJECTIVES

Objectives have been developed for the overall program and for its primary components as given in the following subsections.

I.2.1 Overall Program

The objective of the joint SPS concept development and evaluation program is to develop by the end of 1980 an initial understanding of the technical feasibility, economic practicality and the social and environmental acceptability of the SPS concept.

I.2.2 Systems Definition

The objective of the systems definition effort is to define a baseline systems concept(s), to evaluate technical feasibility, and to provide the requisite information for environmental and socioeconomic assessments.

I.2.3 Environment, Health and Safety

The objective of this program component is to determine the extent of the potential impact of the SPS on the environment and on the health and safety of the SPS workers and the general public.

I.2.4 Socioeconomic Issues

This program component has as its objective the derivation of realistic cost estimates of the SPS and a delineation of international and institutional problems, including resource constraints and regional impacts associated with its implementation.

I.2.5 Comparative Assessment

The objective of this program component is to compare the SPS with various alternative energy sources.

I.3.0 BACKGROUND

Present electrical energy demand projections coupled with the rapid depletion of oil and natural gas has motivated a search for new, inexhaustible, less polluting energy sources. One concept that has been suggested is the Satellite Power System (SPS). In this concept, very large satellites would be placed in stationary equatorial orbit. The solar energy impinging on the satellite would be converted to electricity and then to microwave energy which would be beamed to the earth and reconverted to electricity for terrestrial distribution. The scope of this concept can perhaps be placed in perspective by considering that the generating capacity of 20-25 of these satellites would be equal to all the electrical power generated in the United States in 1975.*

I.3.1 Need

Several studies have been conducted in the past few years to explore the feasibility of the space power concept. These studies have varied greatly in approach and depth of detail, but they have laid the initial groundwork for SPS systems definition and have tentatively explored the environmental and socioeconomic ramifications of an SPS energy system relative to the projected alternatives. DOE (then ERDA) assembled a Task Group on Satellite Power Stations to survey all recent work and to make program recommendations to the ERDA Administrator.[1,2]**

This program plan implements the major part of those recommendations and incorporates NASA's plan for a satellite power systems program definition,[3] as modified by joint agreement. Basically, a period of intensified study is planned to synthesize and extend previous results to address several key issues already identified, and to provide an adequate information base from which recommendations for subsequent SPS efforts can be made.

I.3.2 Recent and Related Work

The Solar Energy Division (SED), Office of Energy Programs (OEP) at NASA Headquarters, several of the NASA Centers and others have conducted a number of efforts related to satellite power systems both in terms of concept definition and supporting studies. A survey of these studies and an extensive bibliography was prepared under the auspices of the ERDA Task Group on Satellite Power Stations.[2]

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*The Edison Electric Institute estimates total U.S. electricity generation in 1975 as 1916 billion kWh. One 10 gigawatt satellite (the most often mentioned size) could theoretically generate nearly 87.6 billion kWh per year. Therefore, 22 satellites could generate about 1900 billion kWh.

**Superscripts indicate references listed at the end of this volume.

Very briefly, in 1968, Dr. Peter Glaser of Arthur D. Little, Inc. proposed a solar photovoltaic satellite for the generation of power to be used on earth. This concept was developed and refined under a series of studies sponsored by NASA's Lewis Research Center and Marshall Space Flight Center and largely conducted by a team comprised of Arthur D. Little, Grumman, Raytheon, Spectrolab, and ECON. The Boeing Company proposed a solar thermal conversion system as an outgrowth of their work on land-based solar energy systems for ERDA and the Electric Power Research Institute. Boeing was assisted in its studies, which were expanded to include nuclear power generation and reflecting systems, by AiResearch and the Georgia Institute of Technology. Krafft A. Ehricke of Rockwell International first suggested the possible use of power relay satellites as well as nuclear power satellites and large orbiting mirrors to reflect sunlight onto the night side of the earth at selected locations.

In 1976 the Johnson Space Center (JSC) and the Marshall Space Flight Center (MSFC) integrated past results and independently conducted additional engineering, environmental, and economic analyses of the SPS.[4,5] More recent NASA and DOE studies have been conducted under the auspices of this plan. The program management component has sponsored several review meetings and has published "Initial Environmental Guidelines for Satellite Power System Concept Development and Evaluation."[6] Recent systems definition work includes establishment of requirements, completion of initial system tradeoffs, subsystem analyses, and formulation of a preliminary baseline systems concept by both JSC and MSFC. The results of these efforts were presented at a quarterly program review in January 1978. Environmental studies to date have resulted in draft reports covering the bioeffects of low-level microwave radiation,[7] radio frequency interference,[8] and the impact of SPS launch vehicles and microwave power transmission on the ionosphere.[9]

I.3.3 Candidate Orbital Energy Conversion Concepts

It is the function of the orbital system to generate sufficient microwave power to provide approximately 5 gigawatts at each terrestrial rectenna busbar after all losses due to transmission and conversion. Studies to date indicate that there are two basic concepts for the generation of power at geostationary orbits: photovoltaic and solar thermal.

I.3.3.1 The Photovoltaic Concept

This concept features a system that would directly convert solar radiation to electricity by means of large arrays of solar cells. One candidate design consists of a rectangular array several kilometers on a side, with two microwave transmitters (see frontispiece). Reflectors may be used to concentrate the solar radiation onto the cells to reduce the number of cells that are required. The solar collector panels are supported by structures which carry the power to microwave generators for transmission to the terrestrial rectenna. A reaction control system is required to keep the satellite in the appropriate orbit and to assure that the solar collector panels point toward the sun while the microwave antenna is directed towards the receiving antenna on earth.

I.3.3.2 The Solar Thermal Concept

This concept uses huge concentrating mirrors to focus the sun's energy on a cavity absorber which provides high temperature heat (800° - $1100^{\circ}C$) for generation of electricity with some type of heat engine. The heat can be converted to electricity by several methods. The satellite size and attitude control requirements are similar to those necessary for the photovoltaic concept.

I.3.4 Microwave Power Transmission

All SPS concepts presently under consideration use a microwave power transmission system (MPTS) for the transfer of power from space to earth. Microwave technology has the potential for high efficiency, large power handling capability, and precise control. Other technological approaches for the transmission of power are not considered suitable at their present state of development. There are, however, some critical microwave technology items that must be developed if SPS requirements are to be met.

One proposed concept utilizes slotted waveguide subarrays which are controlled to direct the power beam to the ground receiving antenna. The subarrays consist of groups of amplitrons or klystrons to convert dc power to microwave power. The SPS transmitting antenna would be a planar phased array, and the ground receiving/rectifying antenna (rectenna) would consist of dipole elements, each connected to a solid state diode to convert the microwave power back to dc power. The operating frequency would be 2.45 GHz and the overall efficiency (energy delivered to the utility busbar divided by energy delivered to the MPTS) is estimated to be about 60 percent.

The frequency of 2.45 GHz was selected because it (1) is in the USA industrial band and therefore should have minimal problems with respect to allocation and radio frequency interference, (2) results in near-optimum efficiency, and (3) avoids brown-outs in rain.

In the system, the microwave beam travels along a pilot signal emanating from the earth-based receiving antenna and cannot be diverted in a coherent form onto any other area. The microwave beam intensity is designed to decrease from about $23 mW/cm^2$ at its center to approximately $1 mW/cm^2$ at the rectenna edge.

I.3.5 Transportation

Propulsion systems are expensive to develop. They are usually the major component of a vehicle system and considering fuel, comprise the majority of the weight at launch. Therefore, technological advancements in propulsion could substantially improve performance and reduce the cost of placing one of these huge satellites in orbit.

Most SPS researchers consider that a successful program will require a new generation of launch vehicles, including a heavy lift launch vehicle (HLLV) which can place on the order of 500 metric tons into low orbit per launch. This compares to a shuttle capability of about 30 metric tons.

New vehicles to transport system hardware and personnel from low earth orbit to geostationary orbit are also needed. These are known as orbital transfer vehicles; several new approaches to propulsion by both chemical and electrical means are under consideration.

I.3.6 Supporting Terrestrial Systems

The supporting terrestrial systems for any SPS concept fall into three categories, viz,

1. The ground receiving/rectifying antenna (rectenna) and its associated systems, including the interface with the power utility network.

2. The launch facilities required for handling earth to orbit transport for construction, maintenance and resupply, and also for providing the necessary communications and control functions.

3. The industrial facilities required for producing the materials and components that would ultimately be assembled into an operational SPS.

The first category, i.e., the rectenna, has been considered in some detail. Investigations to date have used dipole elements, each connected to a solid state diode to convert the microwave power back to dc power. A typical system would consist of panels in an elliptical array tilted at right angles to the incoming wave-front; it would cover an area of nearly 100 square kilometers.

Launch facility requirements and concepts have not been investigated to any significant degree as yet. Neither have the industrial facilities required for producing the components and materials to be used in the system. However, early consideration of these factors can and should be made, particularly with respect to availability and potential impact on the national economy.

I.4.0 PROGRAM SUMMARY

As shown in the SPS program organization in Figure 2, DOE is the lead agency for overall management of the concept development and evaluation program. Implementation of this SPS Program Plan, however, is a joint responsibility of DOE and NASA. It contains five major elements: (1) the overall program management which is the responsibility of the DOE SPS Coordinator, (2) the SPS systems definition which is primarily a NASA responsibility, (3) environment, health, and safety studies which are the responsiblity of DOE's Assistant Secretary for Environment (ASEV), (4) the study of socioeconomic issues which is the responsibility of the Assistant Secretary for Energy Technology (ASET), and (5) comparative assessment of the SPS with alternative energy systems which is also the responsibility of ASET. Figure 2 outlines the SPS program organization. The responsibilities of NASA, ASEV, and ASET are presented in more detail in the remaining chapters of the plan.

The SPS Coordinator has overall responsibility for the program. Guidelines for conduct of the study are formulated in his office,

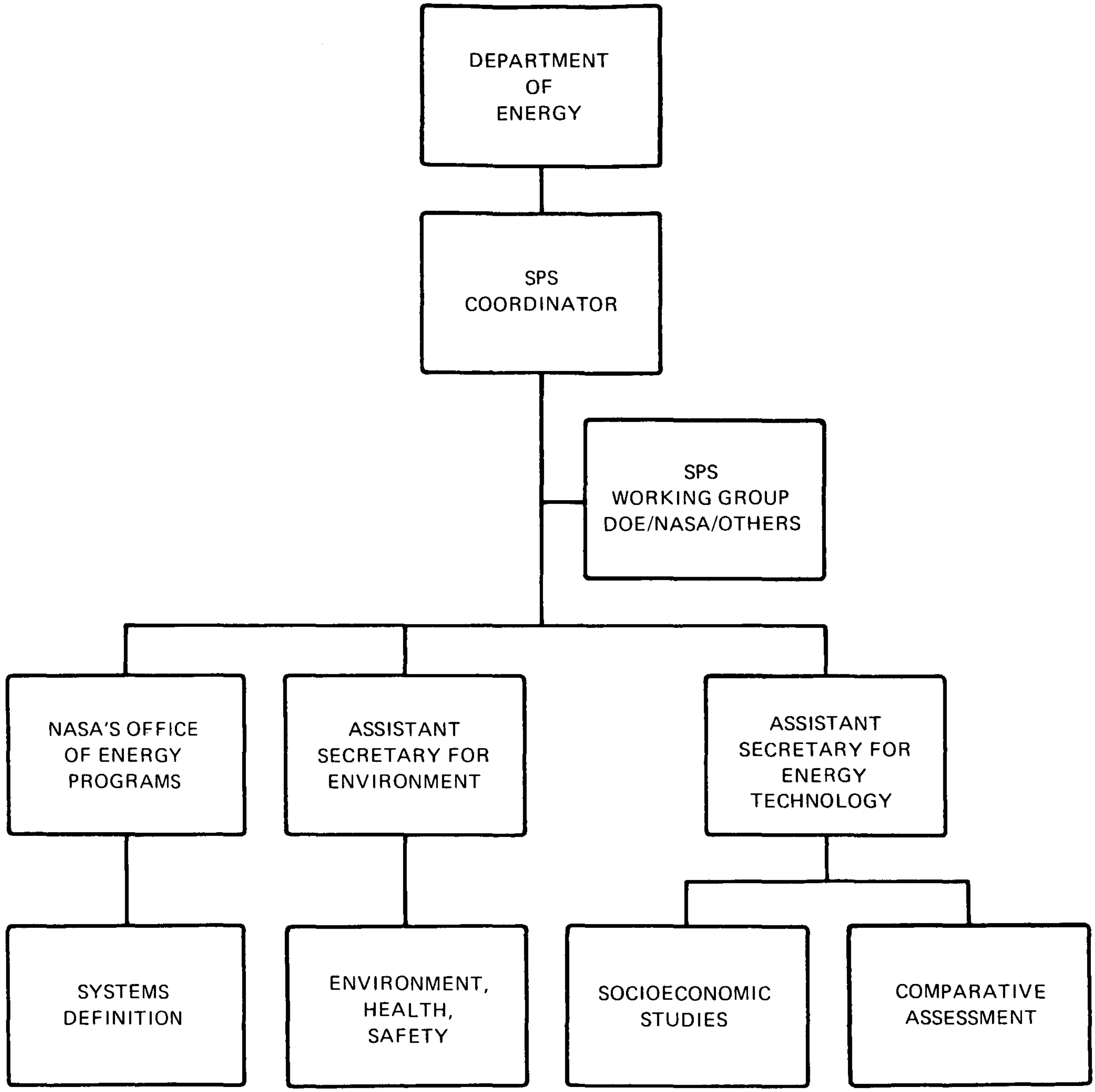

FIGURE 2. SPS PROGRAM ORGANIZATION

for the use of all elements involved in the program. The SPS Coordinator will determine when the work required to achieve each milestone is completed. Study integration for each milestone is accomplished under the supervision of the SPS Coordinator and he will prepare the final program recommendations in conjunction with the SPS Working Group.

The SPS Working Group supports the SPS Coordinator and is made up of senior personnel from both agencies. It monitors the activities carried out under this plan and integrates the results from the performing organizations required to achieve the interim milestones. The SPS Working Group will seek concurrence and additional assistance from outside organizations where that may be helpful.*

DOE and NASA Program Managers will be assigned responsibility for all activities under their respective agency's control. When contracts are entered into for more than $300,000 by either NASA or DOE, the other agency has the option of providing a source evaluation board (SEB) member with full voting privileges to participate in the proposal evaluation process. No contractor representatives will be designated as SEB members. Close coordination will be maintained between the two agencies on all contracts and major modifications.

The plan covers the period from mid-1977 to mid-1980. The driving set of program milestones which guide all substudies and program activities are:

Baseline Concept(s) Selection	October 1978
Preliminary Program Recommendations	May 1979
Updated Program Recommendations	January 1980
Final Program Recommendations	June 1980

The baseline concept(s) selection milestone will focus the evaluation effort in what is considered to be at that time the optimal direction. This will be the responsiblity of the SPS Working Group in cooperation with the SPS Coordinator. Preliminary program recommendations

*Representative organizations include the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), the National Research Council (NRC), the Interagency Panel on Terrestrial Applications of Solar Energy (IPTASE) and the Federal Communications Commission (FCC).

the second milestone, will be basically formulated by the SPS Working Group and presented to the SPS Coordinator using inputs from the systems definition study centers (MSFC and JSC) and the DOE concept evaluation centers. Updated program recommendations, the third milestone, will again be made by the SPS Working Group to the SPS Coordinator and will include all back-up data and information generated during the various studies. The SPS Coordinator will use these inputs to generate his recommendations to the Administration. It is anticipated that the Administration will take these recommendations under advisement and within three months select a course of action regarding the future of the SPS. In the event that a subsequent development program is decided upon, DOE will continue as the lead agency.

Monthly program reviews given to the SPS Coordinator are part of this program plan. Every third month the program reviews will emphasize NASA's systems definition activities. The following month ASEV activities will be emphasized and the third month will be devoted to ASET activities. This cycle will be repeated throughout the program. Special reviews will be held at the direction of the SPS Coordinator. The general intent of the management system is to facilitate the free and timely flow of information between all participating elements of the program in each agency. Furthermore, it is the policy of the SPS program that all relevant documentation be accessible to both the DOE and NASA study teams irrespective of the origin of the documentation. Copies of contracts, correspondence and reports not routinely made available as part of the periodic program reviews will be made available upon request. Personal contact as needed will be strongly encouraged.

The SPS Working Group will perform a continuous technical evlauation of results obtained by the two agencies and advise the SPS Coordinator of changes in study emphasis that might be desirable. The SPS Working Group will have access to all relevant documentation and, with the approval of the SPS Coordinator, may contact principals involved in the program for clarification of technical findings.

A large proportion of the work specified in this program plan will be carried out by the various NASA Centers under NASA Headquarters management or, in some cases, directly under DOE management. Where NASA

Centers are participating in DOE managed projects, the general technical and management procedures established by the ERDA/NASA Memorandum of Understanding[10] will apply. Specific procedures will be established in particular interagency agreements formulated to acquire the necessary NASA SPS program support. NASA Centers participating in NASA managed projects will use normal NASA management procedures.

All participating organizations will submit project reports to support the first three milestones shown in Figure 1. Special reports or assistance to the SPS Coordinator may also be required in the accomplishment of the last two milestones.

Interim progress reports, limited to documentation presented for the quarterly reviews, will also be required. The presentation format will be established by the NASA and DOE program managers with assistance from the SPS Coordinator as required.

A final report will be prepared by the SPS Coordinator subsequent to submission of the updated program recommendations by the performing organizations and presented to the Administration for their use in determining future SPS activities.

	TOTAL FUNDING IN THOUSANDS OF DOLLARS Fiscal Year				
	1977	1978	1979	1980	TOTAL
Systems Definition	1,800	1,700	1,300	800	5,600
Space Related Technology	700				700
Environmental Factors	220	1,940	2,050	1,740	5,950
Socioeconomic Issues	164	537	537	322	1,560
Comparative Assessment	95	376	754	565	1,790
TOTAL	2,979	4,553	4,641	3,427	15,600

CHAPTER II

SPS SYSTEMS DEFINITION PLAN

II.1.0 INTRODUCTION

A number of system studies have been conducted in an attempt to clarify the feasibility and potential of the SPS concept.[11-16] Rather than converging on a particular form, however, the studies have suggested a number of alternative physical arrangements at both the system and subsystem levels. At the system level, for example, the sheer scale of the required photovoltaic array structure has resulted in suggestions that the SPS concept might better be based on a solar thermal cycle. At the subsystem level, the problems of power management and attitude control across a very large photovoltaic array have resulted in a number of proposed array configurations. These alternative array concepts embody different means for conducting power from the sun-pointing collector to the earth-pointing arrays and pose significantly different requirements on array assembly, stabilization and station keeping.

This divergence and resultant uncertainty leads to the two primary thrusts of the technical plan for systems definition presented herein:

(1) the need to converge on the most promising SPS concept and systems configuration, and

(2) the definition of the research, technological and economic goals that must be achieved for that concept to be technically feasible and to become economically viable in the post-2000 time period.

II.2.0 OBJECTIVES

The primary objectives of the systems definition effort are: (1) to identify and define the most attractive SPS concept(s); (2) to specify the technology and cost goals to be achieved for the SPS to be technically feasible and economical in construction and operation, (3) to assess the technical uncertainties in an SPS development program; (4) to provide a quantitative basis from which the environmental and socioeconomic implications of the SPS may be evaluated; (5) to establish an information base for management decisions related to program direction; (6) to formulate an experimental research plan to support the system design, and (7) to provide technology advancement plans for SPS follow-on options.

II.3.0 TECHNICAL PLAN

Figure 1 of Chapter I provides a guide to the sequence of events specified in the systems definition plan. It also indicates other SPS program activities as they interact with the systems definition efforts. Progressive milestones are defined at which time it is anticipated that management will have sufficient information available to determine the appropriate direction of further program activities. More detail is given in the appendix to which the following discussion is keyed.*

The sequence begins with the establishment of top level systems requirements such as the number of satellite power stations, the generating capacity of each station and the number and approximate location of ground receiver sites. These requirements form the basis for the analyses leading to the definition of conceptual systems.

The subsystem requirements are then established and candidate subsystems defined. Design and cost analyses are performed on these subsystems to derive a preliminary baseline system concept(s) including the satellites, their mode of deployment and the required space transportation and ground system configuration. This preliminary baseline system concept(s) serves as a reference for the DOE studies and allows refinement of the

*The appendix is a fold-out chart which, when opened, shows the SPS program profile from January 1978 to June 1980. Opening the chart now will enable the reader to relate the discussion of systems definition activities to the detailed program profile.

methodologies for assessing the environmental impacts and the economic and comparative assessments of candidate concept(s). Recommended preliminary baseline system concept(s) were presented at a review meeting in January 1978 as shown in the appendix.

Subsequent efforts will refine the subsystems and cost analyses. A detailed analysis will be undertaken to formulate and refine the methodologies for estimating system development costs, operating costs and net energy costs. These methodologies will permit the baseline system to be designed to cost as well as to technological goals, and will permit comparisons to be made between SPS and conventional energy systems. The results will be integrated with the results of the DOE studies to permit the selection of the initial baseline system concept(s). The results of the baseline systems definition studies at this point will include: (1) technological goals at the system and subsystem levels necessary for concept feasibility, (2) an initial assessment of technological uncertainty (i.e., the ability to achieve technological goals in time to support a system development program), and (3) an initial estimate of system cost.

Concurrently, an experimental research plan will be defined to provide the experimental data needed to verify critical analytical assumptions and projections used in this selection. The experimental research itself will be scheduled so that results will be available for subsequent technical feasibility assessments.

The next phase of the systems definition studies will evaluate the system requirements against the key issues identified in the DOE's preliminary environmental impact assessment. The system requirements will be updated and further system and subsystem definition and cost analyses will be performed to derive a preferred baseline concept(s). This concept(s) will be evaluated against the DOE baseline environmental impact assessment and will enable preliminary program recommendations to be made. The recommendations will basically indicate areas that require further study.

Study of these areas will lead to a set of updated program recommendations. These studies will examine, in greater detail than was possible before the preliminary program recommendations, such special problems as orbital assembly, maintenance and operations, power management on the ground at the electric grid interface and a variety of system sensitivity and tradeoff studies. Selected system studies will also provide an opportunity for detailed sensitivity and tradeoff analyses of the high risk elements of the system. The study results will then be evaluated by means of a requirements redefinition and a concept reassessment. The latter effort will also assimilate the results of NASA's basic studies in space technology and DOE's studies in environmental/socioeconomic areas to provide a more refined assessment of the technical feasibility and economic viability of the SPS. A technology advancement plan (possibly containing several options) will also be prepared in this study phase. The updated program recommendations and documented results prepared by NASA will be integrated by the SPS Coordinator to arrive at a set of final program recommendations.

This systems definition plan involves numerous interactions with other SPS program activities and includes conceptual iterations as the results of other activities become available. Its structure provides flexibility within this time period for exploring reasonable alternatives for implementing an SPS. The comprehensiveness of the systems definition is further increased by the parallel systems definition studies being performed at two NASA Centers: Johnson Space Center and Marshall Space Flight Center.

II.4.0 MANAGEMENT

This section describes the approach to be used in managing those program elements for which NASA has primary responsibility.

The Office of Energy Programs (OEP), Office of Aeronautics and Space Technology (OAST) is responsible for overall coordination of NASA activities in support of the SPS systems definition effort. Within the OEP this responsibility is assigned to the Solar Energy Division (SED).

In exercising its responsibilities, the SED is the prime point of contact for programmatic coordination between DOE and all participating NASA organizations. Since the overall program is a joint DOE/NASA venture, special attention must be given to the necessity for coordination with DOE. The Johnson Space Center and the Marshall Space Flight Center support the SED in this activity. The Centers work in parallel -- each is charged with investigating the overall system concept. Both Centers have established SPS Study Teams within their program development organizations to manage in-house and contracted activities.

Within NASA the principal mission assignments of JSC and MSFC incorporate the capabilities required for definition of the SPS. Assignments include the development of manned spacecraft and manned flight operations, the development of major propulsion systems, space structures and materials, space processing and energy programs. Each Center's in-house and contracted activities are arranged into increments which parallel the program development methodology of Figure 1. The first increment focuses on analyses, data development and comparative assessment of overall SPS concepts while the second involves more detailed analyses of selected elements of the SPS. The managers of the SPS study teams represent the single authority for all of the Center's systems definition activities. They are responsible for contracted studies and for coordination and integration of other supporting factors. They bear a special responsibility for inter-Center coordination.

The two systems definition Centers have established liaison teams to interface on a day-to-day basis with cognizant DOE organizations. Individuals within these teams are charged with specific technological areas for external coordination. These individuals are the prime points of contact between outside organizations and their internal technical specialists and supporting contractors.

The Solar Energy Division provides programmatic liaison and coordination between DOE and NASA for all areas. Within the SED the SPS Systems Definition Program Manager has overall management responsibility for direction of the NASA SPS study activities at JSC and MSFC.

II.5.0 SCHEDULE

The overall schedule for the conduct of the systems definition program was presented in Figure 1 together with the major program milestones supported by the effort. Major program reviews and reports related to baseline concept(s) selection, preliminary program recommendations and updated program recommendations will occur one or two months prior to these milestones. Working reviews have been scheduled to support these major milestones.

Formal reviews of the systems definition efforts, by both JSC and MSFC, will be held on a quarterly basis. The reviews will be presented to NASA's Systems Definition Program Manager and form the basis for presentations to the SPS Coordinator. Interim progress reports by the systems definition Centers will be limited to documentation presented in the quarterly reviews. The Centers will, however, prepare three project reports as follows:

- Baseline Concept(s) Selection
- Preliminary Systems Definition Program Recommendations
- Updated Systems Definition Program Recommendations

These reports will be approved by the Systems Definition Program Manager and submitted to the SPS Coordinator to mark the accomplishment of the corresponding milestone on the part of the systems definition Centers.

II.6.0 RESOURCES

The following table gives a brief summary of the resources allocated to the NASA managed studies defined herein.

	1977	1978	1979	1980	TOTAL
	FUNDING IN THOUSANDS OF DOLLARS				
Systems Definition					
JSC	900	850	650	400	2,800
MSFC	900	850	650	400	2,800
Space Related Technology	700				700
TOTAL	2,500	1,700	1,300	800	6,300
	MANPOWER IN MAN-YEARS				
Systems Definition					
JSC	34	25	20	15	94
MSFC	25	31	20	15	91
TOTAL	59	56	40	30	185

II.7.0 SUMMARY REMARKS

The systems definition plan has been developed to provide management insight at several key points during the program. At each milestone it will be possible to assess major problem areas, placing management in a position to exercise alternative program options if deemed necessary.

At the end of the systems definition effort there will exist:

- A reference "baseline" conceptual system design.
- An experimental research plan.
- A preferred system design
- An assessment of that design from the perspective of technological advancement and technological uncertainty.
- Technology advancement plans to provide a framework for any follow-on effort.

CHAPTER III

SPS ENVIRONMENT, HEALTH AND SAFETY PLAN

III.1.0 INTRODUCTION

The implementation of any system (or mix of systems) to provide large quantities of electrical power with respect to total projected demand will have an impact on the environment. The SPS is no exception. Factors of interest are the general health of the public and the safety of the workers required to build, operate and maintain the system. A plan for dealing with these factors, as they pertain to the SPS, is contained in this chapter. The plan also treats environmental impacts such as potential atmospheric alteration, radio frequency interference, and the modification of ecosystems.

It is convenient to consider environmental, health and safety (EH&S) factors in four categories.

- Terrestrial Operations
- Launch, Flight and Recovery Operations
- Space Operations
- Microwave Power Transmission

The SPS may impact several layers of the atmosphere. A simplified schematic of these layers, discussed primarily in this section, is given in Figure 3.

III.2.0 OBJECTIVES

The primary objectives of the EH&S effort are (1) to determine if any of the potential environmental health and safety effects (particularly those arising from microwave radiation and launch vehicle emissions) are so severe as to preclude development of an SPS energy system, (2) to provide

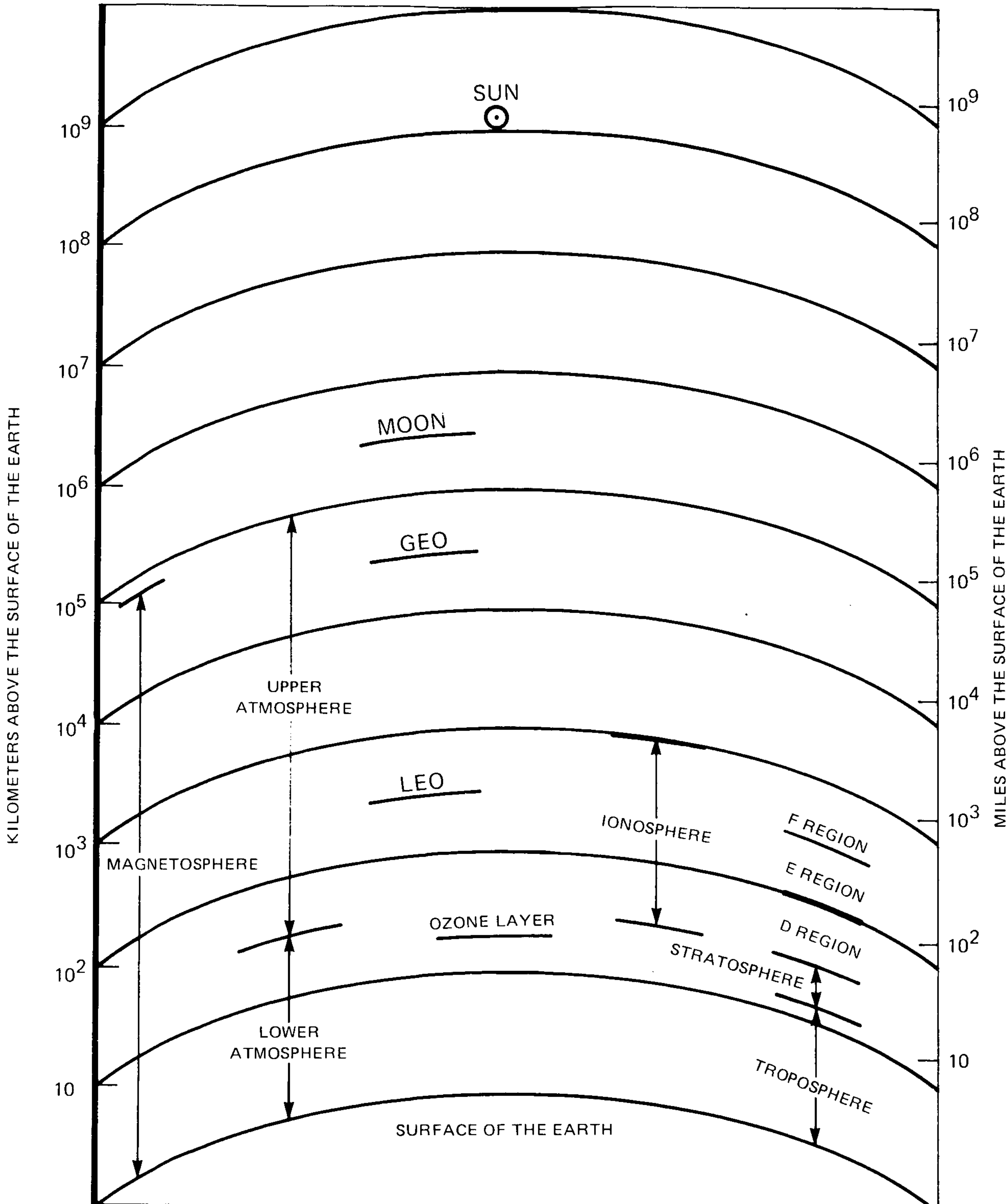

FIGURE 3. APPROXIMATE LOCATIONS OF ATMOSPHERIC REGIONS DISCUSSED IN TEXT

an environmental impact assessment (EIA), and (3) to establish an information base to be used in comparative evaluations.

III.3.0 TECHNICAL PLAN

The SPS concept evaluation methodology, shown schematically in Figure 1 (and in more detail in the appendix) provides a general guide to the sequence of events in the EH&S plan. The figure illustrates the interaction with the systems definition activity and shows the study integration periods and major milestones. Prior to the first milestone (baseline concept(s) selection) a preliminary environmental impact assessment (EIA) is to be prepared. Prior to each subsequent milestone the EIA is to be improved upon to the extent possible, but all identified environmental concerns are to be addressed at each milestone.

The potential environmental impacts of the SPS are among the principal determinants of its viability. The design of the SPS will determine the nature and extent of these impacts so until a baseline concept(s) is arrived at by the systems definition Centers, the study of EH&S factors will be rather generic. As the system becomes better defined, the EH&S studies will become more specific.

Key environmental, health and safety issues are listed on the following page, followed by a discussion of the planned treatment of the issues in each of the four categories. The discussion is keyed to Figure 1 and the appendix.*

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*The appendix is a fold-out chart which, when opened, shows the SPS Program profile from January 1978 to June 1980. Opening the chart now will enable the reader to relate the discussion of EH&S activities to the detailed program profile.

Terrestrial Operations

- Public Health Impacts from Processing Emissions Effluents
- Worker Health and Safety

Launch, Flight and Recovery Operations

- Impact on Public Health of Chemical Pollutants in the Atmosphere
- Impact on Stratosphere (Ozone Layer) and Ionosphere of Propellant Residues
- Launch and Recovery
  - Public Health, Welfare and Safety Impact
  - Worker Health and Safety

Space Operations

- Effects on Ionosphere and Magnetosphere of Chemical and Ion Emissions from Propulsion and Control Systems
- Worker Health and Safety
  - Space Environment
  - Construction and Operation

Microwave Power Transmission

- Direct Public Health Impact from Microwave Radiation
- RFI with Terrestrial and Other Spaceborne Electronic Systems
- Microwave Beam Interaction with Ionosphere and Magnetosphere
- Microwave Radiation and Rectenna Construction and Operation Effects on Terrestrial Ecology
- Microwave Beam Climatological Effects and "Heat Island" Effects of Thermal Radiation at Rectenna Sites
- Microwave Frequency Allocation
- Microwave Exposure Standards

III.3.1 Terrestrial Operations

The environmental impacts of terrestrial operations arise from (1) the extensive extraction of necessary minerals, (2) the manufacturing of SPS components and supporting equipments, (3) the transportation of both raw materials and manufactured products, and (4) the construction of ground-based facilities. Pollution affecting public health, land use problems, and worker safety hazards are all possible from these activities.

Work in this area will begin by explicitly identifying and characterizing the terrestrial operations that have a potential for causing a substantial impact on the environment. These will be delineated in a program assessment/environmental factors report. The preliminary environmental impact assessment (EIA), to be issued prior to the baseline concept(s) selection, will provide the best assessment possible of the magnitude of the identified impacts, particularly with respect to public health, and will identify the additional effort required to satisfactorily assess terrestrial operations. The baseline EIA, prepared prior to preliminary program recommendations, will emphasize the consequences of identified worker health and safety hazards and will attempt to determine and rank their probabilities. The final EIA will be prepared prior to final program recommendations. It will, for each environmental issue identified, evaluate (1) the magnitude of its potential impact, (2) its significance, (3) the acceptability of its associated consequences, and (4) the feasibility of mitigation measures.

III.3.2 Launch, Flight and Recovery Operations

The launch scenarios for establishing an SPS energy source call for a higher order of space transportation activities than all the current and past space programs put together, including the space shuttle. Thus, a major thrust of the program plan in this area is to assess the effects of chemical pollutants and noise generated by SPS launch vehicles on public health and welfare. Another major thrust of the plan is to assess the effect of intensive space transportation activities on the outer atmosphere. Also to be assessed in this area are the health and safety of the workers associated with the launch and recovery facilities, including the crews of the vehicles used to achieve low earth orbit.

Again, the initial studies will be generic in nature and will focus on defining launch scenarios and their more obvious environmental impacts. As the space transportation system becomes better defined, the assessments will become more detailed and will, for example, consider the residues from specific propellants at various levels of the atmosphere. Also, effects of noise and propellant residues on specific communities in candidate areas will be assessed. Toward the end of the three-year study period, indirect effects such as intake of pollutants in the food chain and possible synergistic and cascading interactions with other pollutants and constitutents of the troposphere will be evaluated.

The ozone layer is of particular interest. Past work in this area will be reviewed and once propellants and launch rates and locations are established, studies of both the short-term and long-term implications will receive increasing attention. By the end of the study period, the indicated effects will be assessed to determine if they would affect observable terrestrial phenomena such as incident ultraviolet radiation.

The early phase of the study will identify worker hazards; later phases will evaluate the significance and probability of these hazards. The final phases of the study will consider mitigating measures for all identified impacts, as necessary, and will attempt to quantify their potential effectiveness.

III.3.3 Space Operations

Space operations include the unloading of materials in low earth orbit (LEO), construction of assemblies for use in LEO and for use at geostationary orbit (GEO). The movement of men and supplies between LEO and GEO is another space operation as are parallel activities at GEO. Maintenance of the completed satellites, crew stations and interorbital vehicles is yet another component of space operations. From the EH&S perspective there are two critical issues. First, is the health and safety of the space workers. Second, is the possible impact on the upper atmosphere (especially the ionosphere) from the various propellants used in transportation and attitude control.

The initial phases of the study will concentrate on the definition of problems. It will, of necessity, devote considerable time and effort to the workers' environment and responsibilities. Potential hazards to be studied are natural radiation, space debris, plasmas and meteoroids. In constructing and maintaining the satellite particular attention will be given to the hazards arising from the primary microwave radiation and high voltage sources on the satellite.

Other problems addressed in this work area include effects of SPS-related orbital emissions on the ionosphere and magnetosphere. A wide variety of emission rates will be established as early in the study program as systems definition inputs will permit. These include the satellite propulsion, attitude control and antenna configuration control emissions, the propulsion and attitude control emissions from interorbit vehicles, and those required by the workers themselves. Once defined as to kinds and quantities, their interactions with the ionosphere and magnetosphere will be assessed and implications for terrestrial phenomena will be evaluated. Additionally, the effect on the magnetosphere of the continuous physical "sweep out" of its plasmas by the many large satellites in this system will be investigated.

III.3.4 Microwave Power Transmission

A most significant area of concern is that of the microwave radiation of power central to the operation of the SPS. Considerable uncertainty exists as to the effects of such radiation on the atmosphere and ionosphere, and on organisms, including man, that may be irradiated. Effects on climate due to the radiation and to the waste heat produced at receiving sites are also of concern. In addition, radio frequency interference (RFI) from the microwave radiation on terrestrial communications and other electronic systems appears to be a very important consideration.

Biological effects of continuous low-level microwave radiation, for obvious reasons, require particular attention. There is, unfortunately, a present lack of agreement internationally (and within the U.S.) on acceptable levels for human exposure to microwave radiation.* Resolution of, and agreement on an appropriate exposure standard is most desirable because:

- The exposure level is a determinant of the size of the exclusion area around the rectennas.
- An internationally recognized standard would increase the international acceptability of the SPS generally, and might help to permit the use of microwave energy as an exportable item specifically.
- If exposure standards differ, it is unlikely that foreign populations, or even the U.S. population, would accept the higher exposure level unquestioningly, while other major countries restrict exposure to much lower levels.

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* Chapter 6, "Safe Exposure Limits and Prevention of Health Hazards," in the book Biological Effects of Microwaves by S. Baranski and P. Czerski (Dowden, Hutchinson & Ross, Inc., by 1976) is a clear and comprehensive treatment of the various standards found in the U.S. and throughout the world. Waving aside the subtleties in interpretation, standards for maximum levels of long-term microwave radiation can be found which vary from 10 to 10,000 microwatts per square centimeter.

The first activity in this work area will be to assemble information on completed and on-going studies of direct interest to the SPS. This information will be useful in its own right and will indicate the most promising direction for the application of SPS resources in this area. Contacts, cooperation and formalized means of information exchange will be established with other researchers working in this area at the first available opportunity. These contacts will be maintained throughout the study program. There will also be frequent interchange within the SPS program between the microwave contingent and those working in the area of international impacts. The latter group is responsible for studying the political problems involved in reaching agreements on microwave frequency allocations and microwave exposure standards.

In assessing the direct public health impact of microwave radiation, it will first be necessary to establish a pattern of anticipated radiation levels outside the rectenna areas. Initially, attention will be focused on a single rectenna, later the cumulative effects of all rectennas will be studied. The effects of the anticipated radiation levels on the public, if any, and the terrestrial ecology in the vicinity of the rectennas will be determined based on the best available data. The opinions of recognized experts, both U.S. and foreign, will be actively solicited and incorporated in the analysis.

The initial efforts in the study of radio frequency interference will include establishment of a list of all electronic systems operating in microwave bands near the SPS transmission frequency and its principal harmonics. The impacts of the satellite transmission (and the direct and indirect rectenna radiation) will be assessed and means for mitigating the impacts will be evaluated including a cost analysis. Particular attention will be given to the cumulative effect of the maximum number of transmitting satellites as provided by the systems definition.

A survey of the known or hypothetical interactions of microwave radiation and the ionosphere will be undertaken early in the study program. Efforts will be made to determine the short-term and long-term effects of a beam of the proposed intensity passing through the ionosphere and the cumulative effect of large numbers of beams will also be assessed. The feasibility of an experiment to answer questions in this area will be investigated prior to the baseline concept(s) selection milestone. Effects on other layers of the atmosphere will also be investigated and their potential impacts assessed.

Climatological effects will be established by first investigating the local heating of the ground and atmosphere that could arise from the excess heat radiated from a receiving facility. Direct heating of the atmosphere (especially the troposphere) will be estimated and the resultant effect on the climate assessed. Indirect effects on the climate due to beam interaction with the ionosphere and magnetosphere will also be assessed. As required and feasible, mitigating measures will be evaluated, particularly for rectenna thermal radiation effects.

During the study period alternatives to the tentative SPS frequency of 2.45 GHz will be investigated. A technical and environmental rationale will be developed to justify the nominal frequency selected. The technical and environmental problems associated with various proposed microwave standards will be delineated and tradeoffs conducted to determine a reasonable compromise.

III.4.0 MANAGEMENT

The program elements within the Environment, Health and Safety (EH&S) area are the responsibility of the Office of the Assistant Secretary for Environment (ASEV), Department of Energy (DOE). This section describes the approach to be used in managing these program elements.

An ASEV-SPS task group will be responsible for insuring that the EH&S portion of the SPS program is carried out. The task group will be headed by the Program Manager for Solar Programs, Division of Technology Overview (DTO), and will consist of representatives from the Division of Biomedical and Environmental Research (DBER), the Division of Environmental Control Technology (DECT) and the Division of Operational and Environmental Safety (DOES).

The Program Manager for Solar Programs/DTO is responsible for overview and coordination of all ASEV/EH&S activities. He is the prime point of contact in ASEV for programmatic coordination between the Office of ASET and all NASA organizations. He has the responsibility for coordinating the development of detailed plans, conducting assessments of SPS impacts on the environment and public health, providing interpretation of the results from research and assessment into ASEV-SPS program reports, and representing the ASEV at program reviews.

The representative from the DBER, DOES and DECT are responsible for developing detailed work plans; selecting, initiating, funding and managing projects in support of environmental and health research, operational health and safety assessments and assessments of environmental control options; and for providing reports to DTO for programmatic integration.

Once the detailed plans are formalized funding authority for EH&S activities will reside with the ASEV.

Determination of the potential EH&S impacts depends to a large extent on the NASA systems definition efforts. A timely flow of information between the ASEV and NASA is therefore a prerequisite to a successful study. All reports and copies of contracts and correspondence will be made available by ASEV to appropriate offices in other SPS organizations without restriction. In addition, every attempt will be made by program and project management within ASEV to make use of pertinent studies completed or underway within organizations outside the DOE and NASA, both public and private.

III.5.0 SCHEDULE

The overall schedule for the conduct of the environment, health and safety program was indicated in Figure 1 together with the major program milestones supported by the effort. More detail is given in the appendix. Major program reviews and reports related to environmental impact assessments (EIAs) will occur in one or two months prior to these milestones. Formal reviews of EH&S efforts will be held on a quarterly basis. Interim progress reports by EH&S will be limited to documentation presented in the quarterly reviews. The presentation format for these reviews will be approved by the SPS Coordinator.

The EH&S Program Manager will prepare integrated inputs to the four Environmental Impact Assessments defined in the appendix:

- Program Assessment/Environmental Factors
- Preliminary EIA
- Baseline EIA
- Final EIA

A final report will be prepared by a DOE/NASA Task Force under the direction of the SPS Coordinator subsequent to completion of the final EIA.

III.6.0 RESOURCES

The following table gives a brief summary of the resources alloted to the ASEV managed studies defined herein:

	FUNDING IN THOUSANDS OF DOLLARS				
	1977	1978	1979	1980	TOTAL
Terrestrial Operations	-	150	150	150	450
Launch, Flight & Recovery Operations	20	400	520	460	1,400
Space Operations	50	250	250	250	800
Microwave Power Transmission	150	1,140	1,130	880	3,300
TOTAL	220	1,940	2,050	1,740	5,950

III.7.0 SUMMARY REMARKS

The environment, health and safety plan has been developed to provide management insight at several key points during the program. At each milestone, it will be possible to assess major EH&S problem areas, placing management in a position to exercise alternative program options, if deemed necessary.

At the end of the EH&S effort, there will exist:

- A comprehensive EH&S evaluation of the preferred system concept
- Recommendations for additional study

CHAPTER IV

SPS SOCIOECONOMIC STUDY PLAN

IV.1.0 INTRODUCTION

In addition to its interactions with the physical environment, the SPS will strongly involve important aspects of society, its institutions and its resources.

The SPS will have a highly visible and extensive impact on the utilization of land and mineral resources in the United States. It will take substantial quantities of energy to implement the system, and the capacity of certain types of industrial plants may be severely strained.

These considerations lead to the subject of SPS economics. In addition to the satellite and rectenna there is also the question of the economics associated with the space transportation system and its potential alternate uses (and hence cost sharing). A whole new industry for "space construction" must be developed. Substantial operation and maintenance costs can be anticipated. Perhaps most crucial to the entire discussion of system economics is the large cost, and required financing, associated with design, development, test and evaluation (DDT&E) of the system before any power is generated. Securing the large financing required for the project could make difficult the capitalization of other needed projects.

Problems and time delays can be anticipated in forging the necessary agreements with foreign powers. Operating principles that will be in consonance with the rights of all people and that will distribute costs and benefits in an equitable manner may be extremely difficult to establish. To undertake a systematic study of these, and related SPS issues, they have been grouped into six categories: (1) land use, (2) resources, (3) economics, (4) electrical power distribution, (5) international considerations, and (6) societal interactions.

IV.2.0 OBJECTIVES

The primary objectives of the investigation of socioeconomic issues are (1) to determine if any of the social or economic ramifications of an SPS energy system might significantly inhibit its development, and (2) to establish an information base regarding these issues to be used in comparative assessments.

IV.3.0 TECHNICAL PLAN

The SPS concept development and evaluation methodology, shown schematically in Figure 1 and in more detail in the appendix, provides a general guide to the sequence of events in the socioeconomic study plan. Figure 1 indicates the interaction with the systems definition activity and shows the study integration periods and major milestones. Prior to the first milestone (baseline concept(s) selection) a preliminary environmental impact assessment (EIA) is to be prepared in conjunction with the environmental, health and safety studies and comparative assessment. Prior to each subsequent milestone, the EIA is to be improved upon to the extent possible; all identified socioeconomic concerns are to be addressed at each milestone.

The development and operation of the SPS will have a wide range of socioeconomic impacts. Some of these impacts will derive from the very large scale of the program and the resulting massive demands on U.S. and world resources. Other impacts will be created by various unique features of the SPS; e.g., its use of earth orbit for massive microwave system space operations and the extensive dependence on federal support for DDT&E. The socioeconomic effects of the SPS will be among the principal determinants of its viability. They will contribute to the definition of its relative worth compared to alternative energy systems. The development of a sound estimate of the unit cost of SPS electricity will provide a useful synthesis of some of its purely economic impacts. Many societal and institutional impacts, however, as well as other economic impacts cannot and should not be reflected only in energy costs. DOE's plan for studying the issues involved in these areas is based on the understanding gained from previous studies; it defines the direction that should be emphasized in investigations to be conducted over the next three years. The nature and extent of the socioeconomic effects will depend on the design of the SPS which will not be baselined until October 1978. Until then, descriptions and definitions of socioeconomic effects will be, of necessity, rather generic in form.

Key socioeconomic issues are listed below, followed by a discussion of the planned treatment of the issues in each of the six categories. The discussion is keyed to Figure 1 and the appendix.*

<u>Land Use</u> (Impact of Selected Rectenna, Launch and Recovery Sites)
- Site Availability
- Local Impacts

<u>Resources</u> (National and Regional Resource Impacts)
- Critical Materials and Processes
- Resource Recycle
- Balance of Payments

<u>Economics</u> (Economic Assessment of the SPS Energy System)
- Cost Target Uncertainty Analysis
- Busbar Costs
- Energy Payback
- Net Energy Analysis
- Capital Requirements

<u>Electrical Power Distribution</u> (Assessment of SPS Integration into the Energy Supply System)
- Utility Interface
- Regional/National Distribution

<u>International Considerations</u> (International Impacts of SPS)
- Orbit Availability
- Microwave Considerations
- Energy Export
- Vulnerability

<u>Societal Interaction</u> (Societal Implications of SPS)
- Regional Impacts
- Public Acceptance
- Industrial and Population Migration
- Employment

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*The appendix is a fold-out chart which, when opened, shows the SPS program profile from January 1978 to June 1980. Opening the chart now will enable the reader to relate the discussion of socioeconomic issues to the detailed program profile.

IV.3.1 Land Use

The receiving and rectifying antenna (rectenna) of the SPS energy system is its major land user. The size of the rectenna is dependent upon the power density of the microwave beam, the degree of beam stability, latitude, and the maximum permissible power density at the perimeter of the exclusion area. This last parameter will be a function of the allowable continuous microwave exposure limits for the public, concerning which there is not a uniform agreement. Joint uses of the land may be possible and will be considered.

Interfaces with utility transmission facilities are significant factors in site location. Since the rectennas will be essentially very large power plants, remotely located from most users, there may need to be a non-negligible land use devoted to new transmission and distribution facilities. The number and availability of sites meeting acceptable criteria could be a limiting factor in the size of the system that can be employed.

Another concern is the land associated with the HLLV and support vehicles launch and recovery facilities. The total required area for such facilities is expected to be much smaller than that of the projected rectenna sites. However,the anticipated noise level and the very large number of launches will severely constrain site availability.

The initial phases of the study will concentrate on determining the total number and area of the sites required including broad constraints on their location. As the study progresses, several specific arrays of sites will be evaluated primarily on the basis of their impact on the land involved. In determining area requirements, close consultation with those working on microwave standards will be required. The availability of transportation, workers with requisite skills, living quaters, and related services will be assessed for each array. The potential for industrial development in the vicinity of the rectennas will be considered. Particular care will be taken to evaluate the impact of each array of sites on the quality of life in the affected areas. The potential impacts on air, water, living space and transportation are of immediate concern. In addition to the general assessment of arrays of potential rectenna and launch sites, the Kennedy Space Center will be evaluated specifically for its suitability as an SPS launch site.

IV.3.2 Resources

The impact of the SPS on national and worldwide resources and demands has been estimated in preliminary studies by the Johnson Space Center and the Jet Propulsion Laboratory. In general, there are no resources whose availabilities are deemed certainly inadequate, but additional extraction and processing capacity will be required for aluminum, argon, arsenic, gallium, hydrogen, oxygen, and silicon, and some materials (e.g., aluminum) may depend on the feasibility of greatly increased imports.

The following considerations will be studied in the initial phases of the program and refined as it progresses:

- Estimated total usage rates for needed materials
- Estimated cost changes with time
- Estimated cost changes with production rates
- Production facilities capacities for finished product
- Construction of new facilities
- International economic and strategic impacts, particularly on the balance of payments
- Energy requirements for fabrication
- Recycling of resources

IV.3.3 Economics

The major cost elements of the SPS are:

- Power Station System - consists of the satellite solar energy collection system, the microwave power conversion and transmission system, the microwave reception, conversion and distribution system including real estate
- Space Transportation System - consists of the launch and space transportation vehicles required for system implementation, including associated launch, recovery, and refurbishment facilities
- Space Construction System - consists of the space facilities and equipment for construction and assembly of the power station system, including manpower

- Operational Costs - consists of the costs of manpower, transportation, consumables, and repair/replacement hardware for sustaining and maintaining operation of the power station system
- DDT&E Costs - consists of all non-recurring research and development funds expended prior to initiation of commercialization

Preliminary economic analyses suggest that, if cost targets are achieved for the SPS, then, both on an investment cost and energy cost basis, the SPS could be competitive in the post-2000 time frame. However, the program would require a very heavy front-end investment in order to achieve a first demonstration plant, and this will be expended whether or not the SPS is then shown to be economically viable. This economic risk is a factor of major concern.

In addressing the overall economics of the SPS energy system, it is also important to bear in mind that to date one has generally been forced to deal with cost targets, not data based on explicit design or experiments. This situation will persist to some extent at least until the milestone of selecting the baseline concept(s) has been achieved.

The very first effort in this work area will be to develop a methodology for treatment of SPS economics. An analysis of the uncertainty of the many cost targets used in the systems definition will also be a first priority, useful in its own right and valuable as an input to the methodology. The methodology will establish common ground-rules and principles for arriving at the busbar costs of electricity. The output will be apportioned into the five cost elements defined earlier. It will be necessary to arrive at comprehensive energy payback derivation procedures so that valid comparisons can be made among alternative systems. These procedures will also include an energy analysis and a means for determining the magnitude of the initial energy subsidy required for implementing and operating an SPS energy system. The SPS capital cost expressed in $/kW varies from a low estimate of about $1400 to a high of nearly $6000. This cost is the primary driver in establishing the cost of electricity (COE) for the SPS. It will receive early and continuing attention in this effort, both as part of the economics methodology and as an end product.

IV.3.4 Electrical Power Distribution

Preliminary studies have all indicated that the electrical power output of each rectenna will be 5GW. This is an extremely large plant even by today's standards. But it is today's standards that will determine, in large measure, the distribution system that will exist in the SPS time frame. The addition of many power plants of this size brought on line in a few years could completely swamp the distribution system. There are other questions: Should the SPS service a national energy grid or local high energy demand areas? Will major restructuring of the existing power distribution networks be required? Payment for the electricity provided may have important ramifications, particularly if the SPS energy system is supported by an international organization.

In the earliest phase of this effort, recent study results will be surveyed and assimilated into an overall analysis of increasing depth to appraise the SPS interface with the existing utility industry and regulatory agencies. This appraisal will identify the changes in the utility industry's mode of operation (pricing, distribution, load factor, etc.) required to accommodate an SPS energy system. Particular emphasis will be placed on the baseline concept(s). The appraisal will also analyze the potential adaptability of the utility industry to accommodate the SPS and will evaluate the regulatory process to determine if existing policies bias the selection of future power systems either towards or away from SPS.

IV.3.5 International Considerations

A number of critical aspects of the SPS will affect or be affected by agreement or lack of agreement with other countries. Moreover, the potential delays in establishing such agreements can be of great importance. To begin with, the use of the geostationary orbit belt for solar satellite power stations in the Western Hemisphere will certainly require extended international negotiation.

Operation of the SPS will require international frequency agreements, and joint efforts to adjust to an acceptable level of RFI from the satellite transmissions. Another potential issue is the accumulation in space of debris from SPS activities and its impact on achieving international agreement on the system.

The international use of microwave-beamed energy, extraordinarily convenient with the SPS, could make a major contribution to the U.S. balance of payments as well as assisting in the development and energy independence of other countries that might participate in an international consortium to develop and operate the system.

A final institutional factor requiring study is that of the system's vulnerability to hostile military or terrorist action. This question needs to be considered relative to that of alternative energy systems. While equally large terrestrial power plants would be at least as physically vulnerable to overt attack as an SPS satellite, the expected response of the United States to an attack on its territory could be very different from that to the destruction of one or more of its satellites. Foreign powers might view the latter as a lower risk under limited war conditions.

The initial phases of the study in this area will focus on defining the agreements that will be needed with foreign powers and the anticipated barriers to agreement. The most likely mechanisms for establishing agreements will be investigated including, specifically, United Nations participation. Model agreements regarding orbit availability, microwave frequency allocation and microwave exposure standards will be developed using the information generated in Chapter III. The implications involved in providing SPS energy to other countries, taking into account their possible participation in its implementation, will be delineated. The resulting balance of payments impacts and consequences on international economics will be evaluated. Finally, the vulnerability of the SPS to covert attacks and overt military action will be investigated as will its other potential impacts on international relations.

IV.3.6 Societal Interactions

There are critical aspects of the SPS system that will be affected by its interaction with regional and national segments of U.S. society. Perhaps the most important issue is the centralization of power sources, and hence of society, implicit in the SPS concept. The 5 GW rectennas could lead to the consolidation of much of the population into a relatively small number of urban complexes, both to reduce distribution costs and to better protect the populace from SPS microwave radiation. This degree of centralization could also increase the vulnerability of consumers to power disruption. Financing is a societal as well as resource problem. Questions that must be considered are: Could the necessary capital be derived from private sources? If not all, what proportions? What should be the role of the federal government? Could or should the program be supported by an international organization? It may be necessary to relocate people away from rectenna sites to take advantage of desirable locations for the rectennas, as well as to minimize public safety and health risks from the microwave radiation. On the other hand, relocation of energy-intensive industries nearer to the rectennas could reduce power distribution costs by a significant factor. It has, of course, been well evidenced that any proposed energy system can have difficulty in acceptance if it offers risks of any consequence to the public or to the environment. Public acceptance of the SPS will be attainable only after the demonstration that its benefits adequately compensate for the acceptance of the risks, costs and other benefits foregone due to the system. These considerations will be investigated during the study. Conclusions will incorporate the results of private discussions with relevant public interest groups, as well as responses obtained at regional meetings open to the general public. These issues are less dependent on a specific SPS design and hence will get underway early in the study period.

IV.4.0 MANAGEMENT

The socioeconomic program elements are the responsibility of DOE's Office of the Assistant Secretary for Energy Technology (ASET). This section describes the approach to be used in managing these program elements.

The Chief of the Environmental and Resource Assessment Branch (ERAB), Division of Solar Technology, is responsible for overall management and coordination of the ASET socioeconomic activities. He is the ERAB-SPS Program Manager and prime point of contact in ASET for programmatic coordination between the Office of the Assistant Secretary for

Environment (ASEV) and all NASA organizations. The ERAB-SPS Program Manager will be assisted by representatives from the other ASET program divisions, as required.

Development of detailed plans addressing the SPS socioeconomic issues is the responsibility of the Program Manager. Once the detailed plans are formalized, funding authority will reside with the ASET. Concurrence is required by the ERAB-SPS program manager on all project plans prior to their implementation.

Determination of the potential socioeconomic impact depends to a large extent on the NASA systems definition efforts. A timely flow of information between ASET and NASA is therefore a prerequisite to a successful study. All reports and copies of contracts and correspondence will be made available by ASET to appropriate offices in other SPS organizations without restriction. In addition, every attempt will be made by program management within ASET to make use of pertinent studies completed or underway within organizations outside the DOE and NASA, both public and private.

IV.5.0 SCHEDULE

The overall schedule for studying SPS socioeconomic issues was indicated in Figure 1 together with the major program milestones supported by the effort. More detail is given in the appendix. Major program reviews and reports related to the environmental impact assessments (EIA) will occur one or two months prior to these milestones.

Formal reviews of the socioeconomic studies will be held on a quarterly basis. Interim progress reports will be limited to documentation presented in the quarterly reviews. The presentation format for these reviews will be approved by the SPS Coordinator.

The Program Manager for socioeconomic studies will prepare integrated inputs to the four Environmental Impact Assessments defined in the appendix.

- Program Assessment/Environmental Factors
- Preliminary EIA
- Baseline EIA
- Final EIA

A final report will be prepared by the DOE/NASA Task Force under the direction of the SPS Coordinator subsequent to completion of the final EIA.

IV.6.0 RESOURCES

The following table gives a brief summary of the resources allocated to the ASET studies of socioeconomic issues defined herein:

	FUNDING IN THOUSANDS OF DOLLARS				
	1977	1978	1979	1980	TOTAL
Resources	47	155	155	93	450
Economics/Energy Balance	38	124	124	74	360
Institutional/International	79	258	258	155	750
TOTAL	164	537	537	322	1,560

Note that the Resources category includes Land Use and the Institutional/ International category includes Electrical Power Distribution, International Considerations and Societal Interactions.

IV.7.0 SUMMARY REMARKS

The plan for study of socioeconomic issues has been developed to provide management insight at several key points during the program. At each milestone it will be possible to assess major problem areas, placing management in a position to exercise alternative program options if deemed necessary.

At the end of this effort, there will exist:

- An economic methodology which can be used for the SPS and competing alternatives
- A comprehensive socioeconomic assessment of the preferred system concept
- Recommendations for additional study

CHAPTER V

SPS COMPARATIVE ASSESSMENT PLAN

V.1.0 INTRODUCTION

Establishment of the technical, environmental and economic feasibility of an SPS energy system does not necessarily imply that it should be built. The decision to develop a commercial SPS as a significant energy source to meet terrestrial needs must also consider the projected alternatives. There must be a clear understanding of the potential terrestrial energy systems that could be available in the same time frame, so that the economic and social impacts of the terrestrial systems can be characterized in sufficient detail to be validly compared with the projections of the SPS energy system.

V.2.0 OBJECTIVES

The objective of this study area is to determine how an SPS energy system would compare with projected alternatives at the time of its implementation. The busbar cost of electricity, energy balance, social and environmental considerations will be of particular interest.

V.3.0 TECHNICAL PLAN

The SPS concept development and evaluation methodology, shown schematically in Figure 1 and in more detail in the appendix, provides a general guide to the sequence of events in the comparative assessment. Figure 1 indicates the interaction with the systems definition activity and shows the study integration periods and major milestones. The appendix indicates that the comparative assessment forms a part of each environmental impact assessment (EIA).* Prior to the first major milestone, a comparative methodology will be developed. By the second milestone the data base requirements will be delineated and the methodology refined. Before the third milestone an initial assessment of all alternatives will be prepared and a preliminary comparison with the SPS made. For the final milestone, the methodology data base and assessment alternatives will all be refined so that the final comparative assessment can fairly place the SPS in the range of alternatives.

There are three primary categories of terrestrial systems to be studied. They are:

- Fossil energy systems
- Nuclear energy systems
- Solar energy systems

V.3.1 Alternative Systems

Current work on projected energy systems will be reviewed and that material required by the comparative assessment methodology extracted for the data base. Information determined to be missing will be sought out specifically and, if necessary, developed as part of the assessment activity.

For fossil energy systems particular attention will be given to recent developments in coal power systems such as coal gasification, fluidized bed, and stack scrubbing approaches to central electric power. Open, closed and combined cycles will be included. Direct energy conversion techniques such as magnetohydrodynamics (MHD), thermionics and fuel cells will be reviewed for potential use by the power utilities.

Nuclear energy systems will emphasize light water reactors, but will include fusion and other fission energy systems as appropriate. Special attention will be given to nuclear waste disposal technology.

*The appendix is a fold-out chart which, when opened, shows the SPS program profile from January 1978 to June 1980. Opening the chart now will enable the reader to relate the comparative assessment discussion to the detailed program profile.

Solar energy systems include the central receiver solar thermal plants (the so-called power-towers), distributed solar thermal plants, and terrestrial photovoltaic power plants. These will be assessed. The entire grid operation will also be considered for direct solar systems. The most likely way of using each type of power plant will be identified and grid economic comparisons will be made by using various mixes of solar power plants. Questions of utility reliability, margin requirements, and operational modes place plant comparisons within a grid context. National grid problems due to regional differences in power plants, the use of southwest solar power as a national resource, and the introduction of national load following with solar plants, will also be considered.

There are several other systems to be considered. Foremost among these are (1) ocean thermal gradient power systems (known as OTEC), (2) wind-energy systems and (3) systems based on biomass. Data from these systems will be organized into a performance, economics and impacts framework as for the other systems and grid operation and problems for these systems will also be considered.

V.3.2 Comparison

The comparison effort will include the development of an overall comparative assessment methodology, the assembling of a data base, and the comparative assessment of the SPS against alternative terrestrial systems. The methodology will use the data in each area of concern to give a comparable understanding of the total social cost of each energy system. The methodology will encompass the entire energy cycle from fuel and raw material extraction to deactivation of the plant. The data for the SPS and terrestrial energy systems will be organized into at least the following areas:

- Utility economics of the power plant and energy delivery system (transmission and distribution)
- R&D investment to achieve a commercial prototype
- Resource utilization and availability

- Environmental impacts
- Public health and safety
- Occupational health and safety
- Land use and the impacts of construction on the regional social fabric
- Energy payback
- Waste heat
- Institutional, international, legal, political, security and other social effects which would either increase or impair acceptance

Prior to finalizing the assessment methodology for comparing the social suitability of the SPS compared to alternative energy systems, the current total social cost assessment methodology, and other techniques recently developed for social decision-making will be reviewed and findings incorporated as appropriate.

Assembling the data base will primarily involve the summarization of the appropriate data generated in previous tasks. It will include systems performance, costs and impacts generated under appropriate and comparable scenarios of energy supply and demand.

The comparison itself will provide contrasting measures between the SPS and alternatives for at least the following factors:

- Public safety and health risks
- Worker safety and health risks
- Other environmental impacts
- Land use requirements and impacts
- Resources required
- Institutional/international benefits and problems
- Integrated assessment of impact on "quality of life"
- Total social costing to meet the needs of the SPS decision-maker
- Cost of electricity in mills per kWh
- Cost of generating capacity in dollars per kWh

V.4.0 MANAGEMENT

The comparative assessment is the responsibility of DOE's Office of the Assistant Secretary for Energy Technology (ASET). Managerially, this effort will be the responsibility of the ERAB-SPS manager who is also charged with managing the socioeconomic studies. Therefore, the procedures described in Section IV.4.0 are also applicable here.

V.5.0 SCHEDULE

The overall schedule for the comparative assessment is indicated in Figure 1 and the appendix. Results of comparative assessment activities will become part of the environmental impact assessments (EIAs). The preliminary EIA will report on comparative assessment methodology and data requirements. The baseline EIA will include the initial comparative assessment and the final EIA will include the final assessment. Other reporting and review requirements for the comparative assessment are identical to those given for the socioeconomic studies in Section IV.5.0, and will be included as an integral part of them.

V.6.0 RESOURCES

The following table gives a brief summary of the resources allocated to the ASET comparative assessment effort defined herein:

	FUNDING IN THOUSANDS OF DOLLARS				
	1977	1978	1979	1980	TOTAL
Alternative Systems	60	235	470	355	1,120
Comparison	35	141	284	210	670
TOTAL	95	376	754	565	1,790

V.7.0 SUMMARY REMARKS

The plan for comparative assessment has been developed to adequately display the important characteristics of the SPS and alternate energy systems for use by the SPS decision-maker. At the end of this effort there will exist:

- A methodology for comparing energy systems
- A data base for the SPS and credible alternatives
- A side-by-side comparison of the SPS with other energy systems

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APPENDIX

It is the purpose of this appendix to present a profile of the SPS Concept Development and Evaluation Program. It shows the five functional activities to be undertaken, their major work elements, the relationship of the work elements to each other and to the achievement of the program milestones. It is designed to be unfolded so that the profile can be consulted when reading any of the five chapters of the plan corresponding to the five functional areas.

A time-line has been placed at the top of the chart covering all remaining activities of the program plan. The only entries that are placed exactly with respect to time are the five major milestones. The other entries (ellipses) are located only approximately. The position in the chart indicates roughly when the designated work element is to be completed. The positions are all in the proper sequence with respect to the milestones and to each other. No start dates are implied by the chart; work on many elements has been in progress since the beginning of the program.

The period of the program from January 1980 to June 1980 shows no completed activities. This is because this period is one of intensive integration of the results of the preceding studies by the SPS Coordinator. Working with representatives from the five functional areas the SPS Coordinator will arrive at final program recommendations for submittal to the Administration in June 1980.

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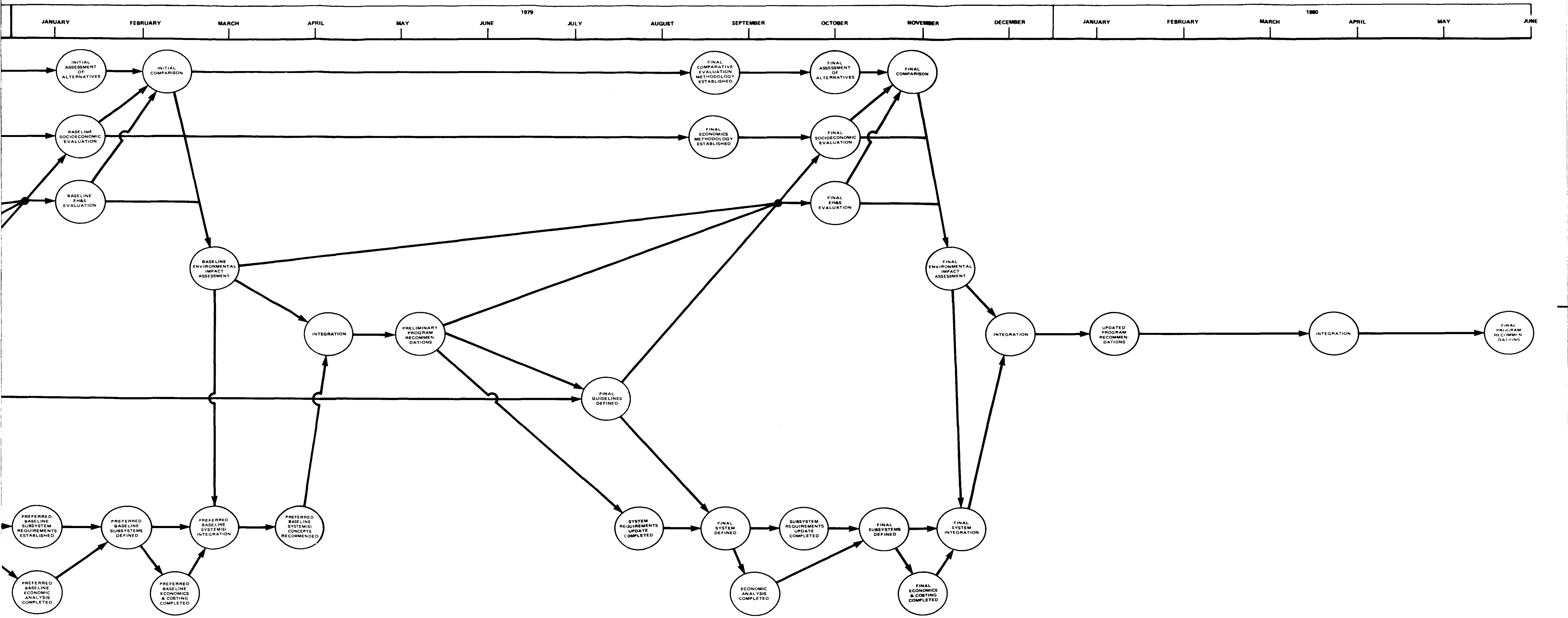
ONCEPT DEVELOPMENT AND EVALUATION PROGRAM PLAN



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